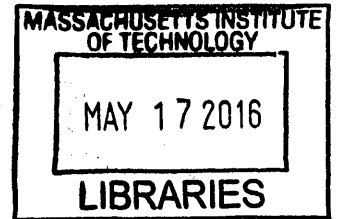


**Sense and the City:  
Representations of Air Quality Data in the 'Smart City'**

by

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**ARCHIVES**

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ABSTRACT

The proliferation of sensor devices in the emerging landscape of ‘smart cities’ provides new mechanisms with which to measure the built and natural environment. City governments increasingly rely on sensor data to monitor infrastructure, mobility patterns, environmental hazards, disasters, and more. At the same time, citizens have increasing access to tools with which to examine urban concerns outside of institutional means. By looking at the use of one specific category of sensor data, air quality, this thesis provides a critical analysis of the plurality of ways in which urban sensing data is generated and represented. Specifically, the thesis examines representations of air quality data intended for governmental to grassroots audiences, and how these representations may prove to be problematic in attempts to reconcile their myriad forms and meanings across contexts and constituencies. Urban planning and design, disciplines that rely on the interpretation of environmental data in order to propose strategies for shaping the built environment, serve as a unique point of convergence of the key tensions that persist in the use of sensor data in cities. Case studies of various urban sensing initiatives in the U.S. and abroad illustrate disjunctions between different modes of sensor data collection and the way that data is communicated, affecting the way that governments negotiate with citizen stakeholders and vice versa. The core research questions this thesis examines are twofold: (1) What are the ways in which air quality sensor data is represented and given meaning in city dashboards, data portals, and other graphic user interfaces for different audiences, and (2) How might sensor data be used in the context of urban planning and design to reveal new frameworks for environmental data collection and representation that promote collaboration between government and citizen stakeholders?

**Thesis supervisor:**

Edward Schiappa

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# one

## **Cities of Information: Air Quality in the ‘Smart City’**

Bruno Latour once posed the question, “Where are the missing masses?” to challenge the way in which scholars studied social relationships with nonhuman objects - a shift in thinking that eventually led to deeper understanding of our human relationship with the nonhuman built environment.<sup>1</sup> Now, during an information age that produces more bits than atoms, digital technology increasingly impacts how we envisage and shape the structural world.<sup>2</sup> Evidence of this can be seen in growing numbers of “smart city” initiatives that rely on data to evaluate infrastructural and civic issues, from mobility patterns to environmental monitoring to 311 reports.<sup>3</sup> It is in this cultural moment of data-centric apparatus that critical research has prompted an important return to Latour’s initial provocation, with a twist. In these imagined urban futures, do we (humans) risk becoming the missing masses ourselves?

The discourse of the “smart city” is based on polarizing paradigms, ones that must be examined closely. On one hand, there is an agenda for smart cities predicated upon top-down data-centric optimization of urban systems, and on the other hand, there is a simultaneous push for citizen-driven mechanisms for accessing urban data. For example, a special edition of

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<sup>1</sup> Bruno Latour, "Where are the missing masses? The sociology of a few mundane artifacts," *Shaping Technology / Building Society: Studies in Sociotechnical Change* (Cambridge: MIT Press, 1992): 225-258.

<sup>2</sup> William J. Mitchell, "City of bits," *Space, Place, and the Infobahn* (Cambridge: MIT Press, 1995).

<sup>3</sup> Steven D. Glaser and Anne Tolman, "Sense of sensing: from data to informed decisions for the built environment," *Journal of infrastructure systems* 14, no. 1 (2008): 4-14.

*Scientific American* that focuses on smart cities features an article describing the impact of innovation on the twenty-first century economy. One author insists, “Future innovations will be driven by cheap information...We thus urgently need new frameworks to help us decide how our lives will fit into a future that is only starting to come into view.”<sup>4</sup> In this view, the notion of the smart city is one that looks toward the future for new technological innovations, and whose economy is driven by information flows. Following this same framework, other articles in this edition include titles such as “Public Transport - Wired-In Mobility,” “We must optimize energy management,” and “Power Electronics at the Heart of Energy Efficiency.” Here again, the discourse focuses on the rhetoric of efficiency, treating the city as a machine that can be optimized and regulated as such.<sup>5</sup> Boyd Cohen suggests using “indicators to help cities track their performance with specific actions developed for specific needs,” pointing to a framework called the Smart Cities Wheel to develop “a common language” among multiple city stakeholders working within this space.<sup>6</sup> (See Fig. 1) The wheel contains categories such as “smart economy,” “smart government,” “smart environment,” etc. with more granular performance indicators for each. Within “smart economy,” example indicators for success would be “local and global interconnectedness” and “productivity.” Such techno-centric views of the smart city have deservedly garnered critique from scholars and practitioners elsewhere.

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<sup>4</sup> Patrick Whitney, “Running Forward, Looking Backwards,” *Energy, Transport, Smart Cities: New Paths for Innovation, Scientific American special issue* (October 2015): 3.

<sup>5</sup> Julian Beinhart, “Normative Theory II: The City as Machine,” Lecture, Theory of City Form, MIT OpenCourseware, 2013. <http://ocw.mit.edu/courses/architecture/4-241j-theory-of-city-form-spring-2013/lecture-notes/lec-3-normative-theory-ii-the-city-as-machine/>

<sup>6</sup> Boyd Cohen, “What Exactly Is A Smart City?” *Fast Co.Exist* (September 19, 2012). <http://www.fastcoexist.com/1680538/what-exactly-is-a-smart-city>



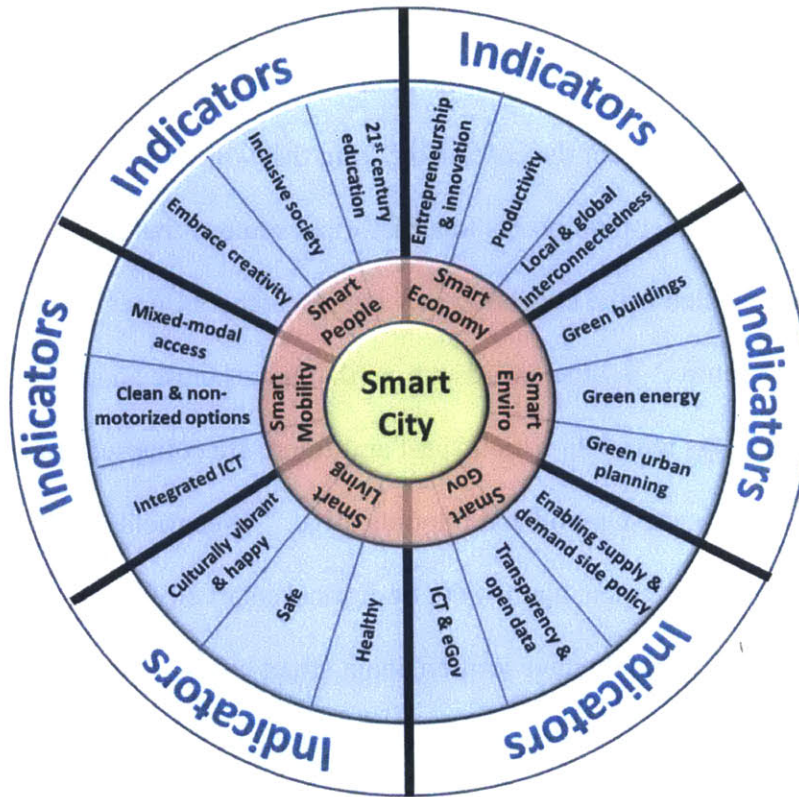


Fig. 1. Boyd Cohen, *The Smart Cities Wheel*. From: "What Exactly Is A Smart City?" *Fast Co.Exist* (September 19, 2012). <http://www.fastcoexist.com/1680538/what-exactly-is-a-smart-city>

In a pamphlet called *Against the Smart City*, Adam Greenfield offers a way to deviate from the technocratic view of the smart city and moves readers toward a social constructionist perspective.<sup>7</sup> He remarks on the notion of optimization and efficiency from a critical perspective, calling optimization “meaningless without some explicit account of which resources must be conserved, which may freely expended and the way in which these determinations of relative value were arrived at” and efficiency as an “index of value” that “overlooks the many simple pleasures afforded by city life that would be utterly unimproved by any optimization.”<sup>8</sup>

By looking at cases such as Korea’s New Songdo, UAE’s Masdar City, and Portugal’s PlanIT

<sup>7</sup> Adam Greenfield, *Against the smart city* (Self-published pamphlet, 2013): 8-12.

<sup>8</sup> *Ibid*, p. 10

Valley, Greenfield points out that a technocratic view of the smart city assumes that the world is “knowable” and measurable by devices and data collection mechanisms that lack bias or distortion. This is, of course, not the case, something that will be discussed throughout later chapters. Importantly, Greenfield points to a rhetorical strategy that many smart cities marketing documents employ, which is the evocation of what researchers Genevieve Ball and Paul Dourish call the “proximate future,” in other words a time that seems close and inevitable but never quite here. This is a “sideways tense” in which “past and future are collapsed, and no distinction is made between the subjunctive mood and the indicative.”<sup>9</sup> Greenfield’s polemic is representative of a larger reactionary movement against the traditional smart city ideology.

Others like Steven Poole have written about smart cities as “utopian” and an “optimized panopticon” [sic] that elides the role and experience of the everyday citizen.<sup>10</sup> After reviewing a variety of smart city approaches across the globe, Poole suggests that competing visions of the smart city are “proxies for competing visions of society, and in particular about who holds power in society.” In other words, who holds power in society determines who gets access to information in society - a *leitmotif* that will express itself again and again in this thesis.<sup>11</sup>

#### *A brief background on data collection in cities*

While contemporary treatment of the term “smart city” is a recent product of corporations, the concept of data-driven governance is not new. Starting in 1790, the United States Census was created due to a need for government entities to track the population of a

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<sup>9</sup> Ibid.

<sup>10</sup> Steven Poole, “The truth about smart cities: ‘In the end, they will destroy democracy,’” *The Guardian*, (December 17, 2014). <http://www.theguardian.com/cities/2014/dec/17/truth-smart-city-destroy-democracy-urban-thinkers-buzzphrase>

<sup>11</sup> Ibid.

growing nation.<sup>12</sup> This involved a meticulous inventory of people and property owners in the country, and the final results determined, among other things, how much representation each state would have in Congress and how much in taxes would be collected due to population proportions. A provision for the Census was also written into the original *Constitution* in anticipation of a need to collect data about citizens:

"Representatives and direct Taxes shall be apportioned among the several States... according to their respective Numbers...The actual Enumeration shall be made within three Years after the first Meeting of the Congress of the United States, and within every subsequent Term of ten Years."<sup>13</sup>

What information was collected, when it was collected, and how it was collected were determined by the national government. Individuals who were counted had minimal agency in terms of what data was collected and how it was used. As the country grew, so too did the amount of data that needed to be collected for each Census.

Commensurately, the time required to process and tabulate Census data also grew. As a result, in 1888, the U.S. Census Bureau held a competition to seek more efficient methods of tabulating Census data. One contestant in particular, a former Census Bureau employee named Herman Hollerith, invented a tabulator device that eventually won him the contract to process 1890 census data. Hollerith's machine consisted of electric components that captured and processed census data by "reading" holes on paper punch cards. In 1911, four corporations, including Hollerith's firm, merged to form the Computing Tabulating Recording Company (CTR), which later came to be known as International Business Machines (IBM). Incidentally, it is this same firm that, in November 2011, registered the trademark for "smarter cities," a concept

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<sup>12</sup> U.S. Census Bureau, "Census.Gov," (July 2015). <http://www.census.gov/history>

<sup>13</sup> U.S. Const. Art. I, Sec. 2.

that, since its inception, has been met with controversial feedback from multiple factions due to its data-driven approach to city management.<sup>14</sup>

IBM's original "smart city" referred almost exclusively to a small number of development projects over the past decade such as Korea's New Songdo, UAE's Masdar City, and Portugal's PlanIT Valley which relied on mobile, fixed, and remote sensing technology to provide feedback on environmental factors, information which would then be used toward urban planning, commerce, governance, and civic engagement.

The idea of smart cities persists, but it has also evolved as a growing pool of stakeholders seeks to craft alternative narratives of the smart city through the development of new initiatives. Rather than focusing on optimization or efficiency, the White House Smart Cities Initiative, announced in September 2015, instead seeks to invest up to \$160 million in federal smart city research proposals that "help local communities tackle key challenges such as reducing traffic congestion, fighting crime, fostering economic growth, managing the effects of a changing climate, and improving the delivery of city services."<sup>15</sup> The Smart London Plan purports to put "people and businesses at its heart" and extends "innovation" to include policy change as well as technological change.<sup>16</sup> The plan also recognizes a gap in data literacy and takes into account the need for public education about data in parallel to making government data more transparent.

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<sup>14</sup> Ola Söderström, Till Paasche, and Francisco Klauser, "Smart cities as corporate storytelling," *City* 18, no. 3 (2014): 307-320.

<sup>15</sup> White House, "Fact Sheet: Administration Announces New 'Smart Cities' Initiative to Help Communities Tackle Local Challenges and Improve City Services," Press release (September 14, 2015). <https://www.whitehouse.gov/the-press-office/2015/09/14/fact-sheet-administration-announces-new-smart-cities-initiative-help>.

<sup>16</sup> Greater London Authority, Smart London Plan (2013). [http://www.london.gov.uk/sites/default/files/smart\\_london\\_plan.pdf](http://www.london.gov.uk/sites/default/files/smart_london_plan.pdf).

Initiatives like these show signs of a shifting narrative of smart cities that aims to resolve earlier tensions between competing definitions of what a smart city actually is.

The Internet of Things industry, predicted to be worth \$14.4 trillion by 2022, has launched a multitude of speculative design frameworks for the use of widespread sensing technologies at various scales.<sup>17</sup> Sensor devices that measure aspects of urban life - from mobility patterns to environmental factors to 311 reports - are part of the smart city dynamic and deserve further study for exactly the same reasons that smart cities are problematic. When used by top-down entities like governments or institutions, sensor devices raise questions of surveillance and imbalance of power. The epistemology of sensor devices can also mislead one to think that the world is measurable and knowable in ways that elide nuance and other ways of meaning making. However, alongside the development of sensing technologies from top-down entities, a shift toward citizen-centric approaches to smart cities has spurred the intervention and propagation of more grassroots data collection tools and initiatives, returning agency and power to citizens.

#### *A close look at air quality sensor data*

By looking at the use of one specific category of sensor data in cities, air quality, this thesis provides a critical analysis of the plurality of ways in which urban data is generated and represented, from governmental to grassroots, and how these representations may prove to be problematic in attempts to reconcile their myriad forms and meanings across contexts and constituencies. Urban planning and design, disciplines that rely on the interpretation of

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<sup>17</sup> Joseph Bradley, Joel Barbier, and Doug Handler, "Embracing the Internet of everything to capture your share of \$14.4 trillion," *White Paper, Cisco* (2013): 3.  
[http://www.cisco.com/c/dam/en\\_us/about/ac79/docs/innov/IoE\\_Economy.pdf](http://www.cisco.com/c/dam/en_us/about/ac79/docs/innov/IoE_Economy.pdf)

environmental data in order to propose strategies for shaping the built environment, serve as a unique point of convergence of the key tensions that persist in the use of sensor data in cities. Case studies of various urban sensing initiatives in the U.S. and abroad illustrate disjunctions between different modes of sensor data collection and communication. A close look at these cases reveals that urban sensing initiatives can highlight where gaps of information exist, which can provide a means of stimulating dialogue between government and citizen stakeholders or serve as a mode of resistance against institutional standards and mechanisms for collecting information when that dialogue is not possible.

The core research questions this thesis examines are twofold: (1) What are the ways in which air quality sensor data is represented and given meaning in city dashboards, data portals, and other graphic user interfaces for different audiences? (2) How might the use of sensor data in the context of urban planning and design reveal new frameworks for urban data collection and representation that actuate collaboration between government and citizen stakeholders?

### *Methodology*

In order to investigate these questions, I used a mixed-methods, comparative approach. Through participant observation, I gathered data at “smart city” conferences at workshops across the United States, Europe, Australia, and New Zealand. At these workshops, I collected marketing materials and program schedules, as well as spoke with project managers, researchers, and marketing representatives for “smart city” projects involving sensors, particularly those that proposed to take an open data approach or civic engagement approach.

I directly participated in citizen sensing projects (i.e. Data Canvas: Sense Your City, Sensing City, Safecast, and SmartCitizen) in order to better understand the user perspective of

these projects. Through this direct participation, I was able to gain access to educational materials, data visualizations, data sets, and project managers that comprise a body of resources that contributed to the analysis of my thesis topic. I also registered for classes at MIT that explored this topic. These courses involved design proposals and prototypes for crowdsourced sensing projects dealing with urban lighting infrastructure and informal transit networks, respectively. Through examining the topic of top-down and bottom-up urban sensing in different categories, I was able to extract and abstract common approaches and strategies among these types of initiatives.

Additionally, I conducted interviews with various individuals working within civic engagement, open source software and hardware, citizen science, urban planning, urban design, and related fields to gather qualitative, anecdotal data about air quality sensing projects, and sensing projects within the urban context writ large. I began by first reaching out to people who I knew to be working with sensors in urban environments; moving forward, I asked interviewees to suggest other individuals who would be helpful informants for this project. All interviewees were given the choice to remain anonymous or to be named in this publication, and all interviews were recorded and transcribed.

Finally, I conducted a visual analysis of various air quality data dashboards, web portals, and visualizations spanning projects of different scales, which I outline in detail in chapter two. For these particular examples, I relied purely on the content available through the website and through connected channels (i.e. links to other pages) for this analysis. The reason for this choice is to conduct an analysis of the experience of a user who only has access to publicly available materials and resources that the dashboard, portal, etc. explicitly provides. This perspective, that

of the user, is supplemented by designer- and project manager-centric interviews featured throughout the rest of my thesis.

### *Chapter overview*

In Chapter 2, I begin by discussing the current landscape of emerging sensing technology and its uses. I trace the idea of sensing back to the scale of the body, our five senses, and make a case for sensors as prosthetic for the human senses. I provide a taxonomy for existing sensor technology based on scale. I discuss the epistemology of how meaning is constructed from sensor data. And finally I provide a brief history of air quality sensing in the United States and problematize the way air quality is measured and represented, given the myriad methods and mediums available to do so.

In Chapter 3, I discuss a specific case study for air quality sensing in post-disaster Christchurch, New Zealand. By looking at different dashboards on which the same air quality sensor data is represented, I reveal the uneven landscape of sensor data communication for different contexts and constituencies. I also discuss and propose models for collaborative government-led and citizen-led sensor data collection and communication strategies.

In Chapter 4, I explore how urban planners and designers are currently working with sensor data to understand infrastructural, environmental, and social aspects of the city. I also discuss how air quality, land use, and media come to matter within this context and how some conventions for translating technical knowledge for urban planning and design might be adopted for communicating air quality data for larger publics.

In Chapter 5, I conclude my argument by highlighting future opportunities for research in this field. I argue for research and praxis that focus on making government and citizen data



interoperable, especially where mutual concerns have been identified. I relate collaborative relationships between governments and citizens to Cicero's *civitas*, the contract binding the collective body of citizens together. I also point out that some of the most important challenges revolve around questions of representation (forms that data/information might take) and audience (for whom the data/information is intended). This is where media studies may continue to contribute within the smart city landscape.

On a more abstract level, this thesis deals with how a growing information economy challenges traditional notions of what cities are made of. During the Industrial Age, when global economies depended on material goods, one might have said that cities were made of brick, mortar, stone, or wood. In the twenty-first century, one might now say that cities are also made up of immaterial information networks that come with their own power implications. In telling the story from specific case studies about air quality sensing in cities, I hope that this thesis slowly helps peel back the layers on these underlying themes.

# two

## Sensing Air Quality: From the Body to Sensors

Some senses are more equal than others.

Myriad propositions from classical, medieval, and modern discourse suggest a hierarchy of these senses. Plato privileges sight as the highest sense, proposing the eye as a “site to entry of *enthusiasm*, divine inspiration, and the path to transcendence” whereas “sensation” (*aisthēsis* in Greek), refers to a perception of the world through the senses and intellect, a junction of the body and mind.<sup>18</sup> Diderot, speaking of passionate (read: divine) love, links tactility to reality: “if you want me to believe in God I would have to touch Him.”<sup>19</sup> Smell and taste “tend to be associated with our animal nature” and are thus lower in the hierarchy.<sup>20</sup> Media scholars have also speculated about the senses. Marshall McLuhan controversially speculated on categories of “hot” and “cool” media.<sup>21</sup> Laura Marks discusses “how the electronic medium of video can have [a] tactile closeness” and elicit the sense of touch both “on the surface and inside” the body.<sup>22</sup> The five senses afford the human body the ability to interface with its environment. However, this ability also has its limitations. For instance, one can sense whether a surface is hot or cold by touching it but not necessarily discern *how* hot or *how* cold. One can sense humidity in the air

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<sup>18</sup> Danijela Kambaskovic and Charles T. Wolfe, "The senses in philosophy and science: from the nobility of sight to the materialism of touch," *A cultural history of the senses in the renaissance*, ed. Herman Roodenburg (London: Bloomsbury, 2014): 107-125.

