Participatory Sensing in the Speculative Smart City

STEFFEN HVIID TRIER

Digital Design and Communication, IT University of Copenhagen, Copenhagen, Denmark, shtr@itu.dk

TOM JENKINS

IxD Lab, Department of Digital Design, IT University of Copenhagen, Copenhagen, Denmark, tomje@itu.dk

This paper explores a bottom-up way to speculate towards future smart cities by inviting residents of Copenhagen, Denmark to participate in sensing activities. It illustrates how the idea of "design things" could support bottom-up citizen participation in a smart city. It uses a research through design approach, deploying a wearable air quality sensor to three Copenhageners. By investigating citizens' perception of the city through this prototype, we illustrate a possible path for engagement in the development of future smart city technologies that offer a greater sense of influence and relevance for residents. Further, citizen participation in sensing activities provides a route to different understandings of smart cities: as a place for people and participation instead of for data and rationalisation.

CCS CONCEPTS • Human-centered computing • Interaction Design • Interaction design process and methods

Additional Keywords and Phrases: Smart cities, participatory sensing, research through design, speculation

ACM Reference Format:

First Author's Name, Initials, and Last Name, Second Author's Name, Initials, and Last Name, and Third Author's Name, Initials, and Last Name. 2018. The Title of the Paper: ACM Conference Proceedings Manuscript Submission Template: This is the subtitle of the paper, this document both explains and embodies the submission format for authors using Word. In Woodstock '18: ACM Symposium on Neural Gaze Detection, June 03–05, 2018, Woodstock, NY. ACM, New York, NY, USA, 10 pages. NOTE: This block will be automatically generated when manuscripts are processed after acceptance.

1 INTRODUCTION

The concept of the "Smart City" is often represented as a digital layer placed on top of existing urban infrastructure, symbolizing an intertwined network of nodes containing various parts of city life and technologies. The assumption of a smart city is that it can better allocate civic resources through thoughtful use of information and communication technologies [31]. As popularly imagined, a smart city depends on the production and analysis of data from all sorts of sensors detecting such varied types of information as traffic patterns, the weather, human activity in public space, whether a trash can is full, and what parking spaces are free.

Taken together, the smart city describes the creation of a connected infrastructure to the internet of things and big data to benefit a municipality, its citizens, and its businesses. By collecting data, cities are able to create "new urban services such as better transport connections, accident risk warnings and home monitoring for part-time and full-time carers," and the promise of this data means that businesses will be able to offer personalised services for their customers. [33]. The smart city also has a role to play in ecological impact of urban centres, as effective use of resources can reduce both energy and CO_2 emissions while minimizing overall costs for governments [39].

In some ways, Copenhagen, Denmark is already a smart city: The municipality provides free access to public data sources to drive city innovation, which offer a unique starting point for the development of smart city solutions. One way the city provides that starting point for innovation is through a partnership with a living lab in the heart of Copenhagen—Copenhagen Solutions Lab (or CSL) [25]. CSL works with smart technologies, businesses, and civic initiatives to create data-driven solutions addressing the needs of both the city and its citizens. They are a huge part of an overall smart city strategy that aims toward better quality of life and economic growth. The vision for Copenhagen is to create a cleaner, healthier city, while keeping up with a rapid growth in population—approximately 1000 new residents every month [25,40,41]. Currently, CSL is tasked with understanding how people use the city, creating better access to services through digital solutions, providing data-driven operations and supervision, and building detailed maps of the city's environment and climate.

The goals of Copenhagen as a smart city are not that different from other smart cities. They reflect a rationalizing impulse that seeks to utilize technical resources to overcome challenges that the government faces, whether societal, environmental or governmental [31]. Bettering quality of life is an explicit part of this project. Supporting "quality of life" entails a particular focus on citizens and their well-being. However, most smart city sensor applications—and the abstract, quantitative data that they produce—only tells part of the story of what is being measured [9]. This data does not tell us *why* traffic is behaving as it does, or *why* so many people are gathered outside of city hall—they can only tell us that they are there. Human life shapes the city, and while sensors tell part of the story, citizens will have to be involved to tell the other part: why they are behaving in certain ways, how they perceive the city, and what needs they actually have. This input is essential to designing a humane smart city, especially if the goal is to improve citizens' quality of life [19,36,42–44]. How do we tap into citizens' perception of the city from a design perspective, engage them in the development of smart city technologies, and allow them to express their concerns or needs as part of that process?

This paper investigates how design can help citizens express their perceptions, needs, and concerns in a smart city. As part of this inquiry, we used a speculative and reflective design practice [2,35] to design a bracelet that measures and displays the air quality of its immediate surroundings. Copenhagen Solutions Lab [25] hoped to increase public awareness of air quality issues and find new ways to communicate their air pollution data to citizens in more meaningful ways. The structure of the paper is as follows. First, we review existing projects and approaches to bottom-up smart cities, followed by the design process and decisions made in developing an air-quality sensing bracelet. After that we describe an ethnographic study of three users of this bracelet, discussing how they understand both Copenhagen and the idea of the smart city. Finally, we reflect on design things as offering a path for future participatory smart cities.

2 BACKGROUND

This project focuses on ambient outdoor air pollution, with an aim towards maintaining the culture of walking and cycling in Copenhagen. Here, the notion of "air quality" is explored through sensing particulate matter (or PM). PM are inhalable and respirable particles that are composed of multiple different substances such as sulphate, nitrates, ammonia, black carbon, dust, salt, water and heavy metals. PM is sorted according to its size; particles greater than 2.5 microns are *coarse*, particles less than 2.5 microns are called *fine* and particles less than 0.1 microns are called *ultrafine*. In terms of air pollution, particles under 10 microns can penetrate our lungs and enter our bloodstream. The smaller the particle, the greater the health risk. PM is emitted by combustion engines, building and manufacturing industries as well as brakes and rubber dust from cars [32]. PM is the most important pollutant to measure when it comes to urban air quality because it is linked directly to heart and lung diseases such as strokes, asthma, bronchitis and lung cancer [45].

