Device Studies of Participatory Sensing: Ontological Politics and Design Interventions

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Declaration

I, Christian Nold confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

Abstract

This study investigates how ubiquitous sensing technologies are being used to engage the public in environmental monitoring. The academic literature and mainstream media claim participatory sensing is contributing to science, improving the environment and creating new forms of democratic citizenship. Yet there have been few studies that examine its material practices and impacts. This study addresses this gap via three ethnographic 'device studies' and an experimental design intervention. The methodology is based on post actor-network theory with a material-semiotic focus on the notion of the 'device' (Law & Ruppert 2013), in order to follow the sensing objects over their lifetime from design, usage with participants and later outputs. The design intervention uses the notion of the device as a research method to materially intervene in one of the study sites as a public controversy. The findings show that despite claims in the literature to be an empirical knowledge practice, the subjects and objects of participatory sensing are continually shifting and blurring. Instead, participatory sensing involves a 'stringing together' of hardware, participants and rhetorics to form new ontological entities and create publicity. However, this creates conflicts with actors for whom environmental pollution is a health concern, who want to organise collectively and want to engage with decision-making. Yet these studies have shown that it is possible to reconfigure sensing devices with situated ontologies. This led to the building of experimental design prototypes that show that participatory sensing can support pluralistic ontologies and build new connections towards decision-making. The contribution of this study is to identify the ontological politics (Mol 1999) of participatory sensing and demonstrate a 'device study' method that combines ethnography with material design to intervene and transform public controversies.

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Abbreviations and Units

ANASE - Attitudes to noise from aviation sources study (Le Masurier et al. 2007)

ANT - Actor-network theory

APD - AirPin Difference - supposed gap between human perception and objective reality

APIC - AirProbe International Challenge

AQE - Air Quality Egg

BAA - British Airport Authorities (now Heathrow Airport Holdings Limited)

CO - Carbon monoxide

dB - Decibel unit of sound pressure (informal usage)

dB(a) - A-weighted decibel unit of sound pressure

dB(z) - Unweighted decibel unit of sound pressure

DIY - Do it yourself

EU - European Union

HACAN - Heathrow association for the control of aircraft noise

iOS - iPhone operating system

IOT - Internet of things

LCD - Liquid crystal display

LED - Light emitting diode

LAeq - Sound pressure dB(a) equivalent to the total energy over a period of time

NGO - Non-governmental organisation

NO_2 - Nitrogen dioxide

NO_x - Generic term for nitrogen oxides

Ohm - Unit of electrical resistance

O_3 - Ozone

PM2.5 - Particulate matter 2.5 micrometers in diameter

PM10 - Particulate matter 10 micrometers in diameter

R^2 - Coefficient of determination - correlation between two data sets

RBWM - Royal borough of Windsor and Maidenhead (Council)

SCK - Smart Citizen Kit

Spime - Sound and time object

STS - Science and technology studies

UCL - University College London

UK - United Kingdom

$\mu g/m^3$ - Concentration in micrograms per cubic meter of air

VOC - Volatile organic compounds

Explanation of key terms

Device

The study uses the notion of the device from Law & Ruppert (2013) to refer to the expansive nature of physical entities to describe the extended and unbounded qualities of devices that include networks of supporters, agendas and impacts. The concept is discussed in depth within the methodology chapter (section 3.1).

Ontological politics

The term refers to tensions and conflicts around which of many realities are made 'real' and which ones are marginalised or prohibited. The concept is based on Annemarie Mol's notion of multiple ontologies (Mol 2002) and discussed in depth within the literature review chapter (subsubsection 2.1.4.2).