<sup>19</sup> *Ibid*, p. 1.

<sup>20</sup> *Ibid*, p. 4.

<sup>21</sup> Marshall McLuhan, “Media hot and cold,” *Understanding Media: The Extensions of Man* (New York: Signet Books, 1964).

<sup>22</sup> Laura U. Marks, *Touch: Sensuous theory and multisensory media* (Minneapolis: University of Minnesota Press, 2002), 1-26.

through smell or touch but not necessarily subtle shifts in atmospheric pressure. This is where sensor technology intervenes -- as prosthetic to the human body, as an alternative means of constructing knowledge about the environment.

*Sensors*, tools or devices that react predictably to their environments and offer ways to measure change in their environments, can either emulate or extend beyond human senses. To return to my prior example, one might use a thermometer as a surrogate for a human hand to measure the temperature of a boiling pot of water. And because sensor devices produce measurements in some form, these measurements can also be documented and compared with each other. This is not to say that one could not discern the *relative* temperature of a pot of water with one's hand; rather, sensors enable the extension and emulation of the senses to perceive the environment, often in a more nuanced, precise way.

Sensors can collect data about their environments at various scales. Science Creative Commons' Puneet Kishor has created taxonomy of sensors, which I have adapted with permission below, to illustrate this range of scales.<sup>23</sup> (See Fig. 2)

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<sup>23</sup> Puneet Kishor, "A Taxonomy Of Sensors," Personal website (2015).  
<http://punkish.org/Taxonomy-of-Sensors>.

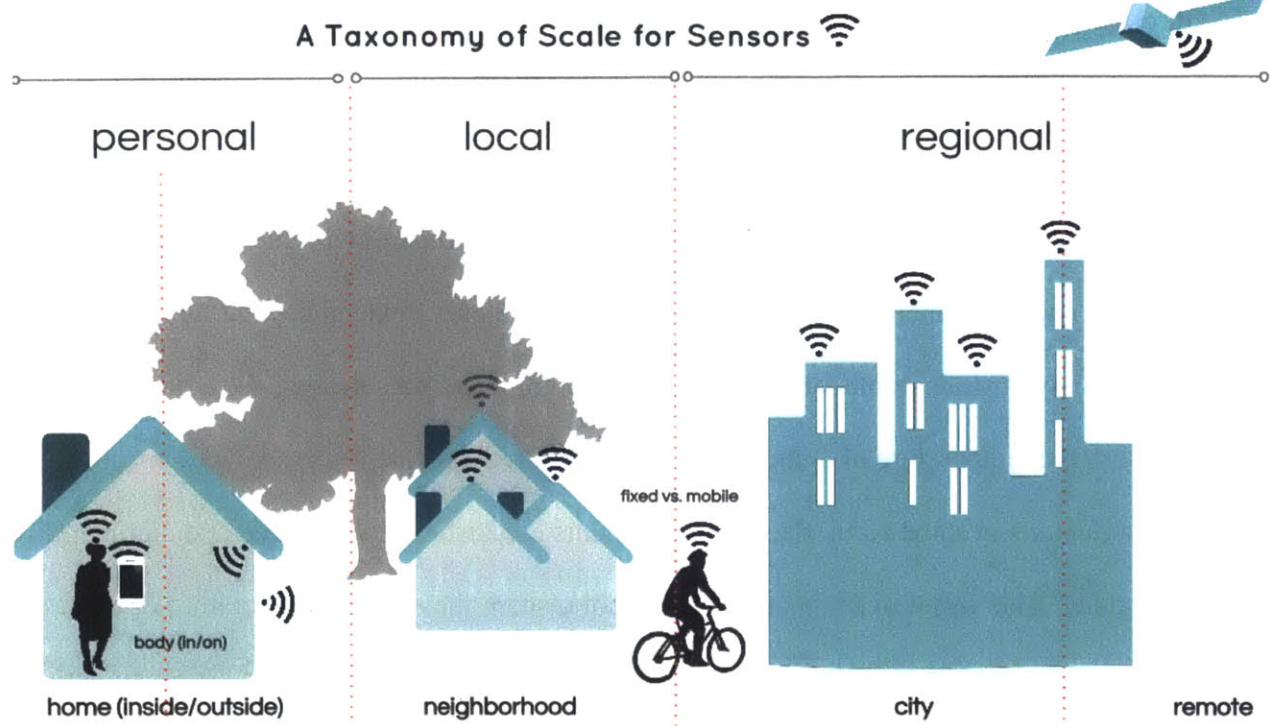


Fig. 2. A taxonomy of scale for sensors.

This taxonomy includes three umbrella categories of sensor devices based on their purview: personal, which includes sensors in/on the body and sensors inside/outside the home; local, which includes sensors within one's neighborhood; and regional, which includes sensors distributed throughout cities and remote sensing from satellite technology. This adapted taxonomy also specifies that sensors can either be mobile or fixed in one place: smartphones, which have a variety of sensors embedded within them (e.g. GPS, accelerometer, etc.), are considered mobile because they can be moved around, whereas camera sensors at traffic intersections are considered fixed because they stay in one place.

Elsewhere in the field of ubiquitous computing or *ubicomp*, a similar taxonomy is used to describe various network scales for embedded computing. Lipshin describes characteristics of

differently scaled ubicomp networks.<sup>24</sup> For this thesis, however, I chose a taxonomy that specifically relates to sensor devices as opposed to one that was more inclusive of other, broader types of computation.

As one can glean from the discourse of political ecology, the politics of environmental scale – that is, the way in which environmental information is represented according to scale – are indicative of power relationships and strategies used by groups to pursue particular agendas. Political ecology focuses on the relationship that people have with the environment, with close attention paid to the political, social, and economic forces that shape and condition that relationship.<sup>25</sup> Goodman, et al. assert, “Natural environments are not merely the stage upon which human actors battle for epistemological and material domination...Environments and human societies are co-constructed.”<sup>26</sup> This suggests multiple ways that environmental knowledge can be shaped and co-constructed by various actors; these constructions embody power through discursive and technological regimes and can thus be translated into political, economic, and ecological outcomes.<sup>27</sup> The following examples illustrate how different actors can manipulate the scale of air quality data collected from different sources in order to construct different narratives of air quality.

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<sup>24</sup> Jason Lipshin, “Network Design: A Theory of Scale for Ubiquitous Computing,” MIT Comparative Media Studies, Master’s thesis (2014).

<sup>25</sup> Anthony Oliver-Smith, “Theorizing vulnerability in a globalized world: A political ecological perspective,” *Mapping vulnerability: disasters, development and people* (London: Earthscan, 2004): 10-24.

<sup>26</sup> Michael K. Goodman, Max Boykoff, and Kyle Evered, eds., *Contentious geographies: Environmental knowledge, meaning, scale* (Farnham, UK: Ashgate Publishing, 2008).

<sup>27</sup> Ibid.

Both the iSeeChange and the U.S. EPA's AirNow (Fig. 3 & 4, respectively) are examples of platforms that visualize air quality data on a regional scale.<sup>28</sup> The former is a climate change storytelling project that takes data about carbon dioxide levels in the atmosphere from NASA's OCO-2 satellite and visualizes it on an aerial map, indicating the latest readings of CO<sub>2</sub>, and their levels of intensity, with a color scale. Generally, if the latest measurement approaches the right side of the spectrum (red), the more CO<sub>2</sub> there is in the atmosphere. The more that the measurements approach the left side of the spectrum (blue), the less CO<sub>2</sub> there is in the atmosphere.

The colored visualizations also follow the path of the OCO-2 satellite. The default location that each user sees on the map is tied to their specific location. For example, if a user were accessing the iSeeChange platform from New Orleans, Louisiana, the map would display the latest readings over that location, or the nearest points to that location. A descriptive statistic for parts per million (ppm) of CO<sub>2</sub>, which refers to the volume of CO<sub>2</sub> in the atmosphere in the column directly overhead a certain point, also appears above the color scale. Users can observe this number on a regular basis – daily, weekly, monthly – to explore questions about whether increases or decreases in CO<sub>2</sub> levels might correspond with weather changes or climate events on the ground.

The project also deliberately focuses on one single variable (CO<sub>2</sub>) as opposed to the multiple other variables that can comprise air quality, arguing that CO<sub>2</sub> is “the greenhouse gas most linked to human activity. Although this approach elides the other variables of air quality that may also contribute to climate change, the choice to focus solely on CO<sub>2</sub> makes it less complex for the user to follow data points from one instance of using the platform to the next. By

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<sup>28</sup> Environmental Protection Agency, “AirNow,” *AirNow.gov*, accessed January 2016. <http://airnow.gov>.

iSeeChange, “iSeeChange.” *iSeeChange.org*, accessed January 2016. <http://iseechange.org>.

joining two vastly varied scales of information, the platform also challenges what counts as environmental knowledge. While research has revealed that media coverage of climate change has played a significant role in translations between science, policy, and the public, the platform provides an alternative means of participating in climate change discourse from outside of traditional structural mechanisms.<sup>29</sup>

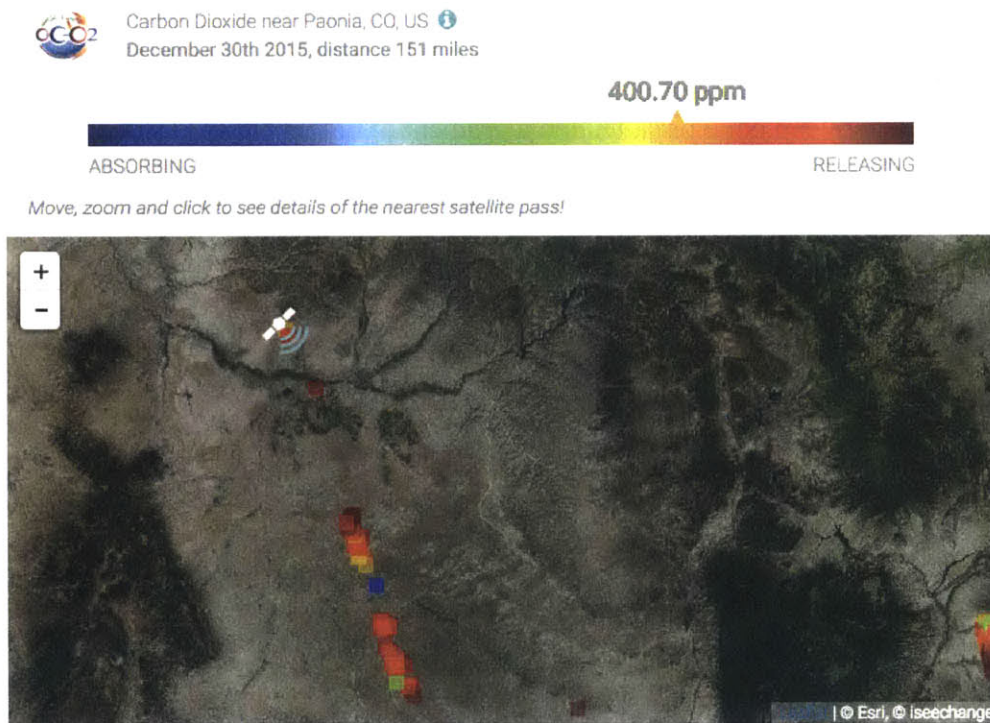


Fig. 3. iSeeChange. NASA OCO-2 carbon dioxide data. From: *iSeeChange.org*, accessed January 2016.

<sup>29</sup> Maxwell T. Boykoff, "Fight semantic drift!? Mass media coverage of anthropogenic climate change," *Contentious Geographies: Environmental Knowledge, Meaning, Scale* (Hampshire: Ashgate Publishing, Ltd., 2008): 39-57.

Katherine McComas and James Shanahan, "Telling stories about global climate change measuring the impact of narratives on issue cycles," *Communication Research* 26, no. 1 (1999): 30-57.

Joe Smith, "Dangerous news: Media decision making about climate change risk," *Risk Analysis* 25, no. 6 (2005): 1471-1482.

The U.S. Environmental Protection Agency's AirNOW portal displays real-time air quality data from over 400 cities internationally, based on the Air Quality Index (AQI), an international standard, which "translates air quality data into numbers and colors that help people understand when to take action to protect their health."<sup>30</sup> The data portal borrows the language of weather in order to convey air quality based on location, using the concept of "forecasts" to predict air quality conditions. There are also multiple ways to access AirNOW data: the website; social media; e-mail alerts; a mobile app; and a customizable AirNOW widget. A viewer can search for AQI forecasts by zip code or state, and a gradient of colors is used to convey various degrees of air quality with green being more desirable and violet on the opposite end of the spectrum, indicating less desirable conditions.

The color scale provides a quick, visual way in which to process the information on the map, making it relatively easy for lay audiences to assess whether air quality conditions are desirable or not. However, it is less clear how or why the AQI measurements are calibrated to their respective colors. Also, it is not immediately clear which variables constitute "air quality" overall (i.e. particulate matter and/or the volume of certain gases). While the AQI provides a single, convenient composite statistic for air quality, in so doing, it also generalizes the concept of air quality and obscures the methods by which it is measured. The map also displays the location of various monitoring stations spread throughout the U.S. Although the monitoring stations are only able to measure air quality in their direct vicinity, much like weather stations, the data that they capture are generalized to represent entire regions.

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<sup>30</sup> Environmental Protection Agency, "About AirNOW: Air Quality Index," *AirNow.gov*, accessed January 2016. [http://www.airnow.gov/index.cfm?action=topics.about\\_airnow](http://www.airnow.gov/index.cfm?action=topics.about_airnow)



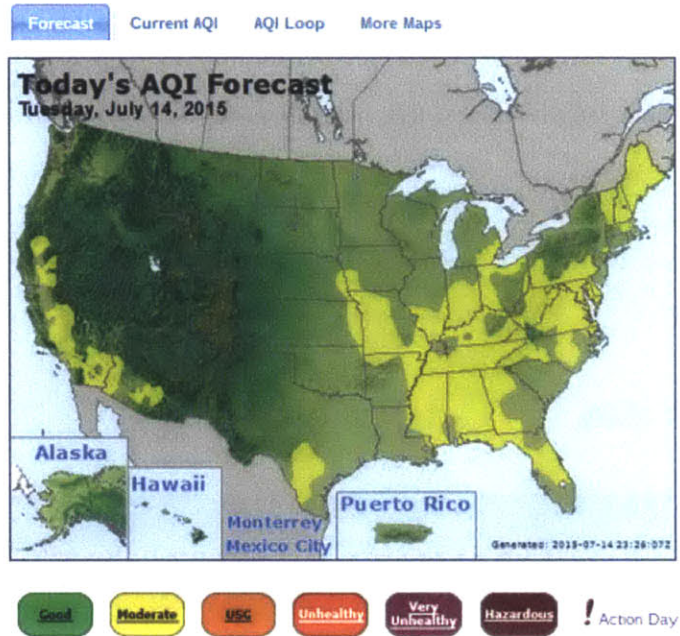


Fig. 4. EPA, *AirNow dashboard*. From: EPA, “AirNOW.” *AirNow.gov*, accessed January 2016. <http://www.airnow.gov/>

SmartCitizen is an air quality sensing platform and project designed to enable those with the SmartCitizen Kit (an open hardware sensor) to collect data on air quality and share it publicly on the platform. The sensors can be bought fully assembled, or they can be assembled using open source hardware parts based on the Arduino platform. Participants who volunteer to host a sensor deploy it at a location of their choosing and elect to broadcast the data so that it becomes publicly viewable on a map. Unlike the two examples above, SmartCitizen’s platform encourages an exploration of very local air quality as opposed to looking at it on a regional scale. As a user of the map, one must click on specific sensors in order to access their readings.

The data reflect particular contexts and particular locations and are not generalized to reflect the air quality of a wider area. However, there is no explicit “standard” against which these measurements are compared. In its current state, the platform is more of an exploratory tool for users to look at data from different sensor sources within a community of volunteers, researchers, and environmental activists.



Fig. 5. SmartCitizen, *Air quality map platform*. From: SmartCitizen, “Map,” *SmartCitizen.me*, accessed January 2016. <http://smarcitizen.me>.

Sensors that operate at the personal scale include – but are not limited to - wearable sensors that can be carried on or in the body (e.g. Propeller Health asthma inhaler); devices that sense domains that are typically considered private such as a person’s home (e.g. Google Nest thermostat, AT&T Digital Life suite); or sensors embedded in mobile phones which can be used to track an individual’s behavior and movements (accelerometer, GPS, et al.). It is at this scale that the tension between preserving personal privacy and foregrounding a culture of open, public data is most prevalent. While wearable devices can be used to track an individual’s fitness and health patterns, that individual may not want that information to be publicly accessible. A similar logic can be applied to the use of sensor data produced within the context of someone’s home or on their personal smartphone. Since the purpose of sensors is to produce data, the mediation of that data through various interpretive processes can determine whether that data is used responsibly or whether it is compromised.

### *Constructing meaning from sensor data*

Philosopher David Hume writes about “impressions” and “ideas” with regard to how human perception functions.<sup>31</sup> “Impressions” refer to sensory, lived experience and “ideas” refer to the *interpretation* of that experience. For instance, the “impression” of a noxious smell might trigger an “idea” of decay, disgust, danger, or death. Through Hume’s framework, sensors are things that gather “impressions” in the form of raw data about their environment, and human actors then synthesize “ideas” about this data by way of interpretation. What this gets at is that even “raw” scientific data endures a process of mediation.<sup>32</sup> For example, in Fig. 6, “raw” data from an open source environmental sensor I built on behalf of a project called Data Canvas: Sense Your City selects for certain features of the environment such as temperature, humidity, UV light, etc. What the sensor measures is limited by its hardware. These readings are then given metrics, which are further categorized in different ways, and given different *meanings* (e.g. water freezes at zero degrees Celsius and boils at 100 degrees Celsius).

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<sup>31</sup> David Hume, *An inquiry concerning human understanding*, Edited by Charles William Hendel (Indianapolis: Bobbs-Merrill, 1955 [1748]).

<sup>32</sup> Lisa Gitelman, ed., *Raw data is an oxymoron* (Cambridge, MIT Press, 2013).

Bruno Latour, "Circulating reference: Sampling the soil in the Amazon forest," *Pandora's Hope: Essays on the Reality of Science Studies* (Cambridge: Harvard University Press, 1999): 24-79.

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Fig. 6. Raw data from environmental sensor. From: DataCanvas: Sense Your City open source grove sensor kit.

Another perspective on how meaning is constructed from sensor data might be through thinking of sensor data as “definitions” of reality. *Definitions* are socially constructed -- that is, they do not necessarily describe the world as it “is” in a positivist sense but rather a way in which it is understood from a certain subject-object position.<sup>33</sup> Similarly, literature in critical cartography seeks to explain this same relationship between what is observed in the world and the interpretation and/or representation of what is observed. Rob Kitchin, Chris Perkins, & Martin Dodge discuss maps as *propositions*, as “ideologically loaded to convey particular messages. A map does not simply represent the world; it produces the world.”<sup>34</sup> Edward Schiappa reinforces this point of view, remarking that maps are “necessarily selective” and

<sup>33</sup> Edward Schiappa, *Defining Reality* (Carbondale: Southern Illinois University Press, 2013), 152-157.

<sup>34</sup> Martin Dodge, Rob Kitchin, and Chris Perkins, eds. *Rethinking maps: new frontiers in cartographic theory* (New York: Routledge, 2011), 13.

“constructed for specific interests and purposes.”<sup>35</sup> Like maps, definitions, and Hume’s “impressions,” sensor data are representational of their environment.

I emphasize that sensor data are representative for two main reasons. First of all, a basic understanding of these core principles is essential to framing the work that those who produce, analyze, and communicate sensor data seek to do. Negotiating how to represent sensor data requires recognition of its limitations, what it can and cannot tell you. Secondly, it is critical to understand that very often we choose to measure and represent what we care about. In this sense, representations of spatial data can be selective; they can be expressions of power as well as constructions of power, the implications of which can determine whether data might be used for “public debate, private commercial enterprise, narrative content,” or otherwise.<sup>36</sup> Because air quality is inherently spatial, and because this thesis will look at how air quality data is represented in a variety of ways, including maps, it is important to keep these principles in mind as we move forward.

### *Measuring air quality with sensors*

Air quality, a term used to relate how much pollution is present in the air, is something that can be detected both by our five senses as well as sensor devices.<sup>37</sup> We can see dust clouds and smog; we can smell certain gases and feel wind. But the human senses alone are not sufficient to evaluate the effects of air pollution. Still, air is mostly invisible and indiscernible by sight, and many common pollutants are odorless, necessitating the invention and *intervention* of

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<sup>35</sup> Edward Schiappa, *Defining Reality* (Carbondale: Southern Illinois University Press, 2013), 157.