Air quality is not easily detectable by humans unless levels are so high that it becomes smog [46]. According to the WHO, air pollution claims around 7 million lives each year [45]. In 2009, the Institute for Environmental Science at Aarhus University wrote that, in the EU 288,000 early deaths were caused by particle pollution (PM), and WHO estimates that 80% of all cities exceed their guidelines for safe air [31,45]. In the EU, the issue of air quality has been addressed in a set of directives beginning in 1996 [32]. According to [32] an increase of just 10 $\mu g/m^3$ for just one day has been linked to a 2 percent increase of hospitalizations of elderly (above the age of 65) and children with asthma. With this in mind, air pollution is an issue that matters to residents of urban spaces. This project uses design to explore issues like these as a matter of concern that affects those residents.

To that end, HCI has taken up Dewey's ideas of "publics" to frame designing for issues [5,6,22,23,29]. Briefly, different publics are created and maintained through interest in an issue—a matter of concern that unites that publics' members through their investment in that issue. As a lens for considering how the design of technologies can support participation in civic life [7,21,22], publics offer a way to mediate and articulate issues for broader discussion and to organize possible future action about those issues. Publics represent a group that is invested in an issue as a common matter of concern. The role of design is to bring publics together as participants in *design things*, defined by Ehn and others as design projects that offer a means for members of a public to access and participate in those issues [3]. In projects like these, design offers a strategy of articulating an issue for the participation of a public that is organized round an issue such as air pollution. The design object as public design then offers a means for members of the public to reflect on how that issue is relevant and meaningful for that citizen in particular [6,8]. Designing around an issue intrinsically involves a larger public into the project through their investment in a matter of concern [3]. Here are three examples of different approaches to public design:

The first of these take a public as a source of information and political activism about an issue and mediates their participation in that issue through technological systems. *Cycle Atlanta* explored the future infrastructure of Atlanta, USA by structuring participation around city planning by using an app to track cycling habits [28]. Through the app, cyclists record their routes and attach notes and remarks to those routes. These data are used by city planners as part of the planning process of the city, and acts as a representative for the cyclist public throughout the planning process. In Copenhagen, the urban theorist and planner Jan Gehl has long taken a person-centred approach to imagine how cities could work more directly for people [16].

In a second model, HCI design became a means of articulating what matters to publics in an open-ended way. Kuznetzov et al. explored what environmental issues matter to residents of Pittsburgh, USA, across four demographics using a set of different environmental sensors: exhaust, smog, pathogens, noise, chemicals and dust [23,24]. Sets of sensors were given to students, cyclists, parents and the homeless for them to express their concerns at different locations. The placement and logic behind that placement offered insight into how these groups understand and communicate environmental issues as matters of concern in their everyday life —what Kuznetsov et al. call *participatory sensing* [23]. This style of engagement can be found in other locations as well: the Smart Citizen project in Barcelona, for example, offers hardware developed for communities and residents to create local maps of noise and air quality [47].

A third approach is exemplified by *Smog is Democratic,* exhibited at the United States Centers for Disease Control and Prevention in Atlanta, USA [8]. This project visualized air pollution measured in 2008 by the Georgia Department of Natural Protection, by disrupting images in a video loop. Each frame of the video corresponds to an hour of PM-based pollution data. Alongside the video was a reading area containing material on PM air pollution and twenty-five photographs of common PM pollution sources. The project communicates air quality data to the citizens rather than the other way around—it put a focus on unseen ambiences of urban pollution and how that pollution could be measured and represented in a gallery context, rather than as an experience situated in the city. While interpretive, this style of project is closely aligned with visualizations like *Luft på din vej* that illustrate air pollution on streets in Denmark [48].

Through these projects, participants were able to express concerns in their immediate environments. Projects like these could conceivably allow the citizens to raise awareness around certain factors (e.g. the hygiene of public toilets, or the levels of volatile organic compounds around children's playgrounds), and the data can be used to create public debates, or for city authorities to utilize when adapting the "smart city" to particular contexts and situations.

3 DESIGN PROCESS

This project uses a design research process rooted in research through design (RtD) [37,38] to explore citizen participation in smart cities via an issue that matters to them. In the project, a variety of different approaches have been used to both develop a prototype that measures air quality, as well as to explore what reflections and consequences this has on individuals within the emerging smart city. RtD is an appropriate method for this style of work, as structured activities of making coupled with rigorous documentation, reflection, and analysis can provide insights into the practices of designing, the qualities of the designed system, use, and the context of use [4,12,14]. To that end, the first phase of this project consisted of meetings with researchers and labs invested in smart city development and air pollution measurements in the city of Copenhagen. These were used to gain a broad understanding of what a smart city is, how air quality is measured, how it is depicted and what the current state of the art is for the city of Copenhagen.

3.1 Generating a design brief

As mentioned above, Copenhagen Solutions Lab was interested in creating a map of the city's air quality as the starting point for future smart city applications. Following EU guidelines [32], Copenhagen has three stationary air pollution measuring stations. Two of these stations measure the air pollution at street level, while the last measures "background pollution" from a rooftop [49]. The background pollution is the constant air pollution of the city, but it is not representative of the pollution at street level—the pollution that citizens and visitors are exposed to. The difference between background pollution and street pollution can be quite significant. Street pollution varies depending on the street and the time of day; a test conducted by the Department of Environmental Science at Aarhus University asking participants to carry a mobile PM-sensor and GPS, showed an average difference in levels of pollution of approximately 30 percent in transit between home and work. Early in 2019, Copenhagen Solutions Lab addressed this need in cooperation with Google's "Project Air View:" throughout 2018 and 2019 a Google Street View car, equipped with PM, carbon dioxide and nitrogen dioxide sensors will measure and map the air quality of Copenhagen. This is in an effort to help citizens better plan their daily routes through the city and to help city planners and politicians to make more sustainable choices [26].This is an important step to secure a cleaner and healthier city that works for its inhabitants and visitors, but data by itself will not help people choose the cleanest route to travel through within the city—the data will have to be communicated in an understandable and functional way. This is the context that the bracelet is designed for. In our first meeting, Copenhagen Solutions Lab expressed an interest in finding out how to present and communicate air quality data to citizens in a meaningful way, and if communicating that data would make people curious as to how it affects them in their everyday lives. This became the brief for the prototyping phase of the project.