Chapter 1

Introduction

> *"In the next century, planet earth will don an electronic skin. It will use the Internet as a scaffold to support and transmit its sensations. This skin is already being stitched together. It consists of millions of embedded electronic pollution detectors, cameras, microphones, glucose sensors, EKGs, electroencephalographs. These will probe and monitor cities and endangered species, the atmosphere, our ships, highways and fleets of trucks, our conversations, our bodies – even our dreams [...] What will the earth's new skin permit us to feel? How will we use its surges of sensation?"* (Gross 1999, para.2)

Both academic research and mainstream media (like the text above) are full of narratives proclaiming the spread of tiny sensor technologies will fundamentally transform the planet and people's relationship with the environment. Computers are no longer just labour-saving devices but have in the last decades become the ubiquitous centres of people's lives (Weiser 1991). It has been argued that the rise and penetration of the smartphone as *"imager-microphone-wireless-sensor packages that we all carry on our belts"* (Estrin 2007, p.3) has led to the advent of participatory sensing, which uses the phone as a *"networked mobile personal measurement instrument"* (Paulos et al. 2009, p.414). The dispersion of hardware amongst the public claims to offer the potential for cheap crowdsourced data collection and placed a massive focus on trying to motivate people to volunteer their time and hardware to identify species (Courter et al. 2012), fold proteins (Foldit 2014) or classify galaxies (Galaxy Zoo 2007). Participatory sensing offers to make people's 'dead time' productive. So waiting at the bus stop becomes an opportunity for gathering data on environmental pollutants to be fed into an 'city operation system' (Koetsier 2012) as part of 'smart cities' (Batty 2012) and an 'internet of things' (Ashton 2009). Participatory sensing and citizen science make a broad range of claims to contribute to science, improve the environment and create new forms of democratic citizenship.

This study is one of few to examine the material practices and impacts of participatory sensing. Throughout I use the term 'participatory sensing' to encompass a range of narratives, practices and devices that do not necessarily define themselves with this phrase, yet share the key characteristic of engaging publics into using sensing devices. The reason I use this phrase is that the combination of the words 'participatory' and 'sensing' embody tensions and possibilities of this practice. The word 'participation' suggests the need for involvement, yet leaves the nature and composition of the participants undefined. This is in contrast to other related terms such as 'citizen sensing' that formally identify the participants as 'citizens', with all the implications this term brings. Furthermore, the phrase 'sensing' has a dual aspect of technical measurement as well as interpretative 'sensemaking'. Other related terms such as 'citizen science' frame this activity as having a 'scientific' goal, which is not always the case (subsection 2.3.3). I suggest the term 'participatory sensing' is an open-ended concept that holds the potential for thinking about this practice as both technical and interpretative, and involving a multitude of participating entities.

Who is supporting participatory sensing?

Research bodies at an international and national level as well as local government, commercial enterprises and civil society groups are all supporting participatory sensing. The EU has funded a wide range of academic and industrial research into participatory sensing with a focus on open science and the potential to engage new audiences in research[1]. The commercial interest in participatory sensing is indicated by the internet of things and smart cities that companies such as Cisco (Evans 2011, Helmy 2014) and IBM (IBM 2009) are heavily investing into. There are also many activist and hobbyist networks (Safecast 2011) using participatory sensing to carry out environmental monitoring.

[1]EU funded participatory sensing projects: Making Sense (Making-sense 2016), CITI-SENSE (Citi-sense 2012), WeSenseIt (WeSenseIt 2017), CobWeb (COBWEB 2017), Citclops (Citclops 2015), Omniscientis (Omniscientis 2014), Mapping and the citizen sensor (Mapping & the citizen sensor 2016) and EveryAware (EveryAware 2011*a*).

Why is participatory sensing worth studying?

The field of participatory sensing revolves around three narratives. The first is a narrative of 'contributory science' (subsection 2.3.1) used by scientists and engineers to argue it creates better science since data can be acquired at lower cost and in greater quantity (Silvertown 2009). The second narrative of 'democratising science' (subsection 2.3.2) is used to argue it can improve public inclusion, empowerment and environmental management by connecting citizens to policy makers (Irwin 1995). The third narrative of 'autonomous networks' (subsection 2.3.3) is used by the maker community and entrepreneurs to argue participatory sensing is creating decentralised networks that reorganise the way cities and environments operate. What all three narratives have in common is that they suggest participatory sensing represents a significant step change in the way science operates, the environment is managed and the public relate to governance structures. This means participatory sensing is potentially an important and novel arrangement of computing, people and environment that has the potential to create new kinds of environmental practices that need to be analysed.