<sup>36</sup> Annette M. Kim, *Sidewalk City: Remapping Public Space in Ho Chi Minh City*, (Chicago: University of Chicago Press, 2015), 66.

<sup>37</sup> Ron Williams, et al., “Air Sensor Guidebook,” *U.S. Environmental Protection Agency* (Washington D.C.: GPO, 2014), 159.

sensor devices to evaluate air quality. Thus, air quality sensors are designed to take measurements of the extent to which air is polluted, and to help generate measurements that can be compared and communicated to others. A variety of instruments and techniques exist to measure specific air pollutants. Air quality sensors usually measure levels of particulate matter (PM), the presence of certain gases (such as carbon dioxide), and in some cases, levels of radiation.<sup>38</sup>

After World War II, an increased awareness of industrial hazards and waste led to more environmental consciousness and activism.<sup>39</sup> Books like Rachel Carson's *Silent Spring* galvanized environmental activists to put pressure on government to take responsibility for pollution.<sup>40</sup> In 1970 under President Nixon, the United States Environmental Protection Agency (EPA) was created, at first made up of an inchoate collective of four reassigned Executive Branch departments. While cities and states, on their own, had previously implemented environmental policies to regulate industrial pollution (e.g. Chicago and Cincinnati in the 1880s, Pittsburg and New York in the 1890s), there had not been a uniform national approach in the U.S. until the 1970s.<sup>41</sup> New national policies to address pollution warranted the need for new methods and strategies for measuring it. There was a need for air quality data. The Texas Department of Health, which had begun air quality studies and sampling years before the

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<sup>38</sup> Ibid, p.1

<sup>39</sup> Environmental Protection Agency, "EPA History (1970-1985), About EPA, US EPA," *EPA History*, accessed December 2015. <https://www.epa.gov/aboutepa/epa-history>

<sup>40</sup> Rachel Carson, *Silent spring*. (Boston: Houghton Mifflin Harcourt, 2002).

<sup>41</sup> Environmental Protection Agency, "Environmental Progress & Challenges: EPA's Update," (Washington, D.C.: DIANE Publishing, 1997), 13.

establishment of the EPA,<sup>42</sup> eventually took over federal air quality monitoring and produced research that informed national environmental policy and led to the adoption of national air quality standards.<sup>43</sup> Currently, the EPA's Office of Air Quality Planning and Standards (OAQPS) manages the monitoring of air quality as mandated by the Clean Air Act.<sup>44</sup>

Along with government efforts to collect air quality data are citizen-led efforts that treat data collection as an act of civic engagement. Inspired in part by the "open data" movement, which emphasizes principles of openness, reusability, and shareability of data, citizen-led environmental quality monitoring seeks to collect data where it may not yet exist, verify new data against existing government data, or to educate the public about environmental concerns, among other motivations.<sup>45</sup> For example, the nonprofit organization Public Laboratory was founded in response to the 2010 Deepwater Horizon Oil Spill, on the basis of collecting grassroots environmental data to monitor cleanup activity (or lack thereof) with do-it-yourself technology. This was a community-driven effort that involved using camera sensors attached to weather balloons to collect and stitch together aerial photographs of affected areas on the Louisiana coastline.<sup>46</sup>

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<sup>42</sup> Texas Commission of Environmental Quality. "History Of The TCEQ And Its Predecessor Agencies," *Texas Commission of Environmental Quality*, accessed January 2016. <http://www.tceq.state.tx.us/about/tceqhistory.html>.

<sup>43</sup> Ibid.

<sup>44</sup> Environmental Protection Agency, "Air Quality, Air Quality Planning & Standards, US EPA," *Air Quality*, accessed January 2016. <https://www3.epa.gov/airquality/>.

<sup>45</sup> Open Knowledge Foundation, "The Open Definition - Open Definition - Defining Open In Open Data, Open Content And Open Knowledge," *Open Definition*, accessed July 2015. <http://www.opendefinition.org>

Jennifer C. Molloy, "The Open Knowledge Foundation: Open Data Means Better Science," *PLoS Biol*, no. 9 (2011): 12.

<sup>46</sup> Public Laboratory of Science and Technology, "Stories from the Public Lab Community," *Stories from the Public Lab Community*, accessed January 2016. <http://publiclab.org/wiki/stories>.

More specific to air quality, a recent emergence and availability of low-cost air sensors costing between \$100 to \$500 USD has made it possible for individuals to collect air quality outside of institutional means.<sup>47</sup> Writ large, low-cost air sensors are still considered to be in an early stage of technology development, and many sensors have not yet been evaluated for accuracy and usability, among other factors.<sup>48</sup> The EPA maintains, “No lower cost sensors currently meet [the EPA’s] strict requirements or have been formally submitted to EPA.”<sup>49</sup> Nonetheless, the availability of air sensing tools, compounded by a desire and need to address and assess air quality in relation to human health, has galvanized much experimentation with low-cost air sensors in disparate contexts, spanning pedagogical applications to advocacy and civic engagement to “quantified self” efforts.<sup>50</sup> The use of low-cost air quality sensing is an important paradigm shift in traditionally government-led assessments of air quality.

### *Challenges of measuring and representing air quality*

Given the multitude of ways in which government and citizen stakeholders can collect and access air quality data, there are many ways air quality data can be visualized or communicated. It is here where media studies may intervene in order to examine what Kitchin, et al. (2015) call the “praxis and politics” of assembling urban dashboards.<sup>51</sup> The term

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<sup>47</sup> Sarah Williams, “Data Visualizations Break Down Knowledge Barriers in Public Engagement,” *The Civic Media Reader*, eds. Eric Gordon and Paul Mihailidis (Cambridge: MIT Press, 2016), In press.

Ron Williams, et al., “Air Sensor Guidebook,” *U.S. Environmental Protection Agency* (Washington D.C.: GPO, 2014), 159.

<sup>49</sup> Ibid.

<sup>50</sup> Emily G. Snyder, et al., “The Changing Paradigm Of Air Pollution Monitoring,” *Environmental Science & Technology* 20.47 (2013): 11369-11377.

<sup>51</sup> Rob Kitchin, Sophia Maalsen, and Gavin McArdle, “The Praxis and Politics of Building Urban Dashboards,” *Social Science Research Network* (Working paper, 2015).



“dashboards” also refers to other data portals and graphical user interfaces (GUIs) for displaying urban data. Ultimately, determining the best ways to visualize air quality data is a problem of *representation*: who produces the information, who the audience is, and its medium of conveyance.

A few challenges complicate the current ways that air quality is currently represented. First, not all air quality data representations are based on the same *standards*. In 1977, an amendment to the Clean Air Act called for daily analysis and reporting of air quality based on a uniform air quality index, motivated by a desire to draw public attention to air pollution and to keep local government agencies accountable for monitoring and enhancing air quality within their jurisdictions.<sup>52</sup> The U.S. Environmental Protection Agency developed a public-facing guide called the *Air Quality Index* wherein standard for measuring pollutant concentrations and health concerns has been established for a number of common pollutants.<sup>53</sup> The index uses a color code to convey a spectrum of air quality, ranging from “good” (green) to “hazardous” (crimson).

Though developed by a U.S. agency, the AQI can be applied to international contexts and has been used across other air sensing projects globally. For example, *The Guardian* notes that the Indian government has not set standards for their air quality monitoring instruments but “makes it mandatory for manufacturing companies to adhere to the US Environmental Protection Agency (EPA) specifications.”<sup>54</sup> The standards that air quality monitoring efforts employ also

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<sup>52</sup> 42 U.S. Code § 7619.

J.C. Fensterstock, K. Goodman, G. M. Duggan, and W. S. Baker, "The development and utilization of an air quality index," In *Proceedings of 62nd Annual Meeting of the APCA* (New York: APCA, 1969): 69-73.

<sup>53</sup> *Ibid*, pp. 18-22.

<sup>54</sup> Janaki Lenin, “India’s Air Quality Figures Can’t Be Trusted,” *The Guardian* (October 20, 2014). <http://www.theguardian.com/environment/india-untamed/2014/oct/20/india-air-quality-delhi-polluted-city-world>.

determine which pollutants are measured and displayed. The EPA specifies six main “criteria pollutants” upon which its standards are based for the Clean Air Act: ozone (O<sub>3</sub>), particulate matter (PM 2.5 and PM<sub>10</sub>), carbon monoxide (CO), nitrogen oxides (NO and NO<sub>2</sub>), sulfur dioxide (SO<sub>2</sub>), and lead.<sup>55</sup>

Alternatively, the World Health Organization’s air quality guidelines target particulate matter, ozone, nitrogen dioxide, and sulfur dioxide.<sup>56</sup> Competing standards can be misleading when comparing air quality from different sources of data.<sup>57</sup> Government-managed air quality dashboards like the EPA’s *AirNow* displays real-time air quality data from over 400 cities internationally based on the Air Quality Index, but the citizen- and journalist-led air quality sensing project Beijing Air Tracks compares its measurements to the World Health Organization guidelines.<sup>58</sup>

Second, the *accuracy* of air quality data often depends on the *resolution* of the sensor, how or whether the sensor used to measure it was *calibrated*, and the overall *goal* of the air quality monitoring effort. In representations of air quality data, all of these factors affect how accurate the information is and, in effect, how reliable one perceives it to be. In terms of

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<sup>55</sup> PM<sub>2.5</sub> refers to “fine particles” which are 2.5 microns or smaller in diameter whereas PM<sub>10</sub> refers to “coarse particles” which are larger than 2.5 microns and smaller than 10 microns in diameter.

Environmental Protection Agency, “Six Common Air Pollutants,” *EPA.gov*, accessed January 2016. <http://www.epa.gov/oaqps001/urbanair>.

<sup>56</sup> World Health Organization, “WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide: global update 2005: summary of risk assessment,” *World Health Organization*, accessed January 2016.

<sup>57</sup> Yazid Benkhellat, Marc Siebert, and Jean-Pierre Thomesse, “Interoperability of sensors and distributed systems,” *Sensors and Actuators A: Physical* 37 (1993): 247-254.

<sup>58</sup> Environmental Protection Agency, “About AirNOW: Air Quality Index,” *AirNow.gov*, accessed January 2016. [http://www.airnow.gov/index.cfm?action=topics.about\\_airnow](http://www.airnow.gov/index.cfm?action=topics.about_airnow).

Civic Data Design Lab, “Beijing Air Tracks,” *Civic Data Design Lab*, accessed January 2016. <http://www.civicdatadesignlab.org/beijing-air-tracks>.

resolution, the distribution of air quality sensing nodes varies from one sensing project to another. In one context, there may be one sensor for every square mile, resulting in a higher resolution of air quality data; in another, there may be one sensor for every ten square miles, resulting in a lower resolution of air quality data. Data portals are not always transparent about the resolution of the data. Some portals mitigate this by displaying the exact location of their sensors, but some others like AQICN, do not. The Data Canvas: Sense Your City project displays the location of all citizen-managed environmental sensors on a map so that those looking at it can tell where the measurements have taken place.<sup>59</sup> (See Fig. 7)



Fig. 7. Data Canvas: Sense Your City, *Sensor locations*. From: Data Canvas: Sense Your City, “Map,” *DataCanvas.org*, accessed November 2015. <http://map.datacanvas.org/#!/cities/Boston>

<sup>59</sup> Data Canvas: Sense Your City, “Sense Your City,” *DataCanvas.org*, accessed January 2016. <http://map.datacanvas.org>.

Calibration is “the process of checking and adjusting an instrument’s measurements to ensure that it is reporting accurate data.”<sup>60</sup> Because sensor performance can change over time due to buildup of dust, bugs, or loss of power, it is important to calibrate sensor devices before, during, and after data collection occurs to account for potential error or drift. The frequency with which sensor devices are calibrated also affects how “accurate” the information is. Then again, accuracy may not always be the end goal, since the motivations behind measuring air quality vary.<sup>61</sup> Sensing projects that focus on education and engagement may not necessarily call into question data validity or quality; some projects are more interested in engaging communities of volunteers or observing general data trends rather than total accuracy.<sup>62</sup>

Finally, there is an element of *bias* to consider. Data can be spatially biased: in the case of New Delhi, air quality “is based on 361 monitoring stations, most of which are in urban areas.”<sup>63</sup> Thus, one cannot assume that air quality reports will be entirely representative across space. Data can also be subjectively biased; in other words, we choose what to measure, which inherently means that we select for some factors and elide others. In the same New Delhi example, “while data is collected for 12 pollutants in a few big cities, in the rest of India, data is collected for far fewer,” and in some places where coal is mined, where metals like mercury are present in the air, those metals are not measured.<sup>64</sup>

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<sup>60</sup> Ron Williams, et al., “Air Sensor Guidebook,” *U.S. Environmental Protection Agency* (Washington D.C.: GPO, 2014), 159.

<sup>61</sup> Sarah Williams. “Data Visualizations Break Down Knowledge Barriers in Public Engagement,” *The Civic Media Reader*, eds. Eric Gordon and Paul Mihailidis (Cambridge: MIT Press, 2016), In press.

<sup>62</sup> Sarah Williams, working manuscript.

<sup>63</sup> Janaki Lenin, “India’s Air Quality Figures Can’t Be Trusted,” *The Guardian* (October 20, 2014). <http://www.theguardian.com/environment/india-untamed/2014/oct/20/india-air-quality-delhi-polluted-city-world>.

<sup>64</sup> *Ibid.*

Sometimes, biases are driven by other constraints, like privacy. Because air quality is often tied to geography, air quality measurements in public data portals (both governmental and citizen-led) usually refers to *outdoor* air quality as opposed in *indoor* air quality.<sup>65</sup> Air quality sensors can measure and store sensitive location data that could be misused.<sup>66</sup> If a sensor were hosted in front of an individual's home and visualized on a map, another person looking at the map could technically identify where the sensor host lives. On the other hand, the perception of what information or what space is private or not can be contextual, contingent upon the constraints set by stakeholders, which includes those interested in collecting and consuming the data.<sup>67</sup> No data set is "complete" or representative of a totally complete "truth" about the world. Extracting meaning from data involves "a complex assemblage of people, instruments, and practices dedicated to [its] production, management, and care."<sup>68</sup>

### *Conclusion*

Due to a variety of factors such as competing standards, stipulations of data accuracy, and bias, the current landscape of air quality measurement and representation faces the unique challenge of synthesizing best practices for communicating air quality. The co-construction of environmental knowledge by different actors allows for varying representations and narratives of air quality. Environmental knowledge can be further politicized and manipulated by representing air quality at different scales or through other framings. Each scalar representation of

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<sup>65</sup> Ibid.

<sup>66</sup> Federal Geographic Data Committee & Homeland Security Working Group, "Guidelines for Providing Appropriate Access to Geospatial Data in Response to Security Concerns," (Washington, D.C.: FGDC, 2005): 16. <http://www.fgdc.gov/fgdc/homeland/index.html>.

<sup>67</sup> Helen Nissenbaum, *Privacy in context: Technology, policy, and the integrity of social life* (Palo Alto: Stanford University Press, 2009), 68.

<sup>68</sup> Lisa Gitelman, ed., *"Raw Data" Is An Oxymoron* (Cambridge: MIT Press, 2013).

environmental information is a proposition for how to view a particular issue and not necessarily a “true” depiction of conditions. Then, although the practice of government-led air quality measurement has been around for some time, emerging technologies that enable citizens to assist with air quality sensing pose new challenges to how to make meaning of these disparate sources of knowledge through different forms of representation, for different aims, and for different audiences. All of these become important when considering *who* is behind the collection of air quality data (or any other environmental information) as well as *for whom* the information is intended.

In Chapter 3, I begin to discuss these issues in relation to a case study centered on a specific city in order to illustrate collaborative government and citizen-led strategies for communicating air quality data across contexts and constituencies.

# three

## **Air Quality Data across Contexts and Constituencies: A Case Study of Post-Catastrophe Christchurch, Canterbury, New Zealand**

In 2010 and 2011, a series of earthquakes shook Christchurch, New Zealand, destroying much of its central business district and city infrastructure. On September 4, 2010, a magnitude 7.1 earthquake caused significant damage to infrastructure, but miraculously there were zero casualties. Several months later on February 22, 2011, another earthquake struck the Canterbury region, registered as a magnitude 6.3 quake on the Richter scale, causing widespread damage. This time, the earthquake claimed 185 lives total, making it the nation's fifth most destructive disaster by death toll.<sup>69</sup> The economic cost of rebuilding remains somewhere around \$40 billion, based on estimates as of 2013.<sup>70</sup> Due to the structural damage of the city and subsequent aftershocks, the city sectioned off an area in the Central Business District called the Red Zone.<sup>71</sup>

With an estimated 80% of its pre-quake buildings now demolished, residents in the city often refer to Christchurch as a “blank slate,” a palimpsest for architects, developers, engineers, urban planners and designers, artists, and citizens. Thus, we cannot talk about Christchurch

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<sup>69</sup> Contributors, Wikipedia, “List of disasters in New Zealand by death toll,” *Wikipedia*, accessed November 2015.

[https://en.wikipedia.org/w/index.php?title=List\\_of\\_disasters\\_in\\_New\\_Zealand\\_by\\_death\\_toll&oldid=682487368](https://en.wikipedia.org/w/index.php?title=List_of_disasters_in_New_Zealand_by_death_toll&oldid=682487368)

New Zealand Police, “List of deceased,” *New Zealand Police*, accessed November 2015.

<http://www.police.govt.nz/major-events/previous-major-events/christchurch-earthquake/list-deceased>

<sup>70</sup> National Business Review, “Christchurch quake cost rises \$10b to \$40b,” *National Business Review*, accessed July 2015. <http://www.3news.co.nz/politics/christchurch-rebuild-to-cost-10b-more-2013042813#axzz3quJGDtyv>.

<sup>71</sup> Canterbury Earthquake Recovery Association, “CBD Rebuilt Red Zone,” (Christchurch, NZ: CERA, accessed November 2015). <http://cera.govt.nz/cbd-rebuild-zone>

without talking about catastrophe, about its narrative of disaster. Anthony Oliver-Smith and Susanna Hoffman write of disaster as a “social construction,” the aftermath of which “can be a time of not just material but social devastation, fragmentation, and despair. For many, it can also be, quite remarkably, a time of social cohesion, purpose, and almost glory.”<sup>72</sup> While the city’s infrastructure was being rebuilt after the earthquakes, so too was its leadership, community, and economy. Patricia Ann Allan writes that in the negotiation of a city’s future after a disaster, “a variety of social relationships between individuals and groups” often emerges, which can then lead to the creation of tension and conflicting agendas.<sup>73</sup>

In particular, this kind of tension in Christchurch might best be captured by the plans for reconstructing the Christchurch Cathedral. The Cathedral, a landmark in the city center, had been partially destroyed by the earthquakes. Although some have lobbied to restore to its pre-earthquake state, other groups have protested that it was an opportunity to have it redesigned and altered, ultimately stalling any resilience efforts from continuing. The controversy might be summed up in one question: should the city be *restored* to what it was before the earthquakes, or should it be *rebuilt* into something new entirely? This tension remains largely unresolved but is nonetheless prevalent in decision-making processes concerning which pre-existing systems and processes should remain, and which should change as Christchurch rebuilds.

From interviews and data collected during a fellowship with nonprofit organization SensingCity and the University of Canterbury Department of Geography, I argue for the importance of assembling knowledge about air quality in the unique post-disaster context of

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<sup>72</sup> Anthony Oliver-Smith and Susanna M. Hoffman, eds., *The angry earth* (Florida: University of Florida, 1999).

<sup>73</sup> Patricia Ann Allan, “The Christchurch Cathedral Controversy,” Project abstract, (Christchurch, NZ: University of Canterbury, 2015).  
<http://www.canterbury.ac.nz/spark/Project.aspx?projectid=265>



Christchurch. Equally important is the ability to communicate this knowledge, usually in the form of data represented on maps, across multiple stakeholders to signal risk and vulnerability. I show a variety of tactics and tools that environmental agencies, city government, nonprofit organizations, and academic institutions use to capture and represent air quality data.

### *Air quality measurement as risk assessment*

Resilience efforts in Christchurch over the past four years have been focused on ways of measuring and managing risk, what Ulrich Beck describes as a means of tracking “hazards which are neither visible nor perceptible to the victims.”<sup>74</sup> Establishing a means to measure air quality in Christchurch after the earthquakes is a problem compounded by rebuilding efforts in the city, as well as a hazard that cannot readily be detected to those affected by it. Air quality is both something that citizens of Christchurch are *affected by* and something that they *contribute to* through their behavior. For city authorities and urban planners and designers in Christchurch, an understanding of air quality affects how policy is interpreted and formed, particularly concerning housing and land use. As a result, any evaluation of risk in air quality conducted by city authorities must then be communicated to publics with the intention to influence or change social behavior. Herein lies the potential for what Beck calls “the fissures and gaps between scientific and social rationality in dealing with hazardous potential of civilization,” in other words, conflicting agendas of *how* risk should be measured and managed.<sup>75</sup>

The importance of assembling knowledge about air quality in Christchurch should not be understated. In post-disaster environments, the task of generating and communicating information about community need is pressing. The communication of this information becomes

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<sup>74</sup> Ulrich Beck, *Risk Society: Towards a New Modernity* (Munich: SAGE Publications, 1992).