3.2 Prototyping

With this brief in mind, we developed a wearable that measures the quality of the surrounding air and visualizes it by changing its colour (Figure 1). Good air quality causes the bracelet to glow green, medium-quality air causes it to glow yellow, and poor air quality means that the prototype glows red. These colours make it easier for a user to interpret the local air quality and allows for reflection on the data in a particular location.

The bracelet consists of 6 components: a Feather Fona 32u4 board, a 1000mAh LiPo battery, a PM7003 particulate matter sensor, and 3 NeoPixel LEDs. The Feather Fona has built-in charging ports that allow the LiPo battery to be charged directly through the built-in micro-USB port, minimizing the overall number of components. The 1000mAh LiPo battery allows the system to run continuously for over 12 hours, allowing for a full day of continuous use. The particulate matter sensor is capable of measuring ultrafine (0.3 – 1μm), fine (1 - 2.5μm) and coarse (2.5 - 10 μm) particulate matter.

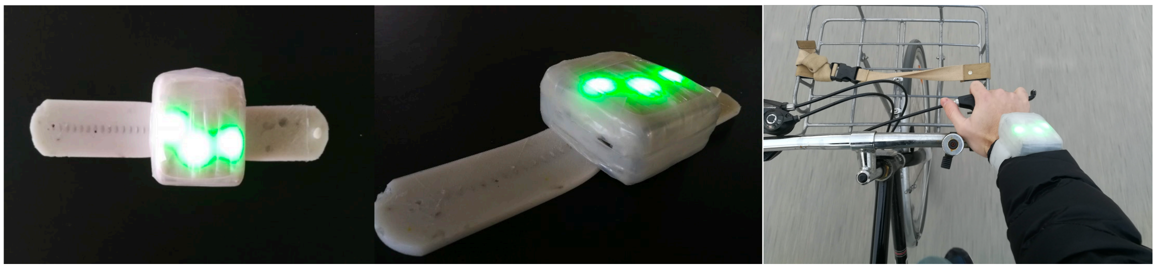

Figure 1: The air-quality sensing bracelet, left, and in transit, right.

3.3 Designing for Air Quality *in situ*

To design a device that supports building awareness of air pollution, and leading to the possibility of future contestation, the artefact would first have to be mobile and wearable in order for the user to reflect on air quality while moving through urban spaces. Second, it would have to be in a users' periphery as they travel. These requirements led to particular design qualities, described below.

3.3.1 Form

The form sensor device emerged from a set of design constraints: it had to be carried with a user and in their peripheral vision at all times as they moved through the city. After considering four different kinds of objects (bracelet, keychain, badge, and glove) we selected the bracelet. The bracelet offers several advantages: It is visible during almost any activity, such as cycling, gesticulating or grabbing things, and bracelets can be strapped to other everyday items such as bags, handlebars, railings or baby carriages, offering flexibility during use. Finally, many people already wear watches, making the form and use familiar.

3.3.2 Function

The original idea of the bracelet was to sense local data and feed it back to a larger system operated by Copenhagen Solutions Lab. This would allow a platform to use mobile air quality sensors as a tool for city planning. It would allow participants to consider air quality through the device as well as via a city-wide heatmap after the fact. However, the ongoing Google Air View collaboration with CSL meant that data produced by the bracelet could not contribute to their data directly. A second strategy of using existing data pre-loaded into the bracelet would mean that less hardware would be required, but the most recent dataset available was seven years old [48]. As a result, the final version of the bracelet displays a changing visualization of air quality data based on local measurements from an internal sensor. This means that the wearer is encountering live data directly, even if that data is not being aggregated and contributing to the overall picture.

3.3.3 Interaction

While moving through the city, the bracelet slowly changes colour to reveal the surrounding air quality. During prototyping, simpler representations using a red/green colour scale were tested, but they did not offer enough variation to prompt exploring different conditions in the city. The bracelets now depict the air quality in three colours based on WHO guidelines. This means that the bracelet will glow green when the measurements for both fine (< 2.5μm) and coarse (< 10μm) PM are below their annual mean value; it glows yellow when one of the PM values are above their annual mean value; and it will glow red when one of the values are above the 24-hour mean value.

This combination of form, function and interaction presents air quality to people as a way of challenging and augmenting their perception of the city. It measures local air quality and presents it to its wearer using a green-yellow-red scale. The three-colour system is meant to prompt reflection on the relationship between citizen and city by making air quality issues more perceptible. The bracelet visualizes air quality data at a particular location to its user, who can then choose a route or think about their space differently. Siting this kind of data in the real world and lived experience of everyday life means that the facts of air pollution, often abstract and difficult to understand directly, become matters of concern that are related to the lived experience of an individual [8].

4 PARTICIPATORY SENSING IN COPENHAGEN

To probe how the air quality sensing bracelet might affect people's perspectives on the city and possibilities for smart city data in it, we recruited 3 participants (see Table 1) for a pilot study intended to gain insights into their sensemaking of artefacts, and what sorts of reflections they had based on their experiences of use. By experiencing air quality data directly, we hoped we might inspire reflection on people's perception of the city, their everyday routines and the concept of smart cities more broadly. The study had three phases: A semi-structured interview [34] and mapping activity [18], a week-long deployment (after e.g. [15]), and finally a second mapping exercise and debriefing interview, analysed using grounded theory to identify common themes [50].

Table 1: Study participants

Pseudonym	Age/Gender	Background
Robert	36/Male	Resident of Copenhagen for 15 years. IT Engineer, cycles for main transportation. Daily routine takes him throughout the city.
Hope	75/Female	Resident of Copenhagen for 35 years. Background in banking, textiles, and teaching, but currently retired. Member of sustainable traffic council as well as inner-city council. Participated in previous unrelated air quality study [32]. Avid walker in the city.
Charlotte	25/Female	Resident of Copenhagen for most of life. Psychology student and operates dance studio. Cycles for transit most of the time, sometimes using the bus.