The contribution of this study

As the literature review (section 2.3) shows, despite the extensive claims made for participatory sensing, surprisingly little is known about the material practices and impacts of this approach. This study shows that participatory sensing involves dramatic ontological shifts concerning what is being sensed and what is doing the sensing that are not accounted for in the literature that I call an **insight gap** (section 9.2). The second issue is a theoretical and methodological gap in how to study the practices of devices and intervene and change them that I call a **methodological gap** (section 9.1). The result of these two gaps is that much of the discourse around participatory sensing is not based on empirical observations and there are few suitable methods for being able to transform this practice. The contribution of this study is to address these gaps through long-term ethnographic studies of four participatory sensing devices from design, usage and eventual outputs. These device studies span across academic research and commercial/maker culture and provide an insight into the material practices of participatory sensing and political impacts of the devices. This study shows how these findings can be applied via an ontological design intervention using prototypes that are built to address the infrastructure of a specific local issue of concern and demonstrate methodological innovation.

1.1 Thesis Structure

Figure 1.1 presents the chapter structure of this study. The literature review chapter (chapter 2) covers how technology relations have been envisaged across three different corpora. It covers theories within science and technology studies and focuses on post actor-network theory approaches. The second review examines human computer interaction from a design perspective and a shift beyond the user. The subject review analyses participatory sensing and categorises it into three major narratives. The methodology chapter (chapter 3) outlines the overall research design and questions as well as data collection and analysis methods. This is followed by three empirical device studies that form the core of this study, Air Quality Egg and Smart Citizen Kit (chapter 4), AirProbe (chapter 5), WideNoise (chapter 6). The three device studies address the central research question of 'what is being sensed and what is doing the sensing'. Chapter 7, 'How do power and politics take place within participatory sensing?', carries out a horizontal analysis across the empirical studies to identify patterns, highlight the ontological politics taking place and identify potential for an alternative approach. Chapter 8, 'What can ontological design offer participatory sensing?', is an empirical chapter that implements the previous findings by returning to Heathrow airport with new sensing prototypes built using an ontological design approach. The prototypes open up the ontological infrastructure of the controversy of noise at Heathrow and demonstrate an alternative approach to participatory sensing. Chapter 9, 'How does participatory sensing construct sensation and the environment?', is the second analysis chapter that addresses the potential of participatory sensing in the light of the Heathrow prototyping study and engages with the two gaps in knowledge. The final conclusion (chapter 10) summarises the overall findings of the study.

Figure 1.1: Diagram of the thesis structure showing the chapter structure. The three empirical device studies are highlighted in shades of orange. The Heathrow prototyping chapter is highlighted in purple.

Chapter 2

Literature review

This literature review comprises a theoretical and methodological review covering the corpora of science and technology studies and design, as well as the subject literature of participatory sensing. The guiding thread for choosing relevant literature is to understand the relationship between people, technology and environment. The focus is both on how this can be theorised but also how it can be transformed and intervened in. The first section involves a review of the different approaches to theorising scientific and technological practices (section 2.1) focusing particularly on actor-network theory, which describes how humans and nonhumans can both be political actors. This theoretical discussion is detailed and explanatory since some of the readers from participatory sensing may not be familiar with this approach. The second part describes the way technology design has shifted towards participatory and experimental approaches that materially intervene via design (section 2.2). It also outlines how STS and design are converging to offer an ontological approach for intervening in controversies. The final section of the review engages with the subject literature of participatory sensing to identify three different narratives across the literature (section 2.3).