<sup>75</sup> Ibid.

a form of signaling *vulnerability* to international communities, creating wider consciousness about the consequence of distant disasters, and laying the groundwork for providing appropriate aid.<sup>76</sup> Disasters are situated between material and social worlds, socially constructed by those who experience them, and people's perception about risk within the context of disaster embody how vulnerability is measured and codified into knowledge, and possibly policy.<sup>77</sup>

In post-disaster Christchurch, the collection of air quality data toward understanding the 'new normal' of air quality after the earthquakes is a form of risk assessment. But the methods and mechanisms used to perform this work are, naturally, a selection of some practices and thus a deflection of others. Before discussing the complications that come with air quality assessment in Christchurch, however, I would first like to provide context on what factors contribute to air quality in the city and what the main concerns are.

### *Air quality in Christchurch*

Its geography, motor vehicle emissions, wood burners, building construction, and Chronic Obstructive Pulmonary Disorder (COPD) mostly govern Christchurch's air quality conditions and concerns. Its topography (hills and mountains), proximity to the coast, and prevailing wind conditions play a role in increasing air pollution levels. Christchurch is prone to the formation of thermal inversion layers in winter, in which cold air at higher altitudes from nearby hills traps pollution near lower urban areas as it sinks downward.<sup>78</sup> (See Fig. 8) This means that pollution is likely to remain trapped at street level for a longer period of time as

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<sup>76</sup> Charles A. Schmitz, *Disaster!: The United Nations and International Relief Management* (New York: Council on Foreign Relations, 1987).

<sup>77</sup> Greg Bankoff, Georg Frerks, and Dorothea Hilhorst. *Mapping vulnerability: disasters, development, and people* (New York: Routledge, 2004).

<sup>78</sup> *Ibid.*

opposed to dissipating.

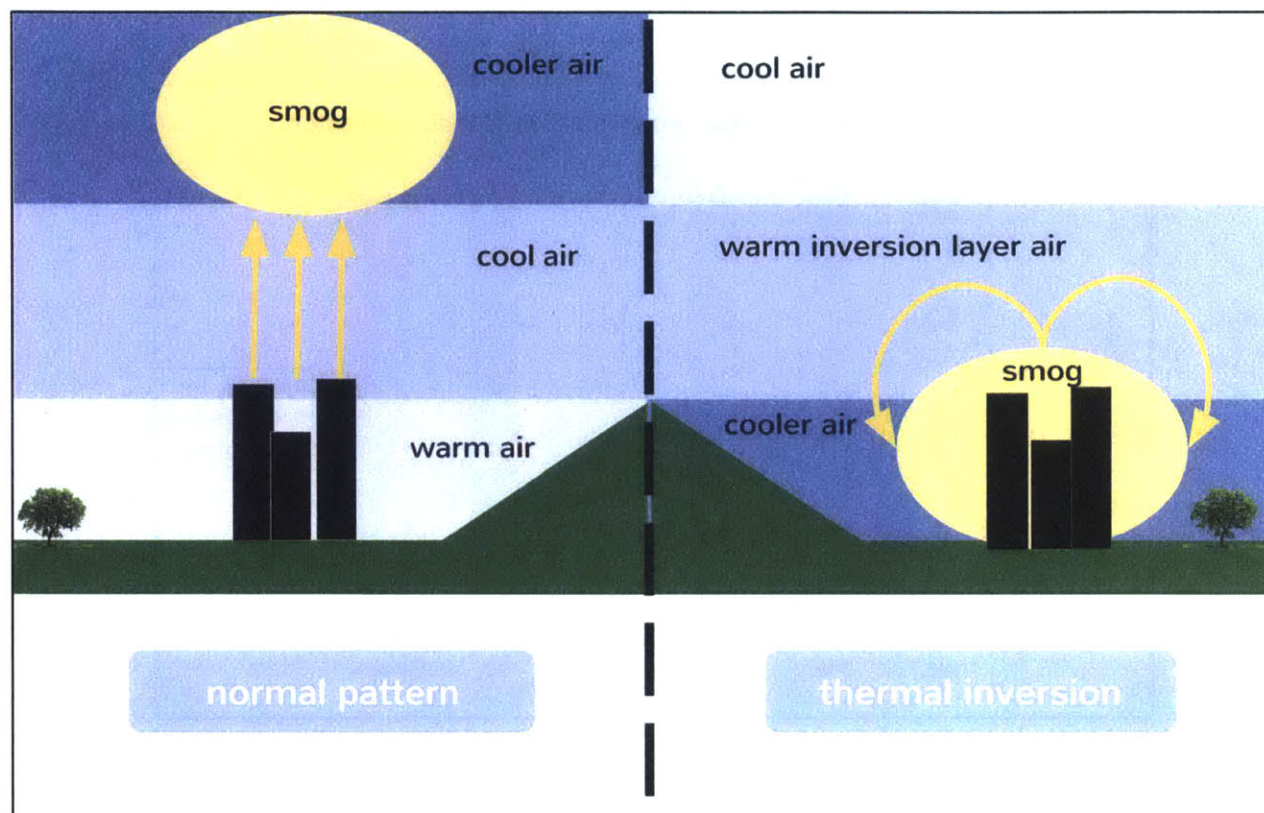


Fig. 8. Thermal inversion layer in Christchurch (2016).

Motor vehicles are a source of carbon monoxide (CO), accounting for 70% of emissions on weekdays and 61% on Sundays, and nitrogen oxide, accounting for 80% of emissions on weekdays and 83% on Sundays.<sup>79</sup> (See Fig. 9) Cheap used cars, which are quite common in Christchurch, also do not help with the air quality on roads. Despite transport policy for stricter

<sup>79</sup> Environment Canterbury Regional Council, "Inventory of Emissions to Air in Christchurch: Report No. R11/17," ed. John Smithson (Christchurch, NZ: ECAN, 2011). <http://ecan.govt.nz/publications/Reports/inventory-emissions-air-christchurch.pdf>.

emissions requirements,<sup>80</sup> I regularly passed by cars with dark smoke coming out of the exhaust pipe on my way to University each day.

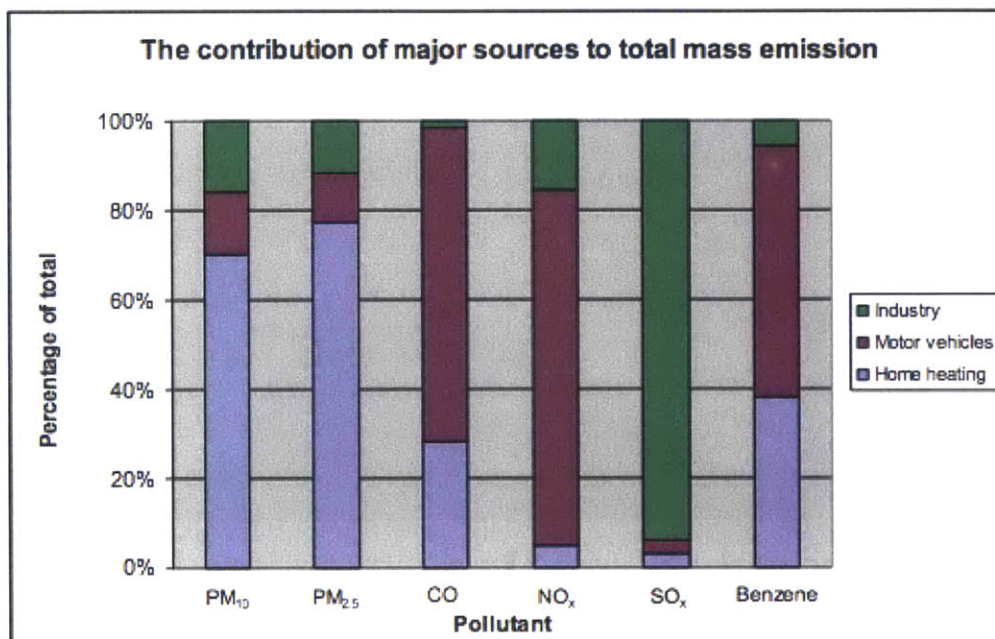


Fig. 9. ECAN, *Breakdown of mass emission sources in Christchurch*. From: “Inventory of Emissions to Air in Christchurch: Report No. R11/17,” ed. John Smithson (Christchurch, NZ: ECAN, 2011). <http://ecan.govt.nz/publications/Reports/inventory-emissions-air-christchurch.pdf>.

Still, only 20% of Christchurch’s winter air pollution comes from vehicle transmission and industry combined. The remaining 80% comes from wood or coal burners and open fires.<sup>81</sup> About 575,000, or 40%, of all households still use wood for home heating, according to 2013 Census figures. Wood fires have lower running costs and tend to be used by people with incomes above \$70,000 a year.<sup>82</sup> A Canterbury District Health Board (CDHB) representative points out that despite heat pumps being up to 500% efficient (as opposed to wood burners, which are 80%

<sup>80</sup> New Zealand Ministry of Transport, “The New Zealand vehicle emissions screening programme,” Pamphlet (Auckland, NZ: Ministry of Transport, 2004). <http://www.transport.govt.nz/assets/Import/Documents/nzvesp-resource-doc22nov04.pdf>

<sup>81</sup> Ibid.

<sup>82</sup> Sunday Star Times, “Are woodburners the best way to heat a home?” *Stuff.co.nz*, (May 7, 2007). <http://www.stuff.co.nz/sunday-star-times/business/money-story-archive/earlier-money-stories/30844/Are-woodburners-the-best-way-to-heat-a-home>.

efficient), “people became attached to the idea of dancing flames” after the earthquakes.<sup>83</sup> As part of a post-disaster cultural phenomenon, Christchurch residents became more reliant on wood burners to keep warm as opposed to heat pumps because the latter rely entirely on electricity for power, a public utility that was not always guaranteed during earlier days of the rebuild. Another air quality concern unique to post-disaster Christchurch is that of building construction as a major contributor to pollution. The construction and demolition of new buildings contributes to the spread of particulate matter in the air.<sup>84</sup>

These air quality concerns make those with Chronic Obstructive Pulmonary Disorder (COPD) and other respiratory conditions particularly vulnerable.<sup>85</sup> Air quality has been deemed one of the key determinants of public health in a city-wide Health Impact Assessment Report, and because air quality is linked to land use, there are socioeconomic patterns that are inevitably connected to air quality impacts in Christchurch.<sup>86</sup> For instance, up to 21% of wood burner households have an annual income of less than \$52,000, and 22% of wood burner households had at least one occupant with chronic respiratory illness.<sup>87</sup> Air quality is related to both public health and land use policy, and the distribution of those air quality risks can potentially reveal underlying patterns of inequity.

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<sup>83</sup> Ibid.

<sup>84</sup> Shelley Robinson, “Construction: A cause of city pollution,” *The Press*, (April 11, 2014). <http://www.stuff.co.nz/the-press/news/10696373/Construction-A-cause-of-city-pollution>. Public Health Advisory Committee, “A Guide to Health Impact Assessment: A Policy Tool for New Zealand, 2nd Edition,” (Auckland, NZ: National Health Committee, 2005). Ministry for the Environment. “Overview of Air Quality,” *Ministry for the Environment* (Auckland, NZ: Ministry for the Environment, accessed July 2015). <http://www.mfe.govt.nz/air/overview-air-quality>

<sup>85</sup> Environment Canterbury Regional Council and Canterbury District Health Board, “Health Impact Assessment: Review of Environment Canterbury’s Air Plan,” CDHB (Christchurch, NZ: CDHB, accessed July 2015).

<http://nhc.health.govt.nz/system/files/documents/publications/guidetohia.pdf>

<sup>86</sup> Ibid.

<sup>87</sup> Ibid.

In an ideal world, having more information about air quality could potentially lead to behavior change and more sustainable practices for heating homes in Christchurch. However, a representative from the National Institute of Water and Atmospheric Research (NIWA) in Canterbury puts it a slightly different way. For their organization, behavior change is not necessarily the end goal of air quality research. Instead, according to a representative from the organization, it has to do with helping people making informed decisions.<sup>88</sup> Whichever the end goal, the covenant on air quality data, and acquiring more of it for Christchurch, is clear.

### *Sensing City*

After the earthquakes, Christchurch City Council and the regional environmental council lacked baseline data that reflected the city's post-disaster air quality conditions, necessitating the gathering of more data to understand Christchurch's current context. Sensing City, a nonprofit that formed post-earthquake in Christchurch along with many other startups, proposed a project that would endeavor to address the lack of air quality data about Christchurch through a partnership with the University of Canterbury Geohealth Laboratory. The project was supported by additional funding from IBM as part of its Smarter Cities Challenge.<sup>89</sup>

Roger Dennis, the founder of Sensing City, says, "My idea was that if you could install sensors producing data about how cities work, you could attract foreign investment and talent. This is where [our organization] comes from -- how to make the most of a crisis."<sup>90</sup> Dennis hoped that being able to leverage a "new world of low-cost sensors" might demonstrate "citizens

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<sup>88</sup> Malcolm Campbell (researcher) in discussion with the author, July 19, 2015.

<sup>89</sup> IBM Corporation, "Smarter Cities Challenge: Christchurch Report," IBM Corporation, 2013. Accessed November 2015. <http://www.cdc.org.nz/wp-content/uploads/2014/12/ibm-smarter-cities-report-christchurch.pdf>

<sup>90</sup> Roger Dennis, in discussion with the author, July 2015.

instead of regulators could be the drivers of information networks.”<sup>91</sup> Within the scientific literature, there was precedence for “lots and lots of cheap sensors” could produce data that was comparable in accuracy to few expensive ones.<sup>92</sup>

The project’s *ethos* was also influenced by Sensing City’s partnership with the University of Canterbury Geohealth Lab, which focuses on the spatialization of public health. Malcolm Campbell, a co-director of the lab, says, “We saw the opportunity to link air quality sensor data to health conditions. You could have a real-time network of sensors that you could use to work out whether air quality was linked to any health condition.”<sup>93</sup>

At the time of writing, Sensing City is testing mid-grade open source air quality sensors called DustMotes within the Christchurch air shed. On a different scale, Sensing City is also interested in testing the Tzoa wearable air quality sensor as another possible mechanism by which to measure air quality. For testing, Sensing City and the Geohealth Lab pursued a collaborative relationship with Christchurch City Council, Environment Canterbury Regional Health, and related government agencies to test the DustMote and Tzoa sensors against existing sensors already in use by these agencies.

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<sup>91</sup> Ibid.

<sup>92</sup> Radu Stoleru, Tian He, John A. Stankovic, and David Luebke, "A high-accuracy, low-cost localization system for wireless sensor networks," *Proceedings of the 3rd international conference on Embedded networked sensor systems* (ACM, 2005): 13-26.

Giles M. Foody, L. See, Steffen Fritz, Marijn Van der Velde, Christoph Perger, Christian Schill, and Doreen S. Boyd, "Assessing the accuracy of volunteered geographic information arising from multiple contributors to an internet based collaborative project," *Transactions in GIS* 17, no. 6 (2013): 847-860.



Fig. 10. Lily Bui, *Sensing City's office in the EPIC building, located in Christchurch's Red Zone* (2015).

### *Communicating Christchurch air quality*

Both measuring and representing air quality in Christchurch for these stakeholders is challenging for many of the same reasons discussed in Chapter 2. First, the city only has three air quality monitoring sites for all of Christchurch, a total area of 551 square miles and a population of 366,100 people. (See Fig. 11). This sparse coverage gives rise to a problem of accuracy. Air quality monitoring sites are only able to collect data about their immediate surroundings. The data is then generalized to represent all of Christchurch. For instance, if a person lives next to an air quality monitoring station, the station's measurements will likely reflect the conditions near that person's home. However, this may not be applicable to a person living 10 miles away from any given air quality monitoring station due to the low resolution of the data. A lower resolution of monitoring stations also lends itself to a type of ecological fallacy, which consists in thinking



that relationships observed for groups “necessarily holds for individuals.”<sup>94</sup> That is, areas on the map covered by air quality stations also represent areas that do not. In logic, this is also known as the fallacy of composition, the reasoning that the whole represents the part.<sup>95</sup>

At the same time, a desire for implementing more monitoring sites also drives one of the core motivations behind the Sensing City collaboration across sectors - to, in the long term, increase the resolution of air quality monitoring sites as well as to share access to more air quality data between stakeholders.

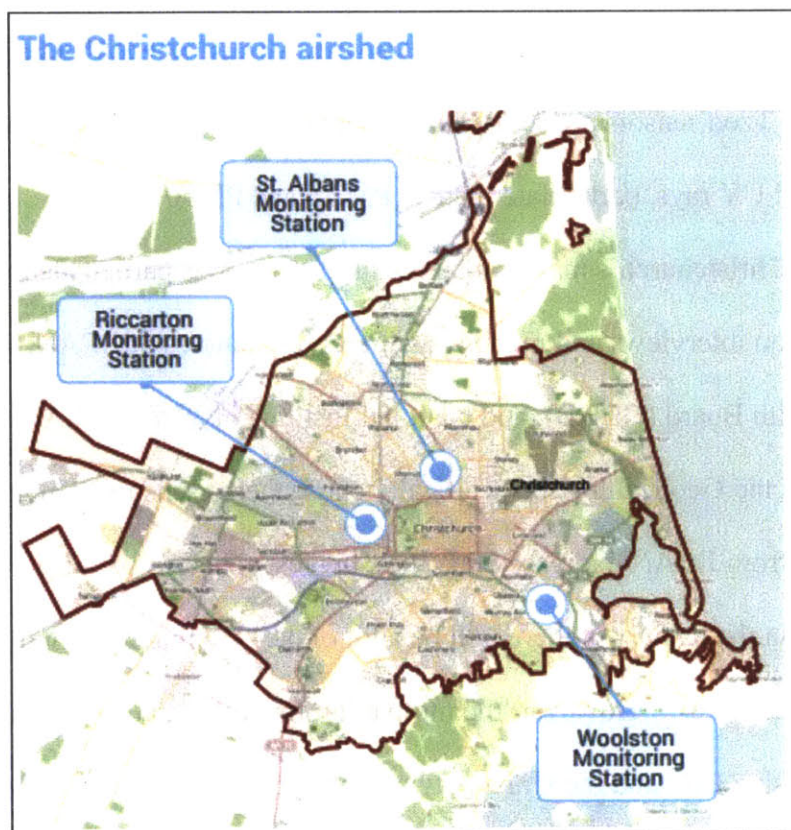


Fig. 11. ECAN, *Christchurch air shed and current air quality monitoring stations*.

From: Environment Canterbury Regional Council, "Environment Canterbury Environmental Snapshot Report: Air Quality in the Canterbury Region.Christchurch," *ECAN* (2014).

<sup>94</sup> David A. Freedman, "Ecological inference and the ecological fallacy," *International Encyclopedia of the social & Behavioral sciences* 6 (1999): 4027-4030.

<sup>95</sup> Merriam-Webster Dictionary, "Fallacy of composition," *Merriam-Webster Dictionary*, accessed January 2016. <http://www.merriam-webster.com/dictionary/fallacy%20of%20composition>.

Second, the compendium of government-operated and citizen-operated sensor tools themselves varies in cost, accuracy, and functionality. ECAN uses air quality sensors that cost \$50K (USD) each. Sensing City's DustMote sensors vary in cost depending on what they are set to measure, and Tzoa sensors cost around \$139 (USD) for a consumer version and \$600 (USD) for the research kit version. ECAN's sensors are calibrated to the U.S. EPA standard, which is "Arizona road dust," but the settings are customized to measure what is most important to measure in the area. For instance, there is little to no nitrogen oxide (NO<sub>2</sub>) in the industrial sector of Woolston, where one of the monitoring stations sits, so ECAN chooses not to measure it. DustMote and Tzoa sensors are set to measure temperature, humidity, atmospheric pressure, ambient light and UV rays, particulate matter (PM<sub>2.5</sub> and PM<sub>10</sub>).

Because Christchurch's main contaminant of concern is particulate matter from wood burners,<sup>96</sup> based on interviews and meetings with representatives of ECAN, the Canterbury Community Health Board (CDHB), and National Institute of Water and Atmospheric Research, Sensing City and the Geohealth Lab specifically chose these sensors to measure PM. Representatives from ECAN expressed that their biggest concerns with using low-cost sensors was "how to clean the data," as "there will be a lot of data coming in from these devices, and it's likely not to be accurate."<sup>97</sup> However, the motivation for collaboratively testing lower-cost sensors with Sensing City and the University of Canterbury is "really comparing them to

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<sup>96</sup> Environment Canterbury Regional Council, "How We Monitor Air Pollution," *Environment Canterbury Regional Council* (Christchurch, NZ: ECAN, accessed July 2015). <http://ecan.govt.nz/services/online-services/monitoring/air-pollution/Pages/how-we-monitor-air-pollution.aspx>

<sup>97</sup> ECAN representatives, in discussion with the author, July 2015.