In the first meeting, semi-structured interviews were first used as a tool to determine the participants' pre-existing knowledge around air pollution and understanding of the term "smart city." Participants were also asked to annotate paper maps of Copenhagen that we supplied. The first map reflected their daily transportation routes through the city. The second was a perceptual mapping exercise: participants were asked to colour areas of the city that they perceived as either very polluted (red), polluted (yellow) or clean (green). We then asked participants to use the bracelet for a week. During the deployment, participants kept a diary of their day-to-day experiences and reflections on the artefact or, if they preferred, to answer daily messages asking them about the artefact's behaviour and their reflections on it. The diary was used as a tool for the participants to reflect upon during the post-deployment interview. After their experiences with the bracelet, we asked participants to reflect upon their experiences as part of the debrief: did the artefact affect their perception of the city and their daily routines? Did it spark new thoughts or discussions of the urban environment and smart cities? How well did it fit with their image of the future of the smart city? To answer these questions, we revisited the mapping exercise to see if their daily routines and perception of the city had changed while using the bracelet. These maps highlighted participants' perception of the city and documented their routines and offered a way to compare participants' experiences before and after using the device.

4.1 Perception of Copenhagen as a Smart City

Before this project, Robert was not familiar with the term "smart city." Initially, he imagined the smart city as something for the citizens to take advantage of, a system to explore the city and what it has to offer in terms of food, drinks, events, or experiences: *"I think it is something where you have some app so you can take better advantage of the city. [...] I would think it was something that somehow could use the city smarter, thus the name Smart..."* After being introduced to broader meanings of the term, he focused on the effects of trash in the water, minimizing cars in the city, better accommodations for bikes and preserving of green areas. This view was evident in the perceptual map exercise (Figure 2), where he marked the lakes of Copenhagen red and areas such as Vesterbro and King's Garden yellow due to large amounts of trash on the weekend. Robert had not considered air quality in his perception of the city. This means that the bracelet offers him a new point of view towards his surroundings and daily routines.

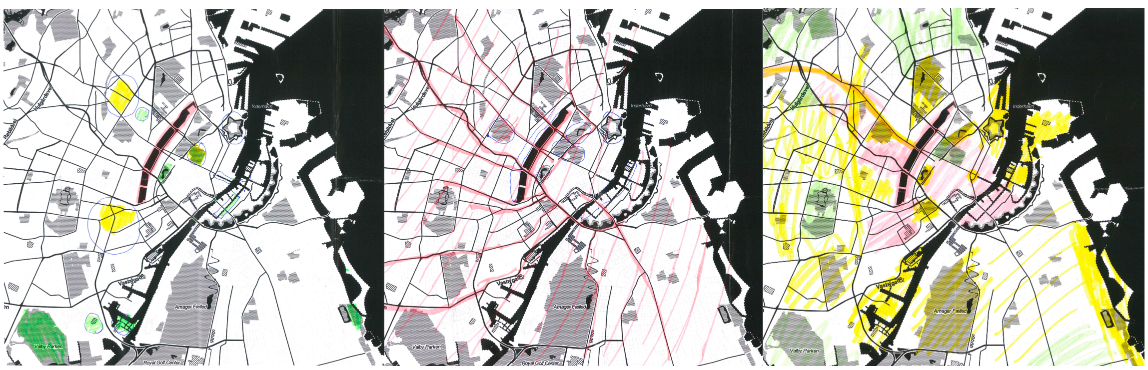

Figure 2: From left, Robert's, Hope's, and Charlotte's perceptual maps of Copenhagen.

Hope was also unfamiliar with the term "smart city." She associated it primarily with efficiency and rationalization. To her, this would mean more cars, more "skyscrapers," more people, and more tourists, which made her sad. To describe what she wanted from a future smart city in Copenhagen she used the term "healthy street." By that, she meant development that emphasized public transport, green spaces and city squares, and generally creating more room for people. She especially emphasized the removal of personal cars, and that cargo should be redistributed to smaller electrical vehicles at "discharging stations" outside the city. She clearly associates "pollution" with air pollution, as opposed to trash in the street and clean streets, which might be due to her previous participation in air quality research: *"I do not have a detailed knowledge about it, but I have been walking around with such an air meter for fourteen days and measured both on the street, in my apartment towards the street—even in the garden it was sometimes criminal how much pollution there was!"* This previous experience had also affected her attitude towards and perception of the city. When filling out the perception map, she began marking the major roads red. Reflecting upon the task, she ended up colouring the whole map red: *"if red is 'really polluted' then I might as well paint the whole map red, it is not just the roads."*

Charlotte's first reaction to the term "smart city" was that it sounded like something that might be used in a Kickstarter video to describe objects that makes the city smarter and more intelligent. *"To make the city more intelligent, to get more out of the city by incorporating technology into one's everyday life. I imagine it a little bit like virtual reality, or augmented reality, but it probably isn't."* When asked about what features a smart city should have and what Copenhagen should look like she replied: *"…just get rid of cars a little bit in inner Copenhagen. Get some kind of closed inner city that is only for pedestrians and cyclists. It could just be so nice. They have worked toward it in many cities abroad, I think, to make it car-free at least in the centre."* Because of her previous experience with noise pollution, her view on pollution is multifaceted. In her map, she emphasized that the green areas were areas of low to no noise, trash, and cars. She, like Robert, put emphasis on the physical presence of trash when describing why certain areas had been labelled red and yellow. Her typical green areas are parks, such as the botanical garden and kings garden. However, she excluded Amagerfælled (a large park area to the south of the city centre) as she found it to be filled with trash. The typical yellow areas for her were the outer areas of Copenhagen such as Frederiksberg, Østerbro and Amager. The red areas are primarily the inner-city, the lakes, Åboulevarden and Nørrebrogade. These are areas with less breathing room and higher levels of noise, trash and exhaust.

4.2 Reflections on Urban Sensing

During the deployment, Robert only occasionally looked at the bracelet while riding his bike, when he stopped at a red light. As a possible consequence of this, he reported in his messages that he had mostly seen the bracelet light up with green. While this surprised him in a positive way, he also indicated that the artefact made him think more about traffic and the pollution it causes: "If the bracelet had not been green, then I think I would look for alternatives routes to work. To see if it would have made a difference, you are interested in driving in as little pollution as possible. Especially when it is twice a day, 5 days a week." In the post-deployment interview, he elaborated further on this: "I think I would have imagined it to show another colour inside the city centre, when you drive along the heavier traffic roads, but nothing." He referred to how the bracelet changed to both yellow and red when he cooked at home, contrasting with the solid green he saw outside. Because of this, the device did not give him any extraordinary experience or induce any curiosity for exploration. While the bracelet did not change his perspective on the city, he did hope to reduce the number of cars in future Copenhagen: "I would rather bike in clean air than next to 400 trucks pumping out carbon dioxide."