2.1 Science and technology studies

Science and Technology Studies (STS) emerged in the 1970s as a broad interdisciplinary field that tried to understand the achievements and problems of science and technology by studying the actions, beliefs and practices of scientists and engineers as actors in the world. The role of STS became the study of science, in particular how scientific knowledge and technological artefacts are *constructed*. Yet this notion of construction is contested in the literature and there are a broadly three positions: 'social constructivism' sees the human as directing technology, 'technological determinism' imagines technology as an autonomous force and a final position of 'actor-network theory' (ANT), which treats them as mutually constitutive. This review maps out the literature of STS to explore these notions of construction to see how they articulate human and technological causality and generate political and ethnographic approaches. The goal of the review is to establish the theoretical foundations of the study and make the literature usable within the empirical and analysis chapters.

Social constructivism

The social constructivist position within STS acknowledges the importance of technology in transforming relationships between people and environment, but argues there is a human 'social' that is responsible for controlling scientific and technological progress. This approach involved researchers observing scientists to analyse them as social communities and explore how their work is entangled with social issues such as gender, class and race. This position appears in the area of the sociology of scientific knowledge in the work of Collins (1974, 1998) and his studies in laboratories. Collins focuses on the effect of scientific reputation, organisational styles and evidential laboratory cultures and describes how they affect scientific research. Collins' approach highlights the human aspects of science as 'tacit knowledge', which is embodied knowledge that cannot be easily communicated (Collins 1974). MacKenzie & Spinardi (1995), from the area of social shaping of technology, use this notion to rethink nuclear weapons in terms of the tacit knowledge of the engineers who built the bombs. They argue once these nuclear engineers die of old age, the tacit knowledge required to build the weapons might also disappear with them, thus leading to the 'un-invention' of nuclear weapons. Technology is thus seen merely as an extension of human agency and something that is socially controllable. This approach is used to retell the development of the bicycle not as progress towards an optimum technology but as a series of social choices (Pinch & Bijker 1984). The study argues 'relevant social groups' have 'interpretive flexibility' (Meyer & Schulz-Schaeffer 2006) to create completely different understandings of the same object. So one engineer sees the pneumatic tire as reducing vibration while another sees it as introducing new dangers. This approach tries to show how different human agendas shape the development of a technology and that the final artefact is only one of the many possible technologies. Pinch & Bijker (1984) highlight the way advertising is important for creating 'closure and stabilisation' of a technology to turn into a finished technology. A criticism made of this approach is that it does not account for power asymmetries amongst the actors and that it stays within the history of the object itself and does not engage with wider structural power relations (Klein & Kleinman 2002). More broadly, social constructivism has been accused of trying to debunk science to unveil a social reality beneath the artefact (Latour 2010). The unfortunate effect of this approach is that technology itself disappears as it becomes *"conceptualized as a mere 'projection screen' in which the social is reflected, and upon which social struggles are played out"* (Berg 1998, p.466).

Technological determinism

The technological determinist position is diametrically opposed to social constructivism since it sees technology as autonomous and without social or cultural forces to steer it. While there is an academic lineage to this position from economics (Ayres 1952) and sociology (Ellul 1964), most contemporary versions of this narrative appear in grey literature and mainstream media, especially computing related texts (Vinge 1993, Kurzweil 2005). Technology is seen as creating utopias or dystopias: Ellul (1980) sees technology as tyrannising humanity and the natural world while Mumford (1971) suggests 'polytechnics' is life-orientated. Winner (1980) argues technical artefacts materially structure society and are inherently political. He presents one of the famous exemplars, of bridges that are deliberately built too low for public buses in order to stop certain classes of people from having access. Contemporary accounts of technological determinism Vinge (1993), Kurzweil (2005) and Kelly (2010) focus on computing and artificial intelligence as autonomous with its own momentum and politically neutral and leading to a situation where technology will transcend humans and lead to a technological singularity. When applied culturally, these ideas are termed transhumanism and become arguments about future changes to reproduction, liberty and morality (Agar 2007). Many of these visions point to notions of feedback systems from 1970s cybernetics that are merged with capitalist mass production. A popular example of this is the idea of Moore's law (Moore 1965), which proposes computer processing speed and memory capacity will exponentially expand for ever. However, critics such as Barbrook & Cameron (1995) argue that the technological determinist position is simply a crude form of free-market libertarianism that rhetorically combines *"market economics and the freedoms of hippie artisanship"* (para.12). Other critics have described technological determinism as caricatures that treat human and technology as *"separate, fixed categories, with fixed properties"* (Berg 1998, p.464). Others have suggested that the classic exemplars of technological determinism such as Winner's bridges are actually impossible to confirm (Woolgar & Cooper 1999). The authors demonstrate that the bridge example is not an empirical study, but functions more like an urban storytelling legend that has become an academic exemplar for the power of technology. These critiques suggest that like social constructivism, technological determinism does not lend itself towards creating detailed ethnographic accounts of technological practices.