[government-operated] instruments so [ECAN] knows the level of reliability of them.”<sup>98</sup>

ECAN’s Senior Air Quality Analyst says, “We’ve been paying attention to what’s been happening. We’re open to have anybody with a sensor try it and put it on our monitoring site.”<sup>99</sup>

Those on the Sensing City and the Geohealth Lab team believe that a more collaborative relationship with government agencies might enable both governments and citizens to collect more air quality data at a potentially lower cost.

Having more sensors also means more platforms with which to manage and represent the data. By looking at the multiple ways that air quality sensors in Christchurch is represented for different audiences, we can begin to understand the challenges that city and citizen stakeholders have of extracting and conveying meaning from the data. ECAN’s website has a comprehensive repository of air quality resources for the public in the form of reports, data, and maps. Air quality data displayed here is most likely to reach policymakers, air quality analysts, and researchers and not necessarily members of the general public. A 24-hour average of PM10 appears in a table, and this data can be sorted in two ways: by the air quality monitoring site in Christchurch and year.<sup>100</sup>

A separate page on the ECAN site allows individuals to look at “high pollution nights,” also in table format.<sup>101</sup> The table includes contextual information about pollution concentrations on the previous day, the number of high pollution nights within the current calendar year, and the second and fourth highest pollution nights within the current calendar year.

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<sup>98</sup> Ibid.

<sup>99</sup> ECAN’s Senior Air Quality Analyst, in discussion with the author, July 2015.

<sup>100</sup> ECAN, “24 hour average,” *ECAN*, accessed July 2015. <http://ecan.govt.nz/services/online-services/monitoring/air-pollution/Pages/24-hour-average.aspx>

<sup>101</sup> ECAN, “High pollution nights,” *ECAN*, accessed July 2015.

<http://ecan.govt.nz/services/online-services/monitoring/air-pollution/Pages/high-pollution-nights.aspx>

**24 hour average PM<sub>10</sub> from midnight (µg/m<sup>3</sup>)**

Select the Site **Christchurch - Woolston** and Year **2015** Go

Sample Date	PM <sub>10</sub> Value (µg/m <sup>3</sup> )
01-Jan-2015	13
02-Jan-2015	17
03-Jan-2015	12
04-Jan-2015	15
05-Jan-2015	22
06-Jan-2015	15
07-Jan-2015	21
08-Jan-2015	21
09-Jan-2015	18
10-Jan-2015	28
11-Jan-2015	27
12-Jan-2015	16

Fig. 12. ECAN, *24-Hour Average of Air Pollution in Christchurch* From: ECAN, “24 hour average,” *ECAN*, accessed November 2015. <http://ecan.govt.nz/services/online-services/monitoring/air-pollution/Pages/24-hour-average.aspx>

Location	Pollution concentration (µg/m <sup>3</sup> ) yesterday (7/11/2015)	For the current calendar year		
		Number of high pollution nights	Second highest pollution concentration (µg/m <sup>3</sup> ) [1]	Fourth highest pollution concentration (µg/m <sup>3</sup> ) [2]
Ashburton	24	1		48
Christchurch air shed *	30	8		52

Fig. 13. ECAN, *High pollution nights table on ECAN's website*  
 From: ECAN, “High pollution nights,” *ECAN*, accessed November 2015. <http://ecan.govt.nz/services/online-services/monitoring/air-pollution/Pages/high-pollution-nights.aspx>

The same air quality data from ECAN is displayed in a public-facing website called Let's Clear the Air ([letsclreartheair.co.nz](http://letsclreartheair.co.nz)). ECAN contracted a web designer to create this data portal and to “put it into a format that was nice to read” in order to reach a different audience.<sup>102</sup> The site relies on graphs and colorful images to communicate the same data, in a way that is visually antithetical to the more bureaucratic looking tables on the official ECAN website.

In one graphic, the number of high pollution days within the calendar year is displayed for each city and displayed side by side. Another section of the site allows users to compare more detailed air quality reports from two cities side by side, which include the 24-hour average figures and high pollution days over time. Instead of tables, the site relies on graphs to convey the data; the graphs are much larger than any of the text in sections of the site that use ECAN air quality data.

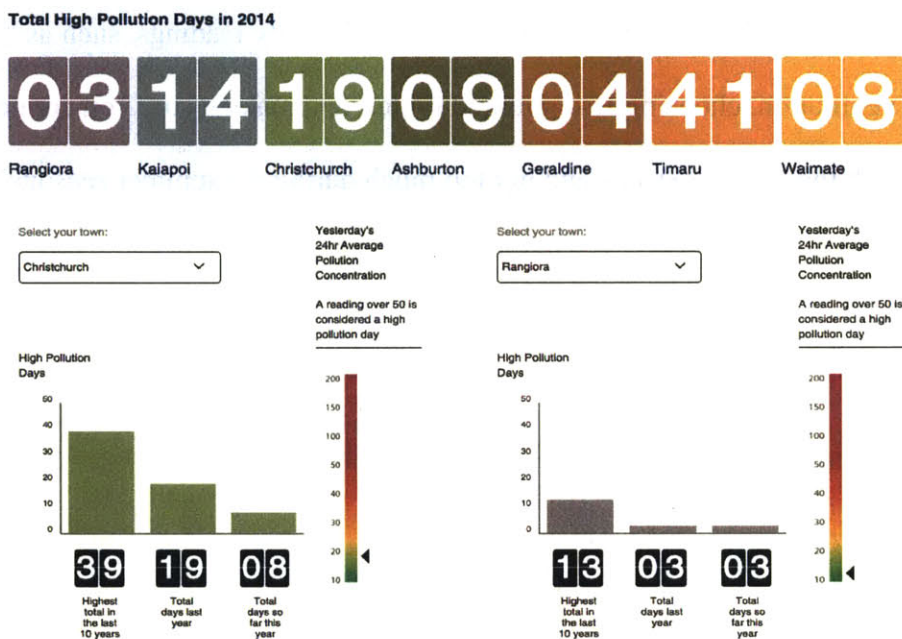


Fig. 14. ECAN, *Let's Clear the Air* website.  
 From: ECAN, “Let's Clear the Air,” [letsclreartheair.co.nz](http://letsclreartheair.co.nz), accessed November 2015. <http://letsclreartheair.co.nz>

<sup>102</sup> ECAN's Senior Air Quality Analyst, in discussion with the author, July 2015.

ECAN deliberately chooses to represent the same air quality data in two distinct ways in order to reach different audiences, one more oriented toward research, technology, and policy, and another, more general public that does not necessarily have technical training.

Sensing City's Tzoa (pronounced "ZOH-ah"), one of the sensors being tested against ECAN's sensors, is part of a wave of new wearable devices that are designed to measure air quality at the scale of the human body. The sensor itself measures temperature, humidity, atmospheric pressure, ambient light and UV rays, particulate matter (PM2.5 and PM10). Measurements are displayed on a smartphone app, which also simultaneously logs GPS information about where the user is; users can view a map of air quality based on measurements from other TZOA users. TZOA's data dashboard, accessed on a smartphone app, is deliberately designed for a nontechnical audience. Air quality is displayed as either "clean" or "dirty," and actionable recommendations are generated based on air quality readings, such as "opening your windows for ventilation, choosing less polluted routes, and making sure you are getting enough sunshine through the winter seasons and not too much during the summer seasons".<sup>103</sup>

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<sup>103</sup> TZOA Wearable Enviro-Tracker, "About," *TZOA.com*, accessed January 2016. <http://www.tzoa.com/about-tzoa>.



Fig. 15. TZO A, *Tzoa sensor and smartphone app*.  
From: Tzoa. "About," *TZO A.com*, accessed August 2015. <http://tzoa.com/about-tzoa>

The resolution of air quality data on the Tzoa map depends on how many users are active in the network of sensors, but at the time of writing, no material on the website for the app mentions this. Also absent from this dashboard is any indication of what air quality standards are employed or how the sensors themselves are calibrated. However, these may not be negative aspects of the sensor and companion platform, given that it is meant for a lay public with little knowledge of air quality standards who is more concerned with whether air quality around them is relatively good or bad, then what to do about it. Testing the Tzoa in Christchurch against the standards employed by ECAN and other government agencies will likely focus on how to make meaning from the disparate sources of data.

### *The role of media in communicating air quality in Christchurch*

Journalism also plays a role in helping educate the public about air quality concerns. *The Press*, a national newspaper in New Zealand, publishes op-eds and other articles about air quality

in Christchurch. One 2014 article includes a data visualization of dust pollution since the earthquakes breaching government air quality standards. The data comes from an air quality monitoring site in Woolston, an industrial part of Christchurch.<sup>104</sup> *The Press* also uses its reach to scaffold ECAN’s public campaigns to target homeowners with wood burners. In a 2015 article, during the southern hemisphere winter, *The Press* reported on Clean Air Plan policy regulations that would result in fines for people burning with visible chimney smoke.<sup>105</sup> The article also pointed to ECAN’s Let’s Clear the Air website, on which local residents could anonymously report on chimneys that violated this policy. (See Figs. 16 & 17)

**Woolston dust pollution since the earthquakes is breaching government air quality standards.**

Blue represents emissions from small particulates such as log burner smoke and shows one high pollution day this winter can be attributed to this. Orange represents dust related to the rebuild, bare land and roadworks.

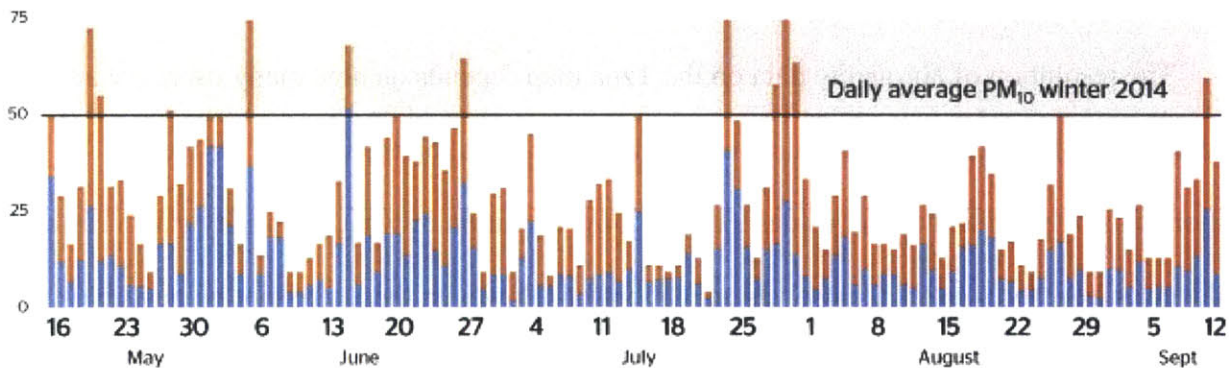


Fig. 16. Shelley Robinson, *Data visualization of dust pollution*.

From: “Construction: A cause of city pollution,” *The Press*, accessed November 2015. <http://www.stuff.co.nz/the-press/news/10696373/Construction-A-cause-of-city-pollution>

<sup>104</sup> Shelley Robinson, “Construction: A cause of city pollution,” *The Press* (April 11, 2014). <http://www.stuff.co.nz/the-press/news/10696373/Construction-A-cause-of-city-pollution>

<sup>105</sup> Chris Barclay, “Environment Canterbury to Target Homeowners with Visible Chimney Smoke,” *The Press* (June 4, 2015). <http://www.stuff.co.nz/the-press/news/69061520/environment-canterbury-to-target-homeowners-with-visible-chimney-smoke>



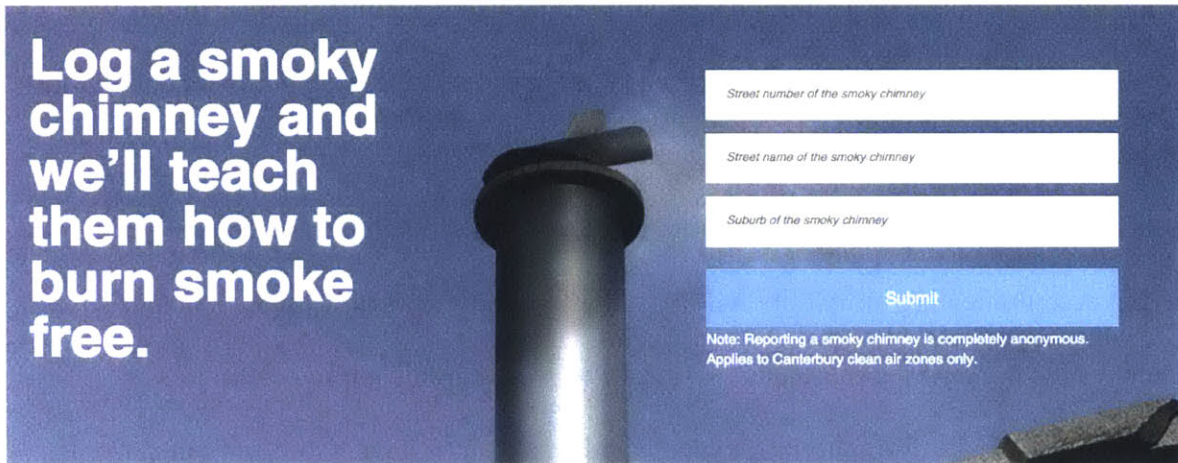


Fig. 17. ECAN, *Let's Clear the Air chimney campaign*.  
ECAN, "Let's Clear the Air," *letscleartheair.co.nz*, accessed November 2015. <http://letscleartheair.co.nz>

This returns to the notion of using the human senses - sight, in this case - to help government agencies address environmental concerns. This has been discussed elsewhere in scholarship about participatory mapping projects and Volunteered Geographic Information (VGI) but remains relevant to observation-based data collection like this case in Christchurch.<sup>106</sup>

Observation-based methodologies in which people identify chimneys that violate environmental policy employ citizens themselves as sensors. One could argue that citizen sensing initiatives can also work to keep humans in the loop of the data collection pipeline.<sup>107</sup> Together with technologically-enabled sensing, Christchurch's air quality monitoring efforts can also be seen as a mixed approach for environmental *surveillance* and *sousveillance*, in which government

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<sup>106</sup> Michael F. Goodchild, "Citizens as sensors: the world of volunteered geography," *GeoJournal* (2007): 211-221.

<sup>107</sup> David N. Crowley, Edward Curry, and John G. Breslin, "Closing the loop—From citizen sensing to citizen actuation," *2013 7th IEEE International Conference on Digital Ecosystems and Technologies (DEST)*, IEEE (2013): 108-113.

agencies and citizens outside of institutional bounds work toward a similar aim.<sup>108</sup> In this way, these efforts are illustrative of the fact that emergent modes of sensing enabled by technology do not necessarily elide or replace human observation.

One common thread through all of these air quality dashboard efforts is the assumption and hope that communicating air quality will in turn affect some kind of change. Whether any of these tactics results in behavior change is still left to be seen, but this might be due to a disconnect between what information is available and what can be done with it. In other words, the data alone would not be enough to generate change; what must follow is a program for action and a clear conceptualization of the data's role in that program toward change.

A representative from NIWA says, "There is still a gap between what the numbers are and what they mean. They generate data but not information."<sup>109</sup> But Malcolm Campbell from the Geohealth Lab at the University of Canterbury sees inherent value in collaborating with media outlets like *The Press* to communicate air quality: "If newspapers published air quality readings every day, you might feel pressure from some channel to do something about it."<sup>110</sup> In other words, Campbell believes that repeated exposure to the conventions of air quality reporting can educate the greater public about how to make meaning and take action based on the information at hand.

Incidentally, weather forecasting in the United States was initially made possible by hundreds of volunteers throughout the country reporting weather observations to the Smithsonian Institute, much like low-cost air quality sensors enable more citizen-based air quality sensing.

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<sup>108</sup> Steve Mann, Jason Nolan, and Barry Wellman, "Sousveillance: Inventing and Using Wearable Computing Devices for Data Collection in Surveillance Environments," *Surveillance & Society* 1, no. 3 (2002): 331-355.

<sup>109</sup> NIWA representative, in discussion with the author, July 2015.

<sup>110</sup> Malcolm Campbell (Director of University of Canterbury Geohealth Lab), in discussion with the author, July 2015.

The introduction of the telegraph enabled faster assemblage of weather information from volunteer weather observers, eventually leading to the ability to observe and forecast weather over the country.<sup>111</sup> Air quality reporting in Christchurch also has the potential to follow this trajectory - moving from citizen-based observations to government-supported mass communication. It may be a matter of developing the structure and organization and collaborative framework among stakeholders across sectors to do so.

### *A Christchurch perspective on smart cities*

On a more general level, both the collection and communication of air quality data in Christchurch are part of a larger ideological construct of the smart city. Projects like Christchurch's air quality sensing are based on a logic that the introduction of new ways to generate data about cities will serve as a panacea for urban problems, a logic that has been criticized as idealistic and utopian.<sup>112</sup> Examining this ideological shift in a post-disaster context in Christchurch alongside Sensing City's air quality sensing project may illuminate new ways of thinking about how individual sensing initiatives scaffold, debunk, or further nuance the larger narrative of smart cities globally.

One resident in Christchurch remarks, "If you're in a wrecked house with no water or sewage, you might not care about whether you have 'smart' water or 'smart' sewage. You care if you have a working toilet."<sup>113</sup> Though specific to the context of post-disaster Christchurch, in many ways, this remark epitomizes the frustration of smarty city critics - that sometimes,

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<sup>111</sup> National Weather Service, "History of the National Weather Service," *NWS*, accessed January 2016. <http://www.weather.gov/timeline>

<sup>112</sup> Sudipta Sengupta, "Smart City - a utopian concept?" *The Times of India* (September 17, 2014). <http://timesofindia.indiatimes.com/city/hyderabad/Smart-city-a-utopian-concept/articleshow/42656817.cms>

<sup>113</sup> Resident of Christchurch, in discussion with the author, July 2015.

technology is not necessarily the solution for certain problems. Malcolm Campbell reflects on his own perception of the smart city ideology before and after becoming involved with the air quality sensing project:

“I’ve been aware of smart cities for a long time - the idea that information somehow delivers a better life, lower cost. Where I wanted to know the answer was...is it true or is it not? What’s changed is that I now realize the amount of work to have a smart city with sensors in everything is on the verge of completely unachievable. The amount of time, effort, and resources required is difficult. It’s not obvious that every problem suits a smart city solution. The risk of using technology for technology’s sake is more obvious to me now.”<sup>114</sup>

But does that mean that one should never propose technological interventions for urban problems? Perhaps it is less dramatic than that. It may be a matter of developing a better understanding of when to intervene, with or for whom, and how.

Founder of Sensing City Roger Dennis says it took one year to get city-level stakeholders on board for the air quality sensing project, post-quake: “This is because [they] were thinking about central services like power, housing, and safety before they could think about next steps.”<sup>115</sup> There was enough support for the project and its value for it to get off the ground eventually, but it was a matter of prioritizing the minimization of other risks and hazards before this could be possible.

Another challenge comes from being involved with smart city projects from an academic perspective, especially where academics are part of larger collaborations across sectors. Campbell describes juggling sometimes-competing interests among project stakeholders as a pain point: “Commercial companies need the freedom to operate. Universities want publications, but universities cannot publish something that potentially compromise a company’s ability to

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<sup>114</sup> Malcolm Campbell (Director of University of Canterbury Geohealth Lab), in discussion with the author, July 2015.

<sup>115</sup> Roger Dennis (found of Sensing City), in discussion with the author, July 2015.

make money, which causes tension in any collaboration.”<sup>116</sup> This tension can also stall consensus about important issues such as intellectual property (i.e. who owns what data, and who gets credit for what work). Low-cost sensing technology itself may not be well suited for scaling beyond the level of research.

For a variety of factors, certain low-cost sensors are easier to manage at the level of smaller-scale research. The feasibility of asking a city to take on the management of the hardware on top of the data is still something to be sorted out in future project plans. It remains to be seen whether the smart city ideology will survive, but it is certainly evolving with case studies like Christchurch. By looking at these cases, it may be possible to glean best practices in for data collection, visualization, and management that can be incorporated into future city governance and civic engagement.

### *Conclusion*

An analysis of air quality monitoring dashboards in Christchurch reveals an uneven landscape with regard to the representation of air quality sensing data. Despite a proliferation of air quality monitoring projects, there seems to be a lack of consensus across projects about best practices for how to represent air quality sensing data. Individual dashboards privilege certain variables to focus on, an editorial decision that foregrounds some information while backgrounding other information. Projects also employ a variety of sensing technologies with varying degrees of accuracy and calibration; standards or indices for air quality; interoperability; resolutions of sensor node distribution.

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<sup>116</sup> Malcolm Campbell (Director of University of Canterbury Geohealth Lab), in discussion with the author, July 2015.