When the conversation was brought back to the concept of smart cities, he stated that he sees personal technologies like these as ideal for use in future smart cities. Robert thought that the data would be relevant for the city council to have and use as there should be made rules, limits and standards for permissible levels of pollution. Robert had no problem imagining the functionality of the bracelet as part of a real product if it was smaller, for example by being incorporated into a smartwatch or fitness tracker, and he appreciated the feedback that the colour change offered. However, he stated that he would have like some kind of tactile or auditory indicators as well. Being a runner, he stated that he liked being able to revisit his routes with a graphical representation of the geographical route and the stats from it. *"My watch makes a line of where I have been, but it also shows, if I have worn my pulse sensor, what zones I have been in. Then it colours the line in green and yellow, and nuances it, kind of like the bracelet also does. [...] I think something like that is fun to look at."* Although for him the device remained mostly green, the bracelet encouraged some reflections on air quality and health within urban environments and offered a means of engaging with these issues by being present in his life.

The first thing Hope stated after the deployment was that she felt cheated–she did not feel that the bracelet was measuring air pollution at all. This reaction was due to her previous experience with a professional-grade sensor: *"It is because I am used to a bigger device, it is more expensive [...], and reacts immediately to everything."* While it could be the difference in precision between the sensors, it is also possible that it has something to do with how the devices fed information back to Hope. In her diary entries, Hope mentioned that the bracelet changed colour on many occasions. However, the changes were brief, and they seemed inconsistent. As with Robert, the device remained mostly green during the deployment. This led to Hope wandering around areas with heavy traffic wondering why the artefact did not indicate high levels of air pollution. Hope also found inconsistencies in measurements at the same place on different days. She wrote: *"Alternates between red and green along the harbour and up through square of Amalienborg Palace. It was more green than red in contrast to yesterday, but that was also a weekday?"* During the interview Hope was able to elaborate further on this instance, especially on how it made her feel when the artefact lit up in a red colour along the harbour: *"I was a little surprised that it shone red along the harbour because it is a route I take very often. I try to avoid cars, so I go through the king's garden to St. Paul's Church and down to the water. That is a route where the cars are furthest away... so, then I thought 'Well, god. That is a shame.'"*

She said that this would not stop her from visiting the harbour on her walks, but she might not go there as often as she had before. Though she had marked the whole of Copenhagen as red on her perceptual map, this experience changed her perception of the harbour area and made an impact on her. There is a tension in her experience: she already considers the whole of Copenhagen very polluted and was struck by what areas she imagined being cleaner—such as the harbour area—to be polluted despite the absence of cars. When the bracelet confirmed her fears, it caused her to rethink the area viscerally. In cases when the bracelet contradicted itself, she bargained with the device, rationalizing the difference as being between weekday and weekend, and hoping that her preferred routes remained the healthiest.

Hope indicated that the artefact inspired some curiosity and exploration for her, as she did not feel like taking the same routes that she usually would. She would have preferred a more dynamic interaction, and possibly a wider colour scale—the air quality device that she used before had a numerical interface that fluctuated constantly, giving her a feeling of precision and authority in the data. Similarly, she wanted the bracelet to be dynamic, as she wants to use the artefact as data to make arguments about air quality for the city council: *"Now there are three [colours], and that is not enough for me. I want to know a bit more closely how and why... even though I am not knowledgeable about it, I can become it if I want to read up on it. It is an argument for getting the cars out of the city, or to only have electric cars in the city. Things like that."*

Hope went into the project with a certain prejudice towards the air quality of Copenhagen. Although she reports that the bracelet mostly indicated green, her overall conception of the city has not changed. That said, the device was still capable of giving her new experiences and intriguing her curiosity enough for her to alter her usual patterns in the city. While she was sceptical toward the accuracy of the sensor, she views devices like these as being highly relevant and useful in fashioning a voice for citizens in future smart cities.

Like the other participants, Charlotte experienced that the bracelet was mostly green, indicating a clean city in terms of air quality. At only two occasions did she recall it showing red; Once at a metro station and another at a street food market by the harbour. When the bracelet turned red, she was surprised and felt that something should be done—mostly that she probably spends too much of her time at these places than is good for her. On the whole, however, the experience left her optimistic, as the bracelet contradicted her perception of the city. When we revisited the perceptual mapping exercise, her second map shows fewer red areas and significantly more yellow and green areas (Figure 3). *"it has slightly contradicted my expectations... [perhaps] Copenhagen is generally cleaner than you think because we have so many bikes."*

The only remaining red areas after the deployment were related to the street food market and where trains operate. The yellow areas were mostly related to high levels of automobile traffic and areas of high human activity.

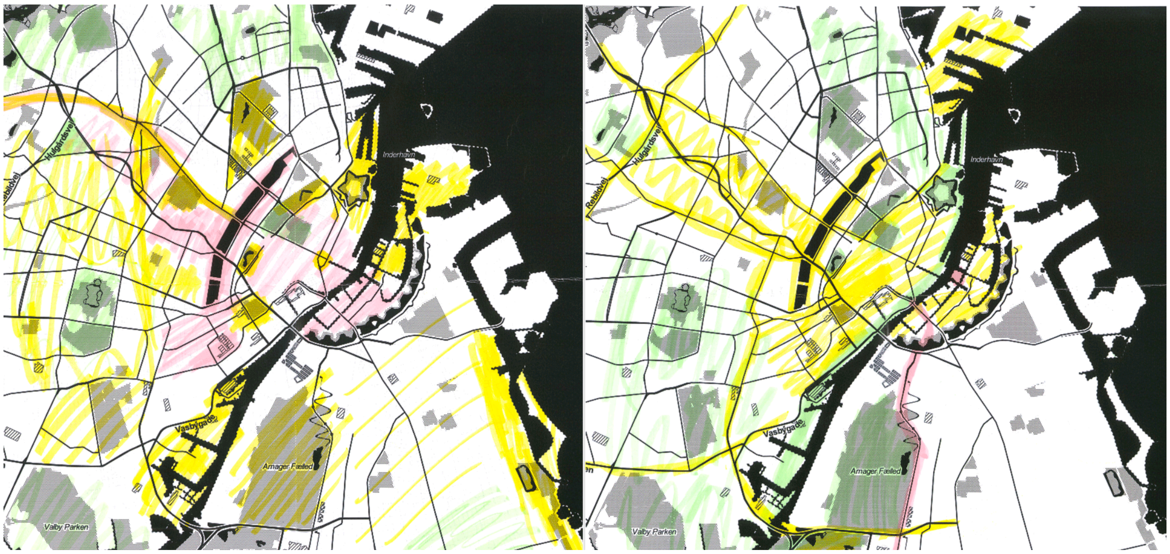

Figure 3: Charlotte's maps before deployment (left), and after deployment (right).