Actor-network theory

Actor-network Theory (ANT) is a subset of STS that tries to create reflexive co-constructive descriptions of the complex relationship between technology and humans. It is not a theory that offers an overarching explanatory framework (Mol 2010) but a 'toolkit' for analysing the world (Law 2004*a*). Ethnographic ANT accounts (Latour 1996*a*, Mol 2002, Law 2002) are characterised by highly granular empirical observations that are interwoven with theoretical arguments. ANT appeared in the 1980s and was particularly associated with Callon (1986), Latour (1987) and Law (1999). Over last 30 years it has also spawned a variety of 'post-ANT' approaches that add flexibility and subtlety to ANT (subsection 2.1.4). Since this approach is the main theoretical framework of the study, the review explores the unique way in which ANT relates towards the agency of technology and politics as well as controversies about this approach.

Many of the early ANT studies were ethnographic studies of scientific work in laboratories (Latour & Woolgar 1979), shellfish and researchers (Callon 1986), hormones and laboratories (Latour 1987), and microbes and public hygiene (Latour 1993*b*). Where they depart from the social constructivist laboratory studies is that they do not treat science and technology as fundamentally 'social' but as socio-material co-constructions. Akrich (1992) argues, *"technological determinism pays no attention to what is brought together, and ultimately replaced, by the structural effects of a network. By contrast social constructivism denies the obduracy of objects and assumes that only people can have the status of actors"* (p.206). ANT thus rejects both technological determinism and social constructivism for the way they are premised on a clear separation between people and technology that provides no detail of their interactions. Instead, the ANT approach focuses on the world as constructed through both human and nonhuman actors (often interchangeably called actants). While the notion of the 'actor' is common within sociology, the designation of nonhuman actors is one of the unique aspects of early ANT research. Within ANT an actor is *"any element which bends space around itself, makes other elements dependent upon itself and translates their will into a language of its own"* (Callon & Latour 1981, p.286). Human and nonhuman actors form conjoined 'actor-networks' as a kind of 'social' (Latour 2005*a*). This approach is controversial, since it frames sociology not as the study of people but of a social consisting of both humans and nonhumans that together perform what we think of as society.

Most of the early criticism of ANT focuses on the perception that it does not provide any space for human agency (Collins & Yearly 1992, Jones 1996, Forbes-Pitt 2011). But according to Law & Singleton (2013), this is a misunderstanding; *"an ANT sensibility isn't saying that people (or salmon or technologies) don't exist. Obviously they do. But it's interested in exploring how they get put together in practices—and how they get distinguished from one another"* (p.491). The point of ANT is to act as a methodological toolkit for decentering humanist accounts of the world to create unusual and experimental narratives of scientific and technical processes but not to eliminate the human. ANT does not use classic sociological concepts such as society, class or gender but analyses how these notions are enacted via a variety of humans and nonhumans. Callon & Latour (1981) argue there is no *a priori* difference between a macro actor like society and micro actors such as an individual body, since all actors are themselves constructed of other actors in a recursive fashion. The only way to identify an actor is through the way it manages to transform the world (Latour 1996*b*). This means a whole range of surprising things can be actors, such as car seat-belts that change people's behaviour and stop them from flying through a car windscreen (Latour 1992). In a famous example, Latour describes a hotel key fob as an actor that due to its bulky physical form and weight changes the way guests behave:

> *"Customers no longer leave their room keys: instead they get rid of an unwieldy object that deforms their pockets. If they conform to the manager's wishes, it is not because they read the sign, not because they are particularly well-mannered. It is because they cannot do otherwise. They don't even think about it"* (Latour 1991, p.105).