These examples are only a portion of the larger ecology of “smart city” air quality monitoring projects and an even smaller portion of all sensing projects in the global “smart city” ecology, one that is further complicated by competing value systems and stakeholder goals. Future iterations of air quality monitoring dashboards may benefit from a rootedness in critical evaluations of how air quality is communicated and for whom. Further work should also consider whether the concept of air quality includes both governmental and citizen data, and if so, how these disparate data sets might be made more interoperable. More importantly, it is necessary to reflect on whether choosing to communicate air quality in certain ways reproduces any pre-existing systems of inequity; for example, if air quality dashboards are only available online, this selects for portions of the population that have access to a Wi-Fi connection, a computer, and some basic literacy.

Beyond building effective communication pipelines, it would also behoove stakeholders to think through other ways to return agency to those most impacted by poor air quality by way of providing service, emergency response, or otherwise.

In Chapter 4, I discuss how government and citizen sensing data are used within the disciplines of urban planning and design, a site of prolific experimentation for the same kind of work in Christchurch. We will again see how air quality, land use, and media come to matter in this context.

# four

## **Air Quality Sensing in Urban Planning and Design: Precedents, Policy, and Propositions**

The city is a sensory experience.

Michel De Certeau describes how *Wandersmanner* (wanderers) can experience a city's acoustic, visual, and olfactory, and haptic stimuli in the act of walking through it.<sup>117</sup> Urbanist Allan Jacobs writes about how reading at a city's surfaces and surroundings as text can reveal clues about human presence and habitus.<sup>118</sup> For instance, deteriorating roof shingles or chipped paint on a wall in a public area may stand in for signs of how well a city or tenant is maintaining a space; even more, observations of conditions of infrastructure can lead to further inquiry as to why a place has or has not been maintained in comparison to others. In *Death and Life of Great American Cities*, Jane Jacobs describes her version of street life on the Lower East Side of Manhattan as the "Hudson Street Ballet," a performance that takes place on sidewalks, storefronts, and public plazas in the modern metropolis - available to those who are able to recognize and interpret it as such.<sup>119</sup> The city is a palimpsest of human experience, of sensorial input and output, but that also inherently makes it a subjective experience. Thus, seeking to represent any factors of the urban environment requires a process of interpretation and mediation.

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<sup>117</sup> Michel De Certeau, "Walking in a City," *The Practice of Everyday Life* (Berkeley: University of California Press, 1988), 91-130.

<sup>118</sup> Allan Jacobs, "Looking at Cities," *Places: Quarterly Journal of Environmental Design*, 1 no. 4. (1984): 28-37.

<sup>119</sup> Jane Jacobs, *Death and Life of Great American Cities* (New York: Vintage, 1961).

The assessment of air quality in a city, even when sophisticated tools and sensors are involved, requires subjective interpretation -- of measurement, scale, resolution, and other factors. Even on the individual level with one's human senses, what may constitute "bad" air quality to one person may be negligible to another's experience of the same air. This is one of the key challenges to "accurately" representing many types of environmental information within the urban context, which contribute to the challenges in crafting municipal policy based on environmental data.

In this chapter, I will discuss how one reconciles the need to capture personal, anecdotal experiences of air quality from individual citizens with an accompanying need to represent air quality in the aggregate in order to shape and drive larger-scale policy decisions. Through a series of case studies, I discuss the problems that urban planners and designers must encounter when engaging non-expert audiences with the collection, interpretation, and representation of air quality data through three distinct use cases.

The disciplines of urban planning and design are sites of marked experimentation for representing environmental data, producing projects that seek to communicate data in relation to land use through the use of emergent technologies such as environmental sensors. Planners and designers, who deal primarily with maps as a medium for communication of environmental information, seek to represent air quality in different ways, at different scales, and for different audiences. Because the practice of communication of information through maps nevertheless carries with it a risk for bias, as discussed in Chapter 2, maps of air quality, by extension, must be treated as *propositions* and not positivist representations of air quality. Planners and designers, in constructing representations of air quality, must consider questions of audience: for whom will this information be, and whom will it best serve? So, looking at the communication of



environmental data within urban planning and design as a problem of representation may offer alternative ways, namely through the lens of media studies, to understand the specific challenges that planners and designers must encounter in this context.

### *Crowdsourcing data for city planning and design*

Before moving forward, let me first stipulate what I mean when I refer to urban planning and design. These are distinct traditions of urbanism whose disciplinary boundaries have been debated in a rich body of literature.<sup>120</sup> Most succinctly put, however, the two disciplines can be differentiated by how they deal with spatial scales, orientation, and space.<sup>121</sup> Urban planning is primarily a “two-dimensional activity, with most plans visually represented in plan view” (read: aerial view, from above), often focusing on maps as a primary medium for communicating land use data.<sup>122</sup> Urban design as a discipline is both “aesthetic and functional, putting it somewhere between art, whose object is beauty, and planning, whose object is utility.”<sup>123</sup> The latter also mostly deals with three-dimensional space and representations, using models and three-dimensional drawings or digital renderings as a primary medium for communicating land use.

Within both disciplines, the incorporation of public engagement during the planning and design process, is instrumental to praxis. The tradition of collaborative planning between municipality, citizens, and other stakeholders aims toward a “negotiated consensus” of how

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<sup>120</sup> Matthew Carmona, and Tse-Hui Teh, *Explorations in Urban Design: An Urban Design Research Primer* (Farnham, UK: Ashgate Publishing Ltd, 2014).

<sup>121</sup> Richard Ewing, “Research You Can Use: Urban Design vs. Urban Planning: A Distinction With a Difference,” *American Planning Association*, Online pamphlet, n.d. <http://www.arch.utah.edu/cgi-bin/wordpress-metroresearch/wp-content/uploads/2012/publications/researchyoucanuse/ResearchJuly11.pdf>

<sup>122</sup> Ibid.

<sup>123</sup> Ibid.

urban space can take shape.<sup>124</sup> Ralf Brand and Frank Gaffikin also argue that a planner's role is to create a forum where "non-hostile discourse among equals" can take place, a two-way knowledge exchange. Public participation in urban design, which became a requirement in federally-funded urban design programs in the 1960s, through the process of public review, comment, visioning exercises, and so on, play a similar role in soliciting feedback from citizen stakeholders to inform the design of urban space.<sup>125</sup>

Despite the requirement of public participation in both urban planning and design, however, citizens do not always elect to participate in these processes, highlighting one of the main challenges that practitioners face in both disciplines. The emergence of digital tools and widespread availability of the Internet has spurred much optimism among planners and designers to "make citizens become more informed and engaged while pushing the temporal, spatial, and social boundaries of participation."<sup>126</sup> Daren C. Brabham writes that the Internet "enables us to harness collective intellect among a population in ways face-to-face planning meetings cannot," suggesting that crowdsourcing public participation through digital means does not differ too much from traditional forms of collaboratively collecting data for land-use mapping.<sup>127</sup> For

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<sup>124</sup> Ralf Brand and Frank Gaffikin, "Collaborative Planning in an Uncollaborative World," *Planning Theory*, Vol. 6, (2007): 282–313.

<sup>125</sup> Jeffrey Hou, "Citizen design: Participation and beyond," *Companion to Urban Design* (New York: Routledge, 2011): 329-40.

Peter Calthorpe, *Urbanism in the age of climate change*, (Washington, D.C.: Island Press, 2010): 50-61.

<sup>126</sup> Ibid.

Robert Laurini, *Information systems for urban planning: a hypermedia cooperative approach*. (Boca Raton: CRC Press, 2002).

Jan-Philipp Exner, Peter Zeile, and Bernd Streich, *Urban monitoring laboratory: New benefits and potential for urban planning through the use of urban sensing, geo-and mobile-web*, Conference paper (Essen, Germany: Lulu.com, 2011).

<sup>127</sup> Daren C. Brabham, "Crowdsourcing the public participation process for planning projects," *Planning Theory* 8, no. 3 (2009): 242-262.

example, some city planners have used Twitter as a tool to solicit feedback from citizens.<sup>128</sup>

Ethan Seltzer and Dillon Mahmoudi write about opportunities for research and practice for treating citizens as “sensors” to collect information toward urban planning and design.<sup>129</sup> This can also include citizens using sensor tools in their mobile phones or other devices to contribute to data collection.<sup>130</sup> These notions are related to the broader concept of crowdsourcing, a term most recently coined by Jeff Howe to describe distributed modes of production that were enabled by digital tools.<sup>131</sup> According to Howe’s definition of crowdsourcing, multiple parties could collectively contribute to completing smaller parts of a larger task.

In recent years, the availability of digital tools and platforms have enabled more experimentation within urban planning and design to solicit and incorporate public feedback on planning processes and policy within the digital space. Projects like SeeClickFix,<sup>132</sup> a platform that allows participants to submit geotagged photographs of non-emergency, infrastructural

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<sup>128</sup> Jennifer Evans-Cowley, “Micro-participation: The Role of Twitter in Promoting Engagement in Planning,” *Social Science Research Network* (2011).

[http://papers.ssrn.com/sol3/papers.cfm?abstract\\_id=1760522](http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1760522)

<sup>129</sup> Ethan Seltzer and Dillon Mahmoudi, "Citizen participation, open innovation, and crowdsourcing: Challenges and opportunities for planning," *Journal of Planning Literature* 28 (2012): 3-18.

Maged N. Boulos, Kamel, Bernd Resch, David N. Crowley, John G. Breslin, Gunho Sohn, Russ Burtner, William A. Pike, Eduardo Jezierski, and Kuo-Yu Slayer Chuang, "Crowdsourcing, citizen sensing and sensor web technologies for public and environmental health surveillance and crisis management: trends, OGC standards and application examples," *International journal of health geographics* 10, No. 1 (2011): 1.

<sup>130</sup> Jeffrey Goldman, “Participatory Sensing: A citizen-powered approach to illuminating the patterns that shape our world,” *Foresight & Governance Project*, White Paper (2009): 1-15.

Michael F. Goodchild, "Citizens as sensors: the world of volunteered geography," *GeoJournal* (2007): 211-221.

<sup>131</sup> Jeff Howe, “Crowdsourcing: A Definition,” *Crowdsourcing: Tracking the Rise of the Amateur*, accessed March 2016.

[http://crowdsourcing.typepad.com/cs/2006/06/crowdsourcing\\_a.html](http://crowdsourcing.typepad.com/cs/2006/06/crowdsourcing_a.html)

<sup>132</sup> SeeClickFix, “SeeClickFix Stories,” *SeeClickFix.com*, accessed January 2016.

<https://gov.seeclickfix.com/solutions>.

issues like potholes or broken pipes to a government-managed database, adopt methodologies for data collection and reporting that are influenced by other projects within the wider practice of citizen science, participatory sensing, citizen sensing, crowdsourcing, et al., all of which involve the distribution of data collection process among many actors instead of a select few. These practices challenge the idea of “expert” knowledge and allow citizens to participate in generating community-based information, effectively being the “eyes on the street” in the city. Jason Corburn argues that this form of “street science” does not seek to devalue institutional knowledge but instead *revalues* forms of knowledge production from the bottom-up.<sup>133</sup>

Still some within the academic community are anxious about digital, crowdsourced methods of public participation may not ensure diversity and may fall subject to a “digital divide” that only includes people who have access to smartphones, computers, or the Internet while excluding those who do not have similar means.<sup>134</sup> Eran Ben-Joseph asks, “What will be the role of professionals and decision makers in the face of growing self-organizing public user interfaces? How can accuracy, truth, and legitimacy of data and information be guaranteed?”<sup>135</sup> Sherry Arnstein also notes that there are varying degrees of “citizen participation” itself, spanning processes that seem more exploitative of labor than productive of public good or citizenship.<sup>136</sup>

While the rhetoric of inclusion and participation more often resonate positively within the context of governance, these same meanings are complicated within the context of labor and

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<sup>133</sup> Jason Corburn, *Street science: Community knowledge and environmental health justice* (Cambridge: MIT Press, 2005).

<sup>134</sup> Eran Ben-Joseph, “City design in the age of digital ubiquity,” *Companion to Urban Design*, (New York: Routledge, 2011):40.

John Palfrey and Urs Gasser, “Activist,” *The Digital Divide: Arguments for and Against Facebook, Google, Texting, and the Age of Social Network*, ed. Mark Bauerlein, (New York: Penguin, 2011).

<sup>135</sup> Ibid, p.

<sup>136</sup> Sherry Arnstein, "A Ladder of Citizen Participation," *JAIP* 35, No. 4. (1969): 216-224.

production. At the time of writing, the academic community has arrived at these and similar questions after having experimented with various methods of crowdsourcing data, both quantitative and qualitative, toward urban planning and design. The collection, analysis, and communication of air quality data is instrumental to urban planning and design, given its connection to land use.<sup>137</sup> That is to say, an area that is zoned for industrial development is more likely to have air pollution than an area zoned for residential development.

Not only is it important for planners and designers to understand air quality (and what constitutes air quality measurements), but it is also crucial for the planning and design process to educate participating publics about these same tenets of air quality. For planners and designers currently experimenting within this space, one hypothesis being tested is this: engaging publics in the collection of air quality data will add to public understanding of air quality and will more likely lead to more informed decision making in participatory planning and design processes.

### **Beijing Air Tracks**

In 2008, the city of Beijing, China, hosted the summer Olympics. In the months leading up to the events, news outlets from all over the world expressed concern about whether air quality in Beijing would be suitable for the games.<sup>138</sup> Reacting to public concern over air quality, the Chinese government enacted policies to shut down over 200 factories in and around the city, banned construction during the Olympics, and required that over three million cars be removed from the roads.<sup>139</sup> The Chinese government also released something called an “air quality index”

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<sup>137</sup> The World Bank, “Urban Planning and Air Quality,” *South Asian Urban Air Quality Management Briefing Note* No. 6. (Washington, D.C.: World Bank, 2002).

Brian Stone, “Air Quality by Design: Harnessing the Clean Air Act to Manage Metropolitan Growth,” *Journal of Planning Education Research* 23. (2003): 177-190.

<sup>138</sup> Sarah Williams, “Beijing Air Tracks: Tracking Data for Good,” Unpublished.

<sup>139</sup> Ibid.

as a means of measuring and communicating air quality in Beijing, but little information was provided about how the numbers were actually developed. Hence, the index could only be interpreted by Chinese government authorities themselves.<sup>140</sup> MODIS satellite data was also technically available to understand general measurements of air quality, specifically particulate matter, but at the regional scale, the data lacked higher resolution and did not reveal the experience of air quality on the ground.

Sarah Williams, an Assistant Professor for MIT's Department of Urban Studies and Planning, saw an opportunity to carry out a research experiment that involved crowdsourcing air quality data on the ground in Beijing during the summer Olympics. At the time, she was working at Columbia University's Spatial Information Design Lab and had been interested in testing some air quality sensors. News about air quality in Beijing in the context of the Olympics gave her and her lab the idea to test the sensors in China.

The Beijing Air Tracks project, led by Williams, sought to either validate or discredit the assumption that the efforts the Chinese government had taken to improve air quality actually made an impact on local air quality. Working with the Associated Press, Williams designed a project that used mobile sensors to measure air quality in the city before and after regulation of factories, cars, and construction were enacted. Williams had approached the *Associated Press* about nine months before the Olympics took place, and the editorial team seemed to like the idea. However, they did not commit financially to funding the project until about three months before the Olympics. The Associated Press had expressed anxieties about working with data that still needed to be collected. Typically, newsrooms work with data that already exist or have been scientifically backed in some way. This was new territory, which meant new risks. Despite the "hot and cold" reaction from the *Associated Press*, the Spatial Information Design Lab moved

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<sup>140</sup> Ibid.

forward with the project as a research project nevertheless. Eventually, the *Associated Press* came around and decided to support the project, with a large factor being that the data about street-level air quality in Beijing simply was not available anywhere else. Reflecting back on the timeline of the project, Williams admits that if the team had not moved forward with developing the tool despite a lack of commitment of funding from the Associated Press, they would not have been able to deliver results with the same turnaround time.

Their team used the MICRODUST sensor, which use optical technology to measure particulate matter in the air, and a carbon monoxide chemical sensor. Both sensors were “connected to GPS receivers and the sensor data was given a geographic location based on the time records associated with the GPS and sensor data points.”<sup>141</sup> Journalists who were already assigned to covering the Olympics for the *Associated Press* were given the sensors and shown how to use them in the field. The goal was to measure air quality in well-known places around Beijing, which included Olympic Park, Tiananmen Square, and the Temple of Heaven, and to be able to record the data in real time. Similar projects elsewhere place emphasis on the advantage of recording air quality in real time as opposed to sending samples to a lab to be analyzed at a later date.<sup>142</sup> Still, this particular method did not come without its challenges.

Williams’ team spent a considerable amount of time calibrating the sensors to make sure that data from one sensor could be compared to another one from the same batch. “It would have been nice to have a local university partner to calibrate our devices,” Williams says.” However, she also notes how difficult it was to identify a local researcher in Beijing who was focused on

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<sup>141</sup> Ibid.

<sup>142</sup> Srinivas Devarakonda, Parveen Sevusu, Hongzhang Liu, Ruilin Liu, Liviu Iftode, and Badri Nath, "Real-time air quality monitoring through mobile sensing in metropolitan areas," In *Proceedings of the 2nd ACM SIGKDD International Workshop on Urban Computing* (Chicago: ACM, 2013): 15.

studying air quality. In the end, the team chose to work with the resources and people they had to calibrate the sensors and collect the data. Many of the *Associated Press* journalists who helped collect air quality data were also photographers. In some cases, while they were using the sensor devices, the photographers were also asked to stop taking pictures in certain areas or to refrain from using the devices. Eventually, Williams decided that the core team from the Spatial Information Design Lab and one photographer from the Associated Press would be the only ones collecting data to protect the safety of the journalists and reduce the risk of losing any data or photographs.

What makes the Beijing Air Tracks project novel is less the results of the experiment and more the methodology and epistemological stance that Williams and her team took in collecting the data and communicating it to a mass audience. First, the team recognized a gap in public knowledge about air quality in Beijing and realized there was both a need and opportunity to generate data that did not previously exist. The data collected for this project challenged a government-issued air quality index in China, holding and institutional source of information up to question. Given that the project gestured toward an overall lack of publicly accessible data rather than the accuracy of government data, Williams' team hedged, "we believed that exposing the conditions with a full disclosure of possible errors was better than not exposing the air quality conditions at all."<sup>143</sup>

Second, the project aspired to represent a different scale of air quality data, focusing on a more localized version of air quality rather than a regional one. In many ways, this debunked the notion that air quality could be generalized across regions and inherently argued that air quality varies across smaller areas. One could also argue that an approach of mapping local air quality also made the idea of air quality more relatable at the individual level. For example,

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<sup>143</sup> Ibid.



understanding what air quality looked like at a recognizable landmark or public space may be easier for some to relate to than an air quality measurement across an entire city.

Third, and most importantly, the team strategically constructed a story around the data, requiring consideration of who the key audience was, which variables to measure, and how to best present the data through news media. When deciding which variables to focus on, out of the long list of environmental pollutants that they could have measured, the team chose to “measure pollutants that would tell [them] the most about the environmental conditions that would impact the athletes,” ultimately focusing on fine particulate matter (PM2.5) and carbon monoxide (CO).<sup>144</sup>

The *Associated Press*’ visualization included a graph of measurements taken at street level in Beijing over time, contextualized by photographs taken in the same spaces the air quality was measured. The visualizations “revealed that the air quality in Beijing was often at a level 10-20 times higher than what was seen in New York City, and often did not meet the World Health Organization standards.”<sup>145</sup> A separate *New York Times* visualization presented a perspective of the Olympic marathon route before and after 3.3 million cars were removed from the roadway in Beijing. In addition to collecting data points, *Associated Press* journalists also took photographs of iconic places in Beijing to capture atmospheric conditions that were visible to the human eye. The data collected from the project was visualized in an interactive graphic, which focused on carbon monoxide because they were more closely associated with vehicle exhaust. These were compared against air quality measurements along the New York City Marathon route.

All of these were rhetorical choices that participating journalists made in order to present the data to a nontechnical public. Limiting the number and type of pollutants to measure,

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<sup>144</sup> Sarah Williams, “Beijing Air Tracks: Tracking Data for Good.” *Unpublished*.

<sup>145</sup> *Ibid*.

concentrating the story on the marathon route, the inclusion of photographs and text next to the data, and casting pollution as harmful to Olympic athletes were all choices that helped frame the story of poor air quality in Beijing. Because the project itself was so focused on the collection of data, the resulting public-facing stories could have easily been about the data itself, but the choice to refine the connection between air quality data and the people it would affect contributed to making the story more accessible.

Working directly with a media outlet was, in this case, an atypical approach for Williams' lab at the time. However, she says that the choice was a strategic one in order to achieve the desired impact. While it meant giving up some control over the final result of the visualizations to the *Associated Press* and *New York Times*, the project reached a broader audience than it might have if it remained solely an academic project. After the story broke, Williams and her dean at Columbia University received several calls and e-mails from the Beijing city government in reaction to the stories. The reactions were mixed – some positive and some negative. On the one hand, the city government seemed, according to Williams, pleased to see that taking cars off that road had made a difference in pollution levels.<sup>146</sup> On the other hand, some reactions were negative, given that using non-governmental air quality sensors on the street in Beijing was technically illegal. For this reason, Williams and her dean both decided that it was best not to engage with the government.