Charlotte had some doubts regarding the design of the bracelet: she felt that the airholes should be bigger or placed more centrally to make wearing it easier. She has been a bit sceptical of its PM indication: she sometimes waved the bracelet around in an attempt to provoke it if she was near a heavily trafficked road: *"if there was a car, or a place with a lot of smog, then I was like 'does it even react?'. [...] then I tried to wave it around like 'hallo!'"* Despite this frustration, she said she could imagine using a more refined edition of the bracelet in the future—she thought that an iteration of the bracelet could be useful or thought-provoking on a bike or a backpack, for example. Generally, she saw it as a helpful tool to build awareness of a common issue while also contributing to its solution. When discussing how the bracelet communicated air quality data, she—like Hope—saw a need for more detail, or a more dynamic scale: *"It could maybe use some numbers [...]. Because red can mean a lot of things, it means that it is over that limit, but you do not know how much over, it could be crazy high.... [maybe] having some kind of maybe scale that slowly changed colour. That could be very cool."* Like Robert, she thought it would be interesting to have a personal digital map of air quality that stored her travels.

Charlotte's positive experience with the bracelet changed how she understood the city. This was due to the bracelet indicating better levels of air quality than she had imagined it would. Although she certainly understood the bracelet as an early prototype, she did not dismiss the idea of having such a device in the future. She felt that it would be a good initiative from the city to deploy technology like this and let citizens help the city council, as she believes that they need comprehensive data to in order to make systemic change.

5 DISCUSSION: SPECULATING IN THE SMART CITY

Through measuring air pollution, the bracelets above provided some visualization of air quality in the city. They were meant to sensitize wearers to the issue of air quality, and at some points changed perceptions of the city, supporting healthier wayfinding. Beyond a purely functional level, the bracelet also supported some speculation towards the roles and services that future smart cities could offer. This section reflects on two directions for future smart city research based on this pilot: ways to create inclusive technology-driven planning processes, and how to invest citizen participation in urban issues through designing technologies for the smart city.

5.1 Supporting Citizen Participation in Urban Planning

In their current implementation, smart cities are systems through which resources, capacities and governance can be better organized by those with planning power, sometimes in conversation with community needs [10]. In contrast, the air-quality bracelet is part of a set of systems and projects that look to produce planning data from the bottom upwards, offering ground-level data for developing urban systems [1,13,30]. In *Planning in the Real-Time City: The Future of Mobile Technology*, Evans-Cowley describes Volunteered Geographic Information (VGI) and the capacity of mobile phone technology for as offering an infrastructure for future urban planning, especially when combined with sensing technologies and participatory collaboration between planners, the public, scientists and other interested parties. She highlights how mobile phones equipped with sensors might detect environmental aspects such as pollution, and in the future might lead to "distributive citizen sensors, also known as participatory sensing" that "[...]could transform data collection" [11]. This approach could lead to large-scale public data collection where citizens act as public researchers. This is closely related to descriptions in [20] of VGI's advantages lying in the "[...]bottom-up approach both to production, maintenance and updating of information and present an effective avenue through which ordinary citizens can be engaged in democratic processes" [20]. This democratic process is what [11] highlights as a "contact zone" between citizens and city planners, which allows for new voices into the development process. While this pilot study is certainly limited in terms of generalizability, the bracelet can be imagined as part of an emerging smart city future where mobile devices are equipped with pollution sensors. As citizens move about, they provide data from multiple areas, aggregating that data over time, in proportion to where people are. Striking the right balance between a technocratic vision of the future and an emergent set of personal interests requires inclusive approaches to data-gathering. Employing personal devices offers a way to engage citizens in a new type of political process, echoing Gehl's idea of "The City for People" mentioned earlier [16]. Here, Hope wanted the bracelet's data to argue urban policy and planning issues to support her vision of Copenhagen.

5.2 Citizen Speculation as Participation in a Design Thing

At various times during the deployment, the artefact prompted participants to encounter the city differently and helped them to reimagine what is at stake in it. During the deployment, the particulate-sensing bracelet entered into our participants' everyday life, encouraging reflection and speculation on how local data affected them in particular, rather than in general. If we consider the bracelet as a *design thing*, the bracelet to some degree offered a new way for participants to participate in a broader matter of concern, engendering both new curiosity as well as new scepticism towards their surroundings. While all participants stated that they would have liked to have a means of accessing the data that they produced afterwards, the bracelet provided a situated visualization that affected their understanding of the city. Unlike the static environmental measuring stations that currently operate in Copenhagen, the bracelet communicated data back to residents. The bracelet offered an opportunity for its wearers to participate directly in sensing, bringing matters of concern out in everyday life so that they can be considered and reflected upon less abstractly. Here, the speculative smart city encourages "breakaway" moments from everyday life, offering smart city residents a way to encounter issues in ways that matter to them.

5.3 Limitations of this study and Future Directions

Notably, many participants made mention of the size, inflexibility, or slowness of the bracelet to respond to the environment. Expectations around sensors and technological artifacts, particularly in a study of the future smart city, mean that there are disconnects between the kinds of interactions that users expected and the level of polish, finish, and size that future technologies in this space would need. Future iterations on the bracelet could produce a more refined material as well as interactive experience. Further, some participants wanted a personal history and visualization of their air quality data, and this would be a promising avenue for future research and implementation. Notably, all participants indicated a willingness for their data to contribute to future smart cities. Finally, the small number of participants means that the insights above should be taken as an indication of possible design avenues rather than deeper truth about smart cities in general. However, the results seem promising for imagining new interactions to help build a smart city for people. These results include how "design things" offer a path to support citizen participation in future smart cities using the example of a bracelet that displays air quality information as provocative and relevant for residents.