Latour's description is typical of the way ANT focuses on the minutiae of socio-technical situations to identify surprising actors and describe how they change the world. The point of this approach is to create unfamiliar accounts that unlock new ways of understanding and intervening in situations. Cupples (2009), for example, used an ANT approach to engage with air pollution as an actor:

> *"If particulate matter is understood not as a pre-given entity which can be measured, ordered and categorised, but as an actor in a network which enrols, interacts with and relates to other actors in the network, its semiotic, material and agentic properties become more visible"* (p.212).

The methodology of ANT

ANT's main focus is on the primacy and power of ethnographic accounts with Law (2008) arguing that its goal is telling stories *"about 'how' relations assemble or don't. As a form, one of several, of material semiotics, it is better understood as a toolkit for telling interesting stories about, and interfering in, those relations. More profoundly, it is a sensibility to the messy practices of relationality and materiality of the world"* (pp.141–142). The intension is that ANT accounts provide new insights into scientific and technical processes and become more powerful than reductionist accounts. Yet ANT does not include any prescriptive methodologies of how to do ANT, only approaches and loose dictums such as *'follow the actors'* (Latour 2005*a*) or *"detect how many participants are gathered in a thing to make it exist and to maintain its existence"* (Latour 2004*c*, p.246). Rather than a theory or methodology, ANT aims at an ethnographic sensibility towards device relations that are supposed to surprise the ethnographer by allowing the world to 'bite back' (Law & Singleton 2013) and *"open up the possibility of seeing, hearing, sensing and then analysing the social life of things – and thus of caring about, rather than neglecting them"* (Mol 2010, p.255). ANT uses sensitising notions such as ‘symmetrical accounts’ (Bloor 1976) that are intended to create an equality between human and nonhuman actors where *“the observer must abandon all a priori distinctions between natural and social events. He must reject the hypothesis of a definite boundary which separates the two”* (Callon 1986, p.199). Many of the early ANT accounts talk about human/object relationships in controlling terms, such as ‘scripts’ and ‘delegating’ of moral imperatives into material form (Akrich 1992). In this vision, the designer scripts the everyday patterns by which humans and machines interact with each other, as in the seatbelt and key fob examples. Yet many of the later ANT accounts create much less linear and strident accounts of the interactions with devices. ANT offers a rich lexicon of terms and concepts that have been used to decide the different hybrid blends between nature and society, such as quasi-objects (Latour 1993*a*), immutable mobiles (Latour 1990), fire objects (Law & Singleton 2005) and fluid technology (de Laet & Mol 2000). This study adopts the sensitising concept of the ‘device’ (Law & Ruppert 2013) as ‘patterned teleological arrangements’, where the device is seen as a purposeful arrangement that has its own ‘teleology’, meaning ‘goal’. There is more detail on how this concept is applied in the methodology chapter (section 3.1).