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<sup>146</sup> Sarah Williams, in discussion with the author, February 2016.

OLYMPICS  
BEIJING 08



**"I just ran the first 50 meters, then I looked around to make sure I was safe and I shut it off!"**  
USAIN BOLT of Jamaica, who coasted through early-round qualifying in the 100 meters

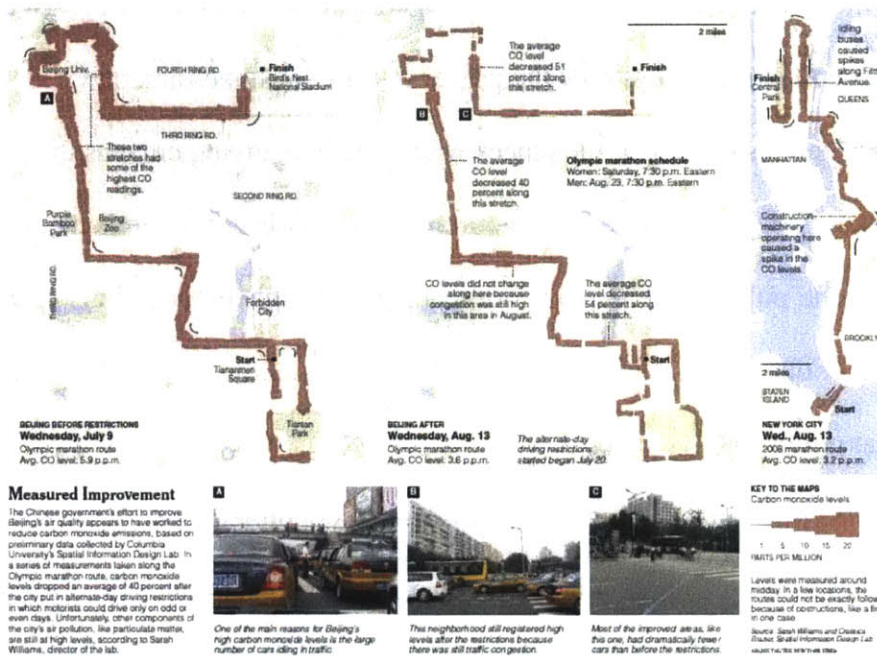


Fig. 18. Spatial Information Design Lab, *Map of the data Williams' and her team collected, as shown in the New York Times.*  
From: Spatial Information Design Lab, "Beijing Air Tracks," *Spatial Information Design Lab*, accessed March 2016.  
<http://www.spatialinformationdesignlab.org/projects/beijing-air-tracks>

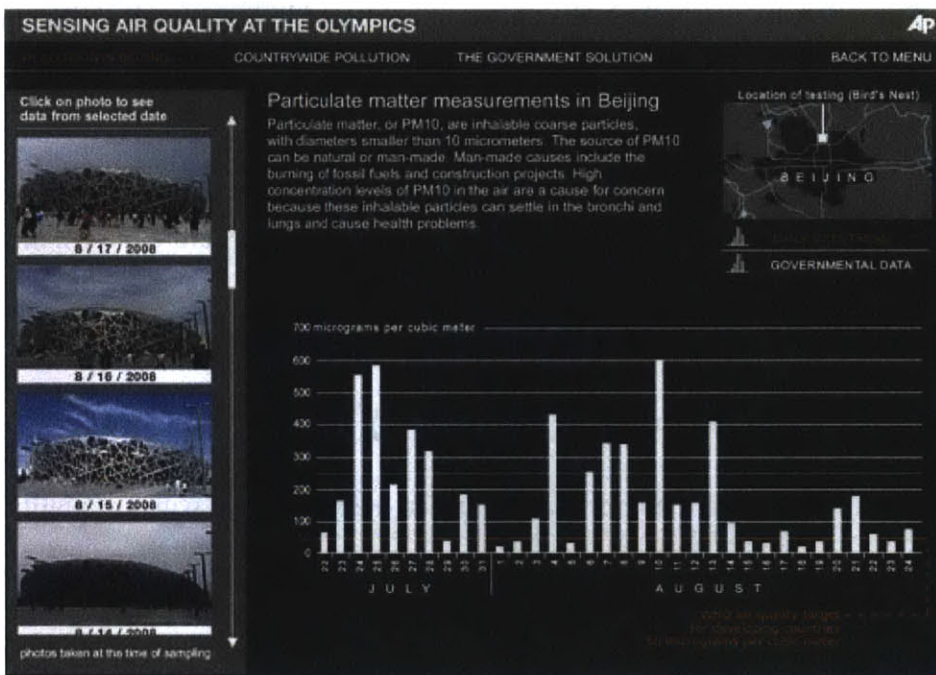


Fig. 19. Spatial Information Design Lab, *Map of the data Williams' and her team collected, as shown in the Associated Press.*  
From: Spatial Information Design Lab, "Beijing Air Tracks," *Spatial Information Design Lab*, accessed March 2016.  
<http://www.spatialinformationdesignlab.org/projects/beijing-air-tracks>

Ultimately, Williams hopes that a crowdsourced approach to air quality measurement in at-risk cities like Beijing can help to stimulate a conversation about policy: “We hope that our model for data collection shows how the power of mobile phones and new sensor technology can be harnessed to tell a story about the places where we live, giving citizens the possibility to change the places where they live.”<sup>147</sup> Importantly, in political environments where environmental and public health data is not readily accessible to the public, using crowdsourced sensing to gather data, even if it is not completely accurate, can help facilitate discourse about environmental policy.

While Beijing Air Tracks was a proof-of-concept project that set out to demonstrate how this type of work could be done, it holds broader implications for how methodologies like this could be adapted to city planning, which often involves engaging stakeholders at various levels of authority. In many ways, the project served as an exercise in designing the communication of complex information for nontechnical audiences, mediated by news outlets like the *Associated Press*. Granted, there are also risks with miscommunication or distortion when working with news outlets as well, especially when the same data is syndicated across multiple major news publications. However, in cases like this one, some possibly inaccurate information served a more useful, productive purpose than no information at all.

### **Visualizing Air Quality for Urban Design**

In lieu of merely mapping air quality, urban designers deal with air quality on a different scale, often concerning changes in building layout, distribution of green space, density of

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<sup>147</sup> Ibid.

buildings, use of major roadways, and so on, to address the dispersion of pollutants.<sup>148</sup> This is based on the belief that it is not only the designation of land use that affects air quality but also how land use is interpreted and expressed in urban morphology. An area may be zoned as residential, but how tall or dense are the residential buildings? Is the building located near an arterial road or far away from one? Is the building adjacent to an industrial zone or open space? How might good or poor air quality, in turn, impact civic life in these areas? These questions, which can only be interpreted at a smaller spatial scale, are the ones that urban designers must ask when addressing air quality.

Anne Whiston Spirn, a Professor of Landscape Architecture and Planning at MIT, authored a report for the Boston Redevelopment Authority, which is an interdisciplinary study on air quality in Boston.<sup>149</sup> The report provided a comprehensive scientific literature review of urban climate, which included air quality studies, for an audience of “urban designers, urban planners, and architects, for whom a chart of readings of particular data points of air quality would not be as useful.”<sup>150</sup> At the time, most urban designers would seek out urban climate literature to learn about air quality, but most urban climate studies dated back the 1950s and 1960s and had not been updated for this particular audience. “A practitioner just does not have the time to wade through the scientific literature...to extract some small part of [it] that might relate to urban design. It’s a problem of translation, and that’s what I undertook,” says Spirn.

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<sup>148</sup> Y. Zhang and Z. Gu, “Air quality by urban design,” *Nature Geoscience*, ed. Jeffrey Raven, (Bonn, Germany: Resilient Cities Congress, 2013): 506.

<sup>149</sup> Anne Whiston Spirn, “Air Quality at Street-Level: Strategies for Urban Design,” Report prepared for the Boston Redevelopment Authority (1986): 1-5, 47-59.

<sup>150</sup> Anne Whiston Spirn (professor of landscape architecture and planning), in discussion with the author, October 2015.

Spirn's education included design courses that also incorporated scientific training in hydrology, climatology, and geology. Hence, Spirn was no stranger to communicating knowledge across disciplinary boundaries. With a nontechnical audience of designers in mind, Spirn elected to convey her findings of how urban form affects urban air quality in text and hand-drawn images. These drawings were based on both her literature review of air quality science at the time as well as empirical studies that she conducted with a team of researchers and students.

The empirical studies that Spirn carried out were part of the Dayton Project, meant to be a study of how to ameliorate winds and air circulation at street level in downtown Dayton, Ohio, despite the presence of tall buildings. In order to better understand how air moved throughout the city, Spirn and her team built a model of Dayton and formed a collaborative partnership with the MIT Wind Tunnel. At the time, the Wind Tunnel was directed by Frank Durgen, who helped place sensors on the model in a grid pattern to detect how air flowed through it. In addition, a student suggested dropping plastic pellets into the tunnel to better visualize where air was flowing, and so that photographs could show where the pellets were being blown, and more importantly, where they were piling up (signaling potential places where pollution could also build up in real life spaces). Because air itself is something that cannot usually be seen with the human eye, it eludes representation in likewise visual mediums like photographs, and simply describing air quality in text or numbers does not carry the same visual impact. For this project, it was a matter of "making the invisible visible. If people could see the spike in measurements [of air pollution], they would get it. They would never forget it."<sup>151</sup>

Spirn's deliberate choice to use images to communicate her research is a rhetorical one. "Most designers are not quantitatively oriented," Spirn says. "Designers tend to be visual and

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<sup>151</sup> Ibid.

spatial thinkers.” Creating hand drawings allowed Spirn to represent urban air quality in the visual language of designers; at the same time, it also allowed her to represent urban air quality at street level, a scale that was not necessarily available in the scientific literature nor empirical studies, which often focused on a more distanced, macro scale.

More importantly, the hand drawings communicate this information in a way that another medium, for example photographs or video, would not have been able to accomplish in the same way, given that airflow is not visible to the human eye. Spirn uses a few consistent drawing techniques to show how pollution affects the built environment. Using dots, such as in Figures 20, 21, and 22, Spirn shows how tree leaves, branches, buildings, cars, and crowds of people can trap air pollutants. This would have been more challenging to show with another medium, such as photography, as the technology does not afford the ability to detect pollutants through the use of a lens. With arrows, Spirn shows how prevailing wind patterns move through urban space, and how built form can contribute to the collection of pollutants near the bases of tall buildings or in areas with vehicle congestion. This technique can be seen in Fig. 21.

Additionally, Spirn chooses different perspectives from which to show, comparatively, the direction and movement of air through urban form. For example, Fig. 21 features various “section” diagrams, which show an orthographic view of buildings from the side, whereas in Fig. 23, she elects to depict an aerial view of the city in order to show how pollution from vehicle exhaust can collect above traffic. Each view accomplishes something slightly different and offers a different relationship between air pollution and space.

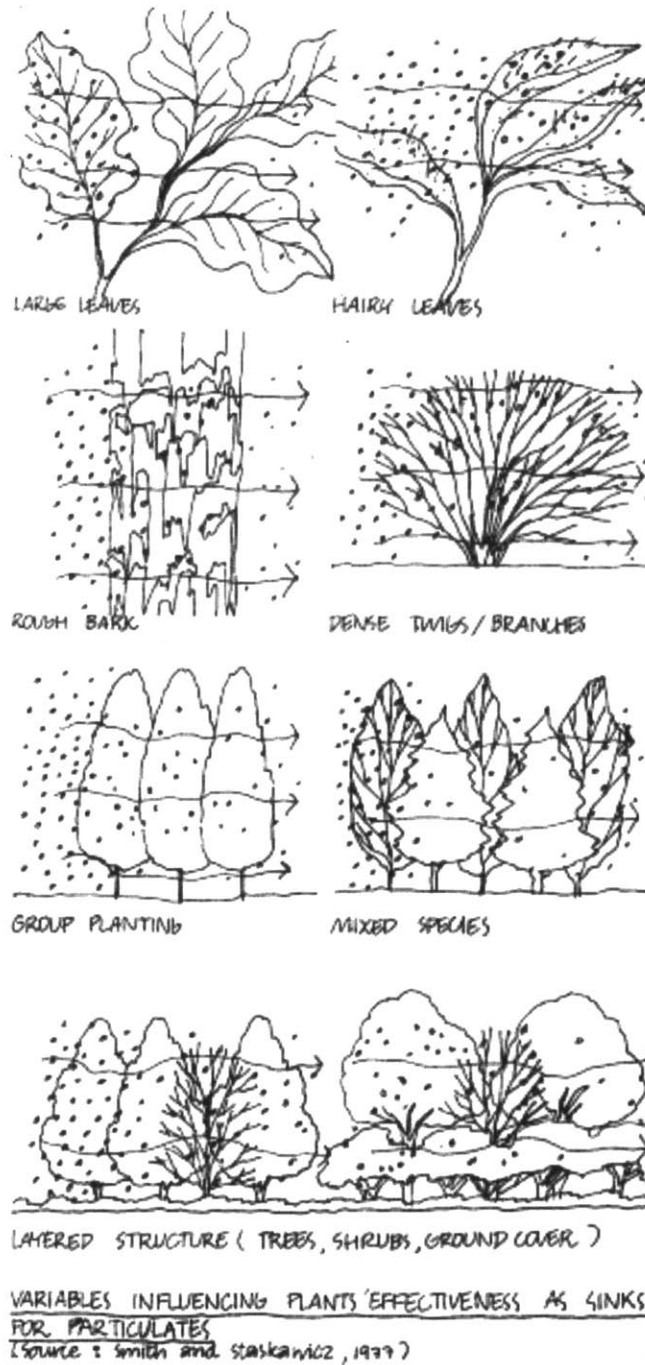


Fig. 20. Anne Whiston Spirn, *Hand drawing of air quality for urban design*.  
 From: "Air Quality at Street-Level: Strategies for Urban Design." *Report prepared for the Boston Redevelopment Authority*. (1986):  
 1-5, 47-59.



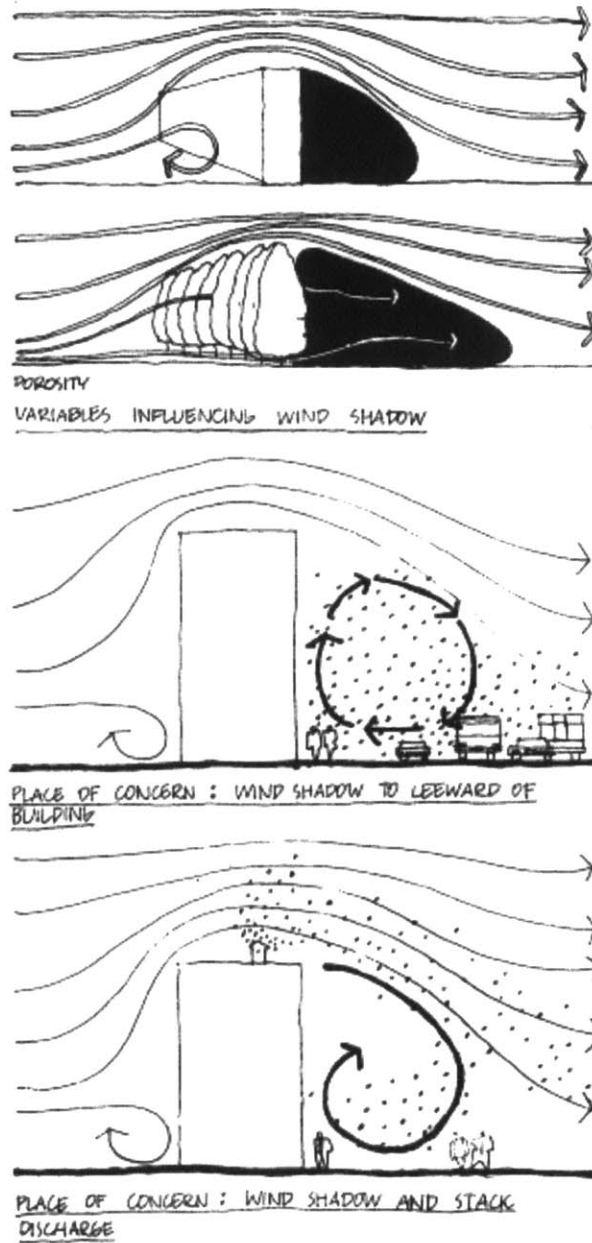
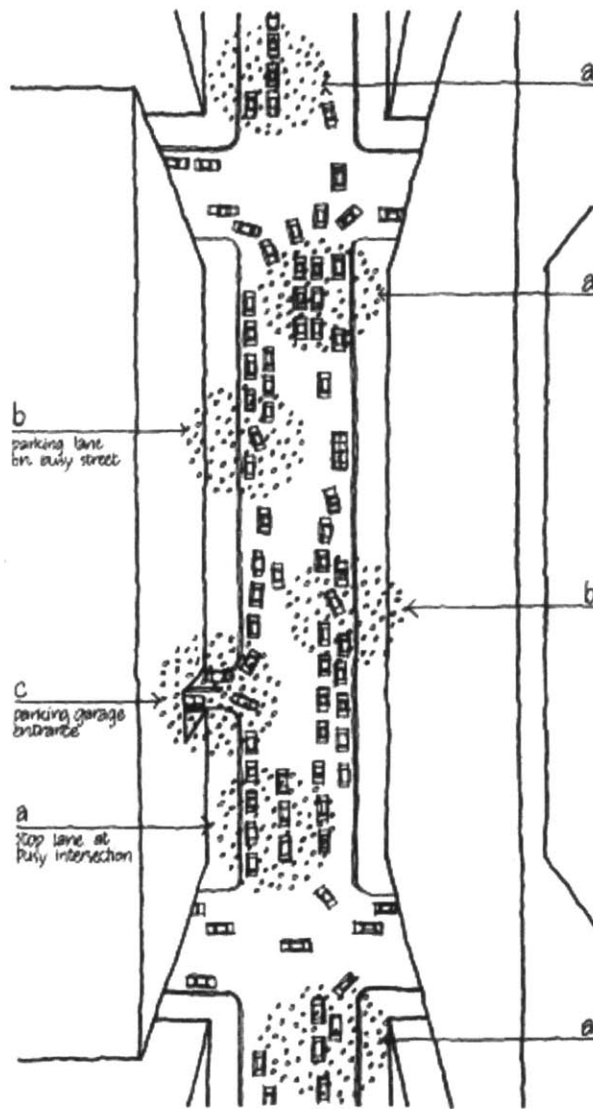


Fig. 21. Anne Whiston Spirn, *Hand drawing of air quality for urban design.*  
 From: "Air Quality at Street-Level: Strategies for Urban Design." *Report prepared for the Boston Redevelopment Authority.* (1986):  
 1-5, 47-59.



PLACES OF CONCERN : HIGH EMISSIONS

Fig. 22. Anne Whiston Spirn, *Hand drawing of air quality for urban design*.  
 From: "Air Quality at Street-Level: Strategies for Urban Design." *Report prepared for the Boston Redevelopment Authority*. (1986):  
 1-5, 47-59.

Despite the potential impact that images, text, and even physical models can have on an audience, representation itself can be limiting.<sup>152</sup> That said, Spirn maintains that nothing compares to taking people out into the field to look at air quality conditions *in situ*:

“I think nothing beats going out in the field with people...I would take people to spots that are low or negligible air pollution, then take them to a point of concentration so they could get a sense that levels of air pollution are a combination of the source of emission and air circulation, and the air circulation is very much a function of the urban form.”<sup>153</sup>

Spirn speculates that with the availability of new and extant technologies, citizens can be engaged to help collect information in the form of checklists of pollution hazards, or even by using devices to measure air quality, toward urban design. In her report to the Boston Redevelopment Authority, Spirn recommends, “Ideally, a city should employ a system that combines stationary and portable monitors [for air quality], exploiting the accuracy of the first and the flexibility of the latter.”<sup>154</sup> Far before urban planners like Williams (above) began to experiment with mobile air quality sensors, Spirn had already proposed a similar methodology for measuring air quality in cities, recognizing the value in collecting data that was representative of air quality at a more local scale than government sensors.

On one hand, being able to collect air quality data with sensors, such as in the case of the Dayton Project, aids in the production of knowledge for urban designers, planners, and architects that does not always cross over disciplinary boundaries from scientific and technical literature and research. On the other hand, as in the case with Spirn’s students and other potential publics,

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<sup>152</sup> Colin Ware, “What We Can Easily See,” *Visual Thinking for Design* (Burlington: Morgan Kaufmann Publishers, 2008).

E. Segel and J. Heer, “Narrative visualization: Telling stories with data,” *IEEE Transactions on Visualization and Computer Graphics* 16.6 (2010): 1139-1148.

<sup>153</sup> Anne Whiston Spirn (professor of landscape architecture and planning), in discussion with the author, October 2015.