6 CONCLUSION

This paper describes a design project and a pilot study that invites residents of Copenhagen to participate in sensing activities and considering the future of smart cities. This study combined an early prototype with a limited number of participants to speculate on both the role of personal technologies in the smart city as well as how future smart cities could be made more accessible to their residents. Currently, smart cities most often refer to initiatives to collect, collate, and utilize data from the city to support better services and more efficient resource allocation. While there are alternative perspectives on the future of smart cities brewing in many locations [1,17,24,27,30,47], by encouraging citizens to participate in issues of the city more directly via design materials we hope to foster richer citizen engagement in designing and participating in the smart cities of the future. The air quality bracelet and participant reflections on its use illustrate a possible route to reconceptualizing the smart city as a place for people and participation instead of data and rationalization.

REFERENCES

1. Irina Anastasiu. 2019. Unpacking the Smart City Through the Lens of the Right to the City: A Taxonomy as a Way Forward in Participatory City-Making. In *The Hackable City: Digital Media and Collaborative City-Making in the Network Society*, Michiel de Lange and Martijn de Waal (eds.). Springer, Singapore, 239–260. https://doi.org/10.1007/978-981-13-2694-3_13
2. James Auger. 2013. Speculative design: crafting the speculation. *Digital Creativity* 24, 1: 11–35. https://doi.org/10.1080/14626268.2013.767276
3. Thomas Binder, Giorgio de De Michelis, Pelle Ehn, Giulio Jacucci, Per Linde, and Ina Wagner. 2011. *Design Things*. MIT Press.
4. John Bowers. 2012. The Logic of Annotated Portfolios: Communicating the Value of "Research Through Design." In *Proceedings of the Designing Interactive Systems Conference* (DIS '12), 68–77. https://doi.org/10.1145/2317956.2317968
5. John Dewey. 1954. *The public and its problems*. Swallow Press, Chicago.
6. Carl DiSalvo. 2009. Design and the Construction of Publics. *Design Issues* 25, 1: 48–63. https://doi.org/10.1162/desi.2009.25.1.48
7. Carl DiSalvo, Tom Jenkins, and Thomas Lodato. 2016. Designing Speculative Civics. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (CHI '16), 4979–4990. https://doi.org/10.1145/2858036.2858505
8. Carl DiSalvo, Jonathan Lukens, Thomas Lodato, Tom Jenkins, and Tanyoung Kim. 2014. Making Public Things: How HCI Design Can Express Matters of Concern. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '14). https://doi.org/10.1145/2556288.2557359.
9. Derek Doran, Swapna Gokhale, and Aldo Dagnino. 2013. Human Sensing for Smart Cities. In *Proceedings of the 2013 IEEE/ACM International Conference on Advances in Social Networks Analysis and Mining*, 1323–1330.
10. Andy Dow, Rob Comber, and John Vines. 2019. Communities to the left of me, bureaucrats to the right…here I am, stuck in the middle. *Interactions* 26, 5: 26–33. https://doi.org/10.1145/3351735
11. Jennifer Evans-Cowley. 2011. Planning in the Real-Time City: The Future of Mobile Technology: *Journal of Planning Literature*. https://doi.org/10.1177/0885412210394100
12. Daniel Fallman and Erik Stolterman. 2010. Establishing criteria of rigour and relevance in interaction design research. *Digital Creativity* 21, 4: 265–272. https://doi.org/10.1080/14626268.2010.548869
13. Joel Fredericks, Martin Tomitsch, and M. Hank Haeusler. 2020. Redefining Community Engagement in Smart Cities: Design Patterns for a Smart Engagement Ecosystem. *Citizen-Responsive Urban E-Planning: Recent Developments and Critical Perspectives*, 13–53. https://doi.org/10.4018/978-1-7998-4018-3.ch002