Critics of ANT have suggested that the choice of selecting and following some actors is arbitrary, since *“who decides who the actors are? It’s fine to tell us that we should believe them when they speak to us, that we should refrain from judging them, but we have to know who to speak to in the first instance, which meeting to attend, who to call on the telephone, who to e-mail, and who to ask for an interview!”* (Miller 1997, p.363). Mclean & Hassard (2004) similarly argue since it is impossible for the researcher to follow actors everywhere, they have to make subjective choices about which actors are relevant and carry out a *“practice of ordering, sorting and selection”* (p.500). The ANT ethnographers Law & Singleton (2013) suggest it is the specificity of the case study that directs the researcher towards certain actors. The ethnographer is an active component of the research, who has to make personal choices that are performative and *“license particular ways of seeing or frameworks, whilst rendering other[s] less visible and less sustainable”* (p.500). The ANT ethnographer does not claim to be an impartial observer but engaged with their site and has to make choices. Therefore the research becomes a way of intervening in the process being studied, *“working in and working on the world”* (p.487). Law & Ruppert (2013) suggest carrying out a device study is not merely a description of a device but becomes a way of interfering with it and ultimately changing it.

Power as understood in ANT

ANT does not take concepts such as human agency as a given but tries to find other metaphors (Sayes 2014). The key guide is the notion of action and acting. Law & Singleton (2013), for example, ask; what kind of power does electricity possess? They argue it is a power to act and transform the world, which functions as a good analogy for the ANT notion of power. ANT thus tries to create detailed descriptions of the minutiae of power as the way things influence each other, *"there might exist many metaphysical shades between full causality and sheer inexistence [...] Things might authorize, allow, afford, encourage, permit, suggest, influence, block, render possible, forbid, and so on"* (Latour 2005*a*, p.72).

In an early ANT text, Latour (1986) compares two different conceptions of power. The first is a 'diffusion model', often used within the natural sciences, where entities are said to have a kind of intrinsic inertia that requires the researcher to explain why these entities ever slow down. Latour describes an alternative model he calls the 'translation model' that he explains via the analogy of a rugby game. While the game is focused on the ball, the ball itself has no intrinsic power and would simply drop to the ground if there were not an unbroken chain of players that keep it moving amongst each other. Power is thus not something intrinsic to the ball but to the distributed action of all the actors combining to keep the ball moving and make the game happen. Latour suggests the token (ball) is not merely passed on but also changed by each one of the participants; *"each of these people may act in many different ways, letting the token drop, or modifying it, or deflecting it, or betraying it, or adding to it or appropriating it"* (p.267). ANT sees power as a kind of game that relies on the cooperation of human and nonhuman participants. Power is thus not something that any single actor 'has', but is a consequence that is 'performed' through collective dynamics:

> *"'Power' is always the illusion people get when they are obeyed; thinking in terms of the diffusion model, they imagined that others behave because of the masters' clout without ever suspecting the many different reasons others have for obeying and doing something else; more exactly, people who are 'obeyed' discover what their power really is made of when they start to lose it. They realise, but too late, that it was 'made of' the wills of all the others"* (Latour 1986, pp.268–269)

Power thus involves building and maintaining collective associations through processes of 'enrolment', where individual actors try to encourage other entities to form networks. Callon (1986) describes enrolment as happening through processes of 'interessement', where allies are gathered and their agendas 'translated' to align with one's own way of doing things. In a case study of scientists studying fish stocks, Callon shows how a process of enrolment allowed the scientist to speak on behalf of shellfish (Pecten Maximus), fishermen and other specialists (Figure 2.1).