<sup>154</sup> Anne Whiston Spirn, “Air Quality at Street-Level: Strategies for Urban Design.” *Report prepared for the Boston Redevelopment Authority*. (1986): 47.

the act of collecting air quality data can foster a nontechnical audience's understanding of air quality risks and how urban form can influence them. In both cases, it is not the data alone that tells a story but rather how the information is visualized and communicated for a specific audience that makes the work successful.

### **Data Canvas: Sense Your City**

In one final use case, I want to note how artists and designers, from without the disciplines of urban planning and design seek to challenge ways in which urbanists view the collection and communication of urban environmental data captured by sensors. In early 2015, I participated in an initiative called Data Canvas: Sense Your City, a project co-funded by swissnex and an art nonprofit called Gray Area in San Francisco. Inspired by the open data movement, Emina Reissinger, the project manager, says that her team was interested in creating a comparative project in which open data collected from different places could be visualized to engage people with data.<sup>155</sup>

In total, swissnex and Gray Matter provided 100 environmental kits to volunteers in 7 different cities around the world to build, host, and deploy the sensors while they passively collected data that was visualized on a map-based platform. The sensors measured particulate matter, CO2 levels, humidity, temperature, and UV levels, among other facts. Visitors to the map-based platform could also aggregate and disaggregate the data in different ways. One could view the data by city, by sensor, by region, and so on, instilling a sense of play or exploration to the site. "It's more about the learning experience," says Reissinger.<sup>156</sup> The project team and

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<sup>155</sup> Emina Reissinger, in discussion with the author, July 2015.

<sup>156</sup> Ibid.

materials disclaimed from the start that the goal of the project was not data accuracy but rather engagement with environmental information.

As a participant in Data Canvas, I was surprised by how collaborative the community of sensor hosts turned out to be. Often, hosts would troubleshoot in a Facebook group in order to help others with sensor assembly or Arduino code. As the sensors were being assembled in various locations around the globe, hosts also began to post pictures of their own sensors, which tended to be decorated and personalized in ways that reflected each host's personality or a group identity. It was also my experience that concern over privacy was not an issue, as all of the sensor hosts needed to opt into the project, which included agreeing to host the sensor near one's house. The data was also anonymized, and the only way to link a person to a sensor would be if a host decided to share their designated user ID.



Fig. 23. Open source Data Canvas sensor kit (2015).

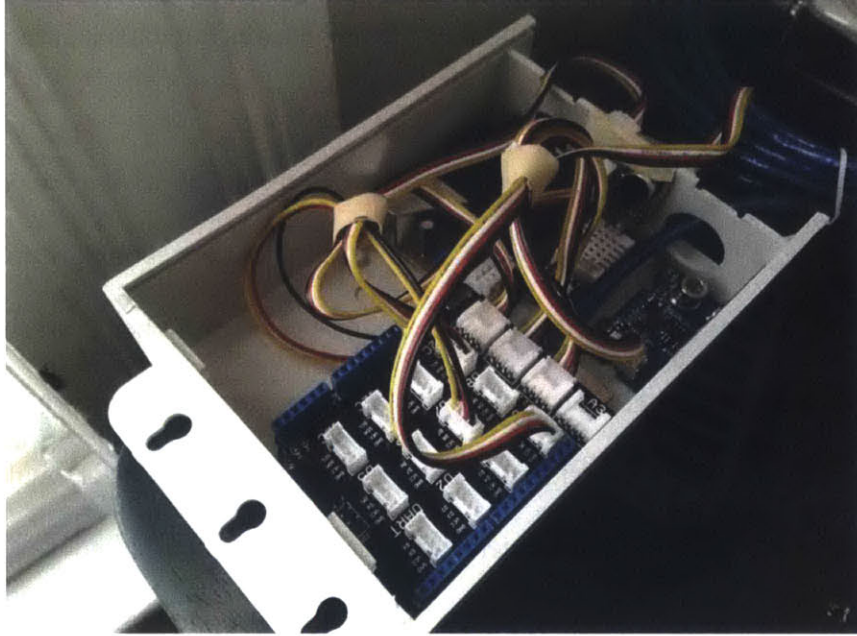


Fig. 24. *Open source Data Canvas sensor assembled (2015).*

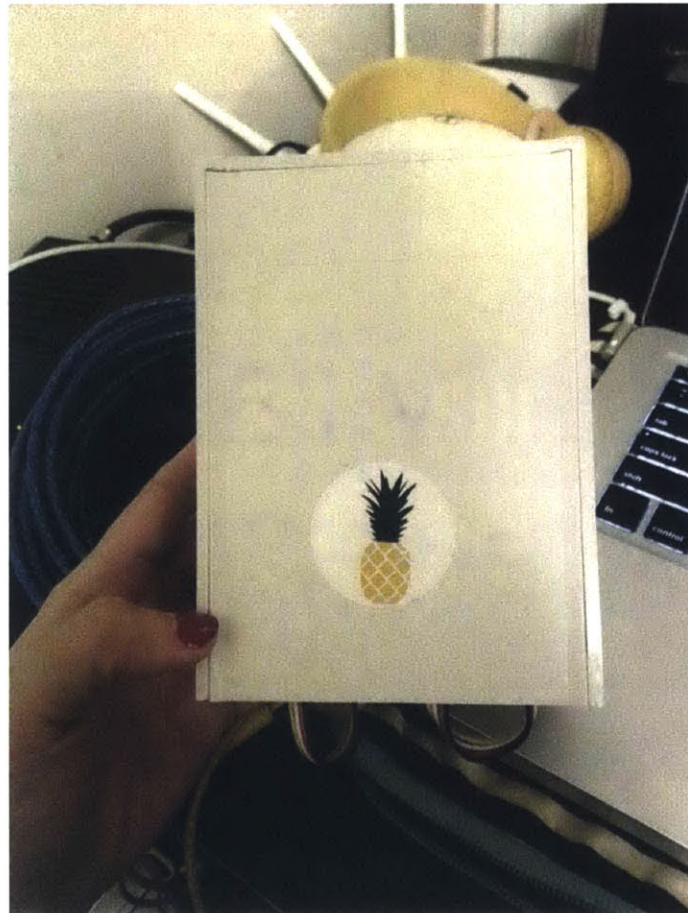


Fig. 25. *Open source Data Canvas sensor shield (2015).*

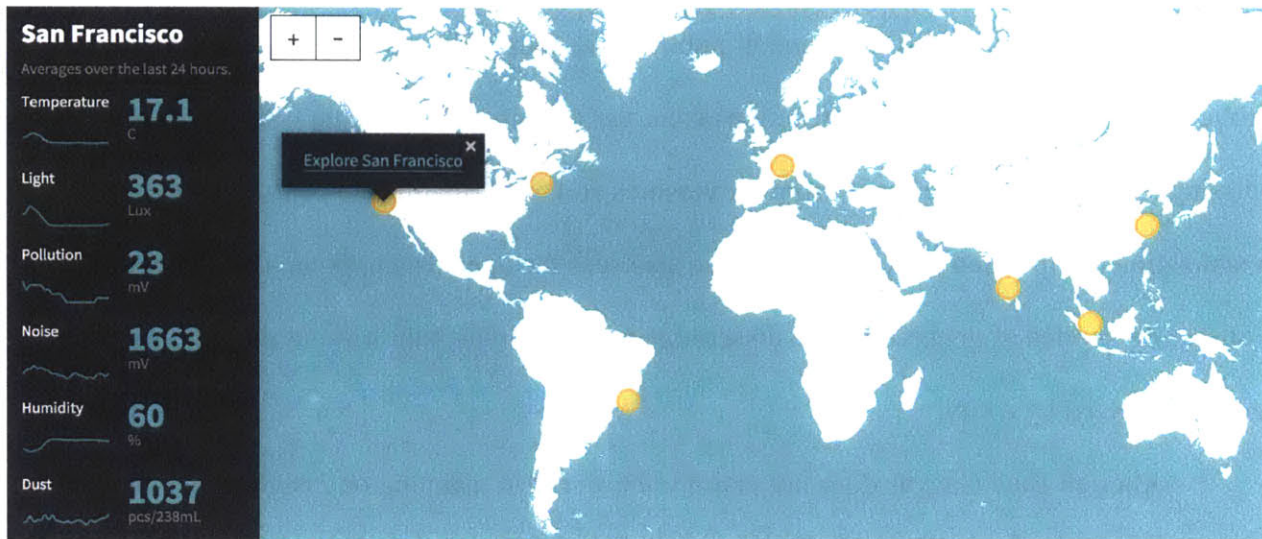


Fig. 26. Data Canvas: Sense Your City, *Map platform*.  
 From: Data Canvas: Sense Your City, "Map," *map.datacanvas.org*, accessed March 2016. <http://map.datacanvas.org>

In addition to providing a map-based platform on which anyone could view the data, the Data Canvas team also hosted a data visualization competition to solicit different ideas for how else to represent the raw data feeds coming from the sensors. Kasper, an audio designer who won the data visualization competition, actually sonified the data feeds so that readings of temperature, humidity, and noise level were read out loud and underscored by music. For him, the experiment was about representing data in other ways to make more accessible the parts of the environment that we cannot see, which resonates with Anne Whiston Spirn's project of "making the invisible visible" with air quality. The project was also about giving citizen control of environmental information, a theme that serves as a common thread among all the use cases in this chapter. The use of open source sensors to collect and visualize environmental data circumvents traditional governmental or institutional means of collecting data, therefore allotting a certain degree of agency to the person or people in control of the process.

Whereas Williams' and Spirn's projects began with planners or designers and then moved to getting feedback from a general public, Data Canvas began with engaging a general public and unexpectedly garnered reactions from various cities. Since Data Canvas began, Reissingger has received requests from universities and municipalities to continue the data visualization competitions through them. She also sees the open data approach as a way of prototyping an idea of generating and disseminating open urban data without the liability of being contracted by a city.

Although Data Canvas does not claim to be an urban planning or design project, it touches upon many of the same challenges that planners and designers face when working with crowdsourced data, namely how to make the data relevant and legible to a wider audience, how to make participation meaningful, and how to capture some aspect of the urban experience. Data Canvas similarly does not aim for accuracy of data but is more interested in how to make information engaging by representing it in different ways, on different platforms, for a target audience.

### *Conclusion*

What can projects like Beijing Air Tracks, the Dayton Project, and Data Canvas teach us? First, we can glean that within urban planning and design - and in Data Canvas, urban art - the use of data for public planning and design processes is still experimental. As it stands, the state of these crowdsourced data experiments focuses on how to convey complex information clearly, and how to encourage collaboration across sectors to do so.

It remains to be seen whether these approaches are sustainable or successful for city planning and design, but an acknowledgement of the limitations of crowdsourced methods can help with refining the approach. As it stands, there exists a polarizing paradigm of opinions



about whether the use of emergent technologies like sensors successfully accomplishes the type of information collection about cities that more traditional, refined, and tested approaches offer. At the same time, it is important to establish precedents for how emerging technologies can be used in the information gathering process in order to evaluate claims that digital tools can enable more inclusiveness or more participation in city planning efforts. Those situated within the academic community, such as Williams or Spirn, have the advantage of coming from a position of knowledge production, either for other scholars or for practitioners hoping to look at specific use cases. One might argue that projects like Beijing Air Tracks or the Dayton Project assume less risk than if they were developed in industry, given that their ultimate aim would be to create and pass on new knowledge as opposed to being driven by a need to make profits.

Second, these projects demonstrate the ability to collect and use data outside of institutional and governmental means, often filling gaps in existing data because it is either unavailable or nonexistent. In some cases like Christchurch, NZ, as was discussed in Chapter 3, there is a lack of baseline information about the environment. While it might cost more money and take more time for a government or institution to collect that data, an effective crowdsourcing initiative may be able to generate that same data in less time, and at a lower cost. The emergence of low-cost sensing technology also returns agency to the individual; instead of relying on governments or institutions to provide information about pollution, individuals might consider using an open source sensor or consumer-grade wearable sensor to measure air quality more independently.

Lastly, there remains an unfortunate “digital divide” that excludes individuals who do not have access to digital platforms or tools from participating. While the use of emergent technology invites new modes of distributed information collection, it risks further marginalizing

those who do not yet have access to these tools. Larger still is the need to address the issue of data literacy among publics, which would enable individuals to interpret data and understand how to use emergent sensing tools. While there is much experimentation with these tools in the disciplines of urban planning and design, these practices are still niche and implicate a smaller circle of researchers and practitioners. That said, these newer methods should not necessarily replace traditional means of collecting and representing information, but they might at least offer new forms of doing so.

# five

## **Civitas**

Despite the emergence of urban air quality sensing initiatives around the globe, they only encompass a fragment of other types of sensor-based projects. However, through a close look at one specific category of sensor data, air quality, I have been able to discuss some of the prevalent challenges that practitioners and researchers face concerning the collection, analysis, and communication of crowdsourced sensor data writ large.

My goal is not to argue for air quality sensing projects, or any other sensing project, to be accepted wholesale. Rather, I hope to have provided a more nuanced perspective of air quality sensing projects that seem to be proliferating across cities around the world. Not only do governments and institutions rely on varying methods of communicating air quality data for purposes of policymaking and public engagement, smaller citizen-led air quality sensing initiatives simultaneously offer alternative – and sometimes resistant narratives – for air quality in certain contexts.

While emerging sensing technology provides a means to capturing and representing information about the urban and natural environment, it is by no means a solution in and of itself. The collection of sensor data - or any data, for that matter - is connected to matters of human interest, and ruled by decisions based in human value systems. In short, we measure what we care about. Consequently, the concept of air quality is socially constructed and comprises a series of choices about what to measure, how to measure it, how to represent it, for whom to represent it, and so on.

The hope behind many of the urban air quality sensing projects I discuss is not necessarily to achieve accuracy in measurement of air quality, nor is it to arrive at a definitive truth about air quality. Instead, I argue that these projects, in terms of shared values, endeavor to instill a sense of *civitas* into their intended audience, a sense of stewardship toward one's idea of a public body. The Latin term *civitas* refers to the social body of citizens bound together, responsible for the citizenship of one another.<sup>157</sup> This can be observed in air quality dashboards and data portals like the EPA's AirNow (discussed in Chapter 2) disseminate information about air quality to a general public in order to provide transparency of government data such that in the event of a crisis or emergency, there would be a resource for air quality data that could be publicly accessed. Media campaigns for air quality such as Beijing Air Tracks (discussed in Chapter 3) call attention to air pollution as a public health risk while also advocating for policy change. Personal air quality monitors like Tzoa and grassroots air quality sensing projects like Data Canvas: Sense Your City (discussed in Chapters 3 and 4, respectively) aim to give people individual access to air quality data where they choose to measure it.

To return to the discussion about corporate-led "smart city" proposals in Chapter 1, it is exactly this sentiment of *civitas* that is often lacking in the narratives of optimization that dominate "smart city" discourse. For instance, IBM's Smarter Cities program promotes an image of smart cities as ones that are enlivened by technologies that can help measure aspects of a city toward better management of urban systems. This seems to set the management of cities in parallel with the management of software, a matter of debugging problems or optimization of processes. However, my analysis of air quality sensing initiatives for this thesis has revealed a

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<sup>157</sup> William Smith, "CIVITAS (ROMAN)," *A Dictionary of Greek and Roman Antiquities* (London, UK: John Murray, 1875), 291–293.

Claude Nicolet, *The world of the citizen in republican Rome* (Berkeley: University of California Press, 1976), 21–23.

“smart city” narrative closer to Jane Jacobs’ conceptualization of a city as a system of *people* instead of a system of machines or devices.<sup>158</sup> Sensors can act as proxies for “eyes on the street,” a form of citizen surveillance Jacobs argues is necessary in cities, and sensors ultimately offer a form of stewardship over contested spaces.

After having evaluated these case studies of air quality sensing, a new set of questions has arisen from this work. These may also give way to future opportunities for further research about air quality sensing initiatives in cities:

**1. What must be done in order for city governments and top-down entities to be able to collaborate with citizen-led, bottom-up efforts to monitor air quality?**

Within this field, in theory and in practice, this is the largest gap to be filled. The biggest barrier to governments and citizen-led initiatives collaborating more often is the use of differing methodologies, tools, and strategies. No two initiatives agree exactly on how to carry out the wider project of measuring air quality, whether they share a top-down or bottom-up approach or not. If the value of sensor data in urban planning and design depends on its clarity, accuracy, and applicability to citizens and planners alike, it is incumbent stakeholders from both government and citizen groups to establish best practices for assessing the value of that data, whether it means establishing shared standards, shared tools, or even simply shared goals. This would help both groups clarify the best paths toward collaboration.

The wide array of projects that span government and citizen air quality monitoring projects examine different scales of data collection and representation, often on purpose so as to fill the gap that the other does not provide. However, this also poses a challenge to how to represent these different scales in conjunction with each other. In addition, while some projects

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<sup>158</sup> Jane Jacobs, *Death and Life of Great American Cities* (New York: Vintage, 1961), 35.

do decide to make their data open and therefore part of the public domain, different air quality projects may not always share the same data format, thus presenting a challenge to interoperability. More work might be done toward understanding how to combine different scales and formats of data across platforms and audiences. Although there are many air quality monitoring projects run by governments or citizens, there are few precedents that demonstrate both parties working in tandem with established protocol for data collection. It is also worth considering that challenges to collaboration are not related to hardware or data at all but rather a lack of common values and strategies.

## **2. To what extent can providing or having access to air quality data change behavior?**

Beneath this field of work lies the assumption that providing information about air quality to a public will influence behavior in some way, but this needs to be further tested. Inherently, this begs the question of what the goals of each air quality project is or should be. For instance, if the goal of building an air quality platform is to influence people to reduce carbon emissions by driving less often, it is worth asking whether making air quality information more accessible can affect change, or whether more complex, system problems are at stake, such as a lack of public transportation or alternative options for mobility.

Future research might help enlarge our frame of thinking to include the wider ecology of factors that contribute to poor air quality. While I have argued that citizen-led air quality monitoring initiatives do revalue “local knowledge” and provide counter-narratives to traditional means and methods of constructing environmental knowledge, the obstacles to sustaining meaningful impact in society may not be attitudinal but rather socioeconomic, political, or otherwise. Social processes create unequal access to risk as well as the resources to ameliorate risk, and these inequalities are a result of power relations that inevitably operate in every society.

Providing information as a public good may be the first step toward increasing capacity for activism or political organization toward meaningful change.

Many of the projects discussed in this thesis also rely on media in some way to communicate air quality data to a designated public. A related question to ask would be: in what ways is a media strategy for communicating air quality limited, and what is it that *cannot* be achieved through data visualization and communication alone? What are the other factors that affect individual behavior and policy change when it comes to air quality?

This issue also includes the question of ‘exit rights’ to technologies and infrastructure that exist to support current methods of collecting and communicating air quality information. Heavily deployed technologies – whether longstanding or emergent – run the risk of making viable alternatives practically nonexistent. While important to consider how institutions and citizens might collaborate more on environmental monitoring initiatives, providing assurance that the potential to opt out is available becomes an important practical and ethical issue.

### **3. Does grassroots air quality sensing hold the potential to collapse amateur and “expert” knowledge communities?**

Whereas data collection was historically performed by specialists who had training to do so, and who collected data for government agencies or institutions, the tools and processes for doing so - albeit in ways that may be less accurate or less official - are now more available to a wide public. On one hand, this poses a threat to communities of experts who formerly dominated the space of data collection. Institutions and governments can now be held accountable by citizen data collection initiatives. On the other hand, while grassroots tools enable communities of people outside of institutions to define and investigate environmental issues independently, citizen groups may lack formal training to properly calibrate tools, to run sophisticated analyses

on data, and to make sense of the information collected in a way that can instill confidence in key decision makers. Further research might also be done about intellectual property rights for data collected by individuals or groups of individuals toward grassroots initiatives, or even governmental and institutional initiatives.

There are also opportunities to create educational models both inside and outside of the classroom to bridge the gap between “expert” and “nonexpert” knowledge communities in this space. Some tools like the Air Quality Egg and SmartCitizen have been incorporated into classroom curricula to educate students about the advantages and disadvantages about using sensors to collect and communicate environmental data.<sup>159</sup> These same projects have also gone on to create documentation of their sensor tools, making this information available to a wider public to access.

As human beings, we need air in our lungs and our bloodstreams to stay alive. Air is everywhere, a common denominator that is part of every human experience, and yet *air quality* is something that divides people deeply and unfortunately across socioeconomic strata. Using mechanical sensors to measure air quality makes visible the otherwise invisible, ultimately serving a very human *telos*, perhaps best summarized by Richard Kearney, who writes in the *New York Times*: “Full humanity requires the ability to sense and be sensed in return.”<sup>160</sup>

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<sup>159</sup> Liz Barry, “Air Quality Class,” Public Laboratory (n.d.). <https://publiclab.org/wiki/air-quality-class>

<sup>160</sup> Richard Kearney, “Losing Our Touch,” *New York Times Opinionator* (August 20, 2014). [http://opinionator.blogs.nytimes.com/2014/08/30/losing-our-touch/?\\_r=0](http://opinionator.blogs.nytimes.com/2014/08/30/losing-our-touch/?_r=0)