14. William Gaver. 2012. What should we expect from research through design? In *Proceedings of the 2012 ACM annual conference on Human Factors in Computing Systems* (CHI '12), 937–946. https://doi.org/10.1145/2208516.2208538
15. William W. Gaver, Mark Blythe, Andy Boucher, Jarvis Nadine, John Bowers, and Peter Wright. 2010. The Prayer Companion: Openness and Specificity, Materiality and Spirituality. *Proceedings of the SIGCHI conference on Human factors in computing systems.*
16. Jan Gehl. 2010. *Byer for mennesker.* Bogværket.
17. Kavita Gonsalves, Marcus Foth, Glenda Caldwell, and Waldemar Jenek. 2020. Radical Placemaking: Immersive, Experiential and Activist Approaches for Marginalised Communities. In *Connections, Exploring Heritage, Architecture, Cities, Art Media.*
18. Joachim Halse, Eva Brandt, Brendon Clark, and Binder (eds.). 2010. *Rehearsing the Future.* Danish Design School Press, Copenhagen.
19. Alison Heppenstall and Nick Malleson. *How to make smart cities human again.* Retrieved February 18, 2020 from http://theconversation.com/how-to-make-smart-cities-human-again-88453
20. Serene Ho and Abbas Rajabifard. 2010. Learning from the crowd: the role of volunteered geographic information in realising a spatially enabled society. In *In GSDI 12 World Conference: Realising Spatially Enabled Societies.*
21. Tom Jenkins. 2018. Cohousing IoT: Design Prototyping for Community Life. In *Proceedings of the Twelfth International Conference on Tangible, Embedded, and Embodied Interaction* (TEI '18), 667–673. https://doi.org/10.1145/3173225.3173244
22. Tom Jenkins, Christopher A. Le Dantec, Carl DiSalvo, Thomas Lodato, and Mariam Asad. 2016. Object-Oriented Publics. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (CHI '16), 827–839. https://doi.org/10.1145/2858036.2858565
23. Stacey Kuznetsov, George Davis, Jian Cheung, and Eric Paulos. 2011. Ceci n'est pas une pipe bombe: authoring urban landscapes with air quality sensors. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '11), 2375–2384. https://doi.org/10.1145/1978942.1979290
24. Stacey Kuznetsov and Eric Paulos. 2010. Participatory Sensing in Public Spaces: Activating Urban Surfaces with Sensor Probes. In *Proceedings of the 8th ACM Conference on Designing Interactive Systems* (DIS '10), 21–30. https://doi.org/10.1145/1858171.1858175
25. Copenhagen Solutions Lab. *Hvem er vi?* Retrieved February 18, 2020 from https://cphsolutionslab.dk/what-we-do
26. Copenhagen Solutions Lab. Rykket til luftkvalitet: Air-View samarbejde om luftforurening. *Copenhagen Solutions Lab.* Retrieved April 15, 2020 from https://cphsolutionslab.dk/what-we-do/themes/climate-monitoring/air-view-samarbejde-om-luftforurening
27. Christopher A Le Dantec, Caroline Appleton, Mariam Asad, Robert Rosenberger, and Kari E Watkins. 2016. Advocating Through Data: Community Visibilities in Crowdsourced Cycling Data. In *Bicycle Justice and Urban Tranformation: Biking For All?*, Aaron Golub, Melody Hoffmann, Adonia Lugo and Gerardo Sandoval (eds.). Routledge.
28. Christopher A Le Dantec, Mariam Asad, Aditi Misra, and Kari E Watkins. 2015. Planning with Crowdsourced Data: Rhetoric and Representation in Transportation Planning. In *CSCW '15: Proceedings of the 18th ACM Conference on Computer Supported Cooperative Work & Social Computing*, 1717–1727.
29. Christopher A Le Dantec and Carl Francis DiSalvo. 2013. Infrastructuring and the Formation of Publics in Participatory Design. *Social Studies of Science* 43, 2: 241–264.
30. Monique Mann, Peta Mitchell, Marcus Foth, and Irina Anastasiu. 2020. #BlockSidewalk to Barcelona: Technological sovereignty and the social license to operate smart cities. *Journal of the Association for Information Science and Technology* 71, 9: 1103–1115. https://doi.org/10.1002/asi.24387
31. Saraju P. Mohanty, Uma Choppali, and Elias Kougianos. 2016. Everything you wanted to know about smart cities: The Internet of things is the backbone. *IEEE Consumer Electronics Magazine* 5, 3: 60–70. https://doi.org/10.1109/MCE.2016.2556879
32. Finn Palmgren, Danmark, and Danmarks Miljøundersøgelser. 2009. *Luftforurening med partikler: et sundhedsproblem.* Hovedland.
33. Rudy Provoost. 2013. Smart cities: innovation in energy will drive sustainable cities. *The Guardian.* Retrieved February 18, 2020 from https://www.theguardian.com/sustainable-business/smart-cities-innovation-energy-sustainable
34. Irving Seidman. 2005. *Interviewing as Qualitative Research: A Guide for Researchers in Education and the Social Sciences, 3rd Edition.* Teachers College Press, New York.
35. Phoebe Sengers, Kirsten Boehner, Shay David, and Joseph "Jofish" Kaye. 2005. Reflective design. In *Proceedings of the 4th decennial conference on Critical computing: between sense and sensibility* (CC '05), 49–58. https://doi.org/10.1145/1094562.1094569
36. Padmanand Warrier. Smart Cities Need H.E.A.R.T. *Forbes.* Retrieved February 18, 2020 from https://www.forbes.com/sites/forbestechcouncil/2018/04/13/smart-cities-need-h-e-a-r-t/
37. John Zimmerman and Jodi Forlizzi. 2014. Research Through Design in HCI. In *Ways of Knowing in HCI*, Judith S. Olson and Wendy A. Kellogg (eds.). Springer, New York, 167–190.
38. John Zimmerman, Erik Stolterman, and Jodi Forlizzi. 2010. An Analysis and Critique of Research Through Design: Towards a Formalization of a Research Approach. In *Proceedings of the 8th ACM Conference on Designing Interactive Systems* (DIS '10), 310–319. https://doi.org/10.1145/1858171.1858228
39. Smart city technology for a more liveable future | McKinsey. Retrieved April 28, 2020 from https://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/smart-cities-digital-solutions-for-a-more-livable-future
40. About. *BreatheLife2030.* Retrieved April 15, 2020 from https://breathelife2030.org/about/
41. *Smart City.* Retrieved February 18, 2020 from https://urbandevelopmentcph.kk.dk/indhold/smart-city
42. Creative city, smart city ... whose city is it? Retrieved February 18, 2020 from https://theconversation.com/creative-city-smart-city-whose-city-is-it-78258
43. Making cities smarter: Better decision making with collective intelligence | Deloitte Insights. Retrieved February 18, 2020 from https://www2.deloitte.com/us/en/insights/deloitte-review/issue-20/people-for-smarter-cities-collective-intelligence-decision-making.html
44. Smart city overview | Deloitte Insights. Retrieved February 18, 2020 from https://www2.deloitte.com/us/en/insights/focus/smart-city/overview.html
45. WHO | Ambient air pollution: Pollutants. *WHO.* Retrieved February 18, 2020 from http://www.who.int/airpollution/ambient/pollutants/en/
46. The Issue. *BreatheLife2030.* Retrieved February 18, 2020 from https://breathelife2030.org/the-issue/
47. Smart Citizen empowers communities to better understand their environment. Retrieved October 12, 2020 from https://smartcitizen.me/
48. *Luft på din vej.* Retrieved February 18, 2020 from http://lpdv-en.spatialsuite.dk/spatialmap?
49. *Luftmålestationer: København.* Retrieved February 18, 2020 from https://envs.au.dk/faglige-omraader/luftforurening-udledninger-og-effekter/overvaagningsprogrammet/maalestationer/maalingerpaastationerne/koebenhavn/
50. The Discovery of Grounded Theory: Strategies for Qualitative Research - Barney G. Glaser, Anselm L. Strauss - Google Books. Retrieved October 12, 2020 from https://books.google.dk/books/about/The_Discovery_of_Grounded_Theory.html?id=oUxEAQAAIAAJ&redir_esc=y