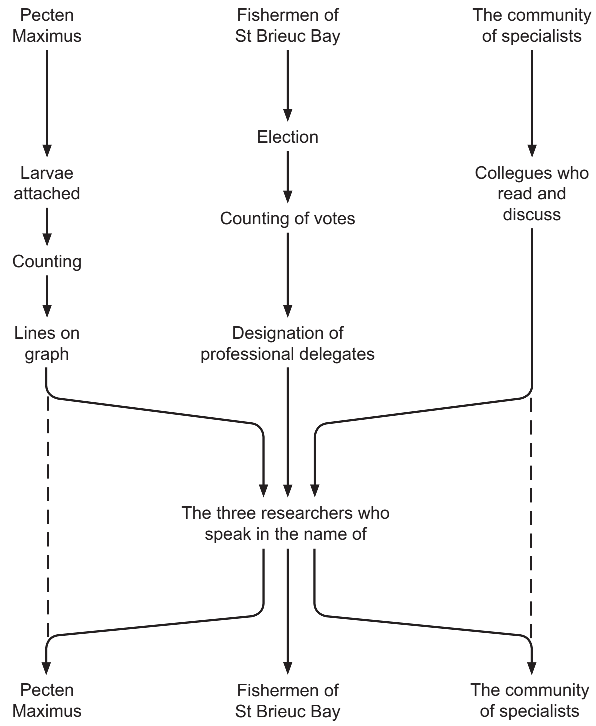

Figure 2.1: Diagram after Callon (1986) showing the translation of interests that allow the researchers to speak on behalf of shellfish (Pecten Maximus), fishermen and specialists.

For the researchers to carry out their scientific work, they had to 'convince' the shellfish to enter the traps and enrol the fishermen into their project and get their colleagues to read their paper. Callon describes this as translating the interests of these entities into accepting the scientists as legitimate spokespeople. If any of theses entities, such as the shellfish, had refused to enter the traps, or the fishermen rejected the authority of the scientists, the whole of the research project would have broken down. Translation involves building and maintaining the collective relations but has a Machiavellian quality of redirecting interests. Power thus takes place through tangible devices that Callon calls *'devices of interessement'* such as the fish traps and academic publications. For these networks to last they need to be ‘stabilised’ and become ‘blackboxed’ (Latour 1987) to begin to look like a single actor. ANT accounts focus on describing the way these processes of enrolment, translation and blackboxing take place to show *“how things like power get done”* (Law & Singleton 2013, p.496). In contrast, there are fewer case studies looking at ‘domination’ (diffusion) -type relationships. In situations such as the occupation of Palestine, ANT case studies focus on the role of nonhumans such as water (Gasteyer et al. 2012) or electricity (Shamir 2013) where *“the purpose here is to explore how electrification ‘makes politics’ rather than merely transmits it—how electrification participates in the formation of distinct ethno-national groups rather than simply reflecting it”* (Shamir 2013, p.5).

Due to ANT’s unusual way of conceptualising power dynamics, there are disagreements about how useful this is, and to what extent it allows actors to create meaningful political analysis, and offer potential for change. Miller (1997) suggests ANT accounts distribute responsibility across the actor-network, making these accounts into a *“a murder story with no murderer!”* (p.361). Miller is frustrated because *“surely there has to be a guilty party at some point, someone on whom to pin the blame, even if only collectively?”* (p.360). Indeed ANT is not very practical for institutional blame games since it does not accept actors as isolated individuals. More broadly, there is a conflict with classic categories of political theory, since *“Actor-Network Theory offers no path back into social analysis, into questions of domination, exclusion, resistance and transformation – the stuff of politics – once its work of mapping is done”* (Sterne & Leach 2005, p.192). Fuller (2000) argues this diffusion of responsibility provides metaphysical justification for capitalism to *“keep the elites in constant circulation, thereby reinforcing the appearance of justice in the system”* (p.15). ANT merely has the appearance of radicalism but actually disempowers any collective campaigning for change. For Fuller, the notion of a translation model where power is in the formation of networks makes it hard to know where to attack, *“what, on a sympathetic reading, may appear to be an amorphous network of highly contingent nodes may be portrayed, less sympathetically, as an all-pervasive system whose general structure cannot be purposefully altered by some strategic intervention, let alone a social movement”* (p.26). Fuller is right to suggest that the ANT model of power is very different from classic social movements. Within ANT, political change is based around a pragmatist approach to controversies that might spark material publics into being (subsubsection 2.1.4.1).

Post-ANT

It has been more than 30 years since the early concepts of ANT were outlined and there is a perception amongst researchers that some of its concepts of 'networks' and 'the social' have been misinterpreted (Gad & Jensen 2010). With today's ubiquitous language of computer networks, the ANT notion of the network is easily misunderstood as a mechanical entity, despite Latour's insistence to the contrary (Latour 2004*b*). Thus there has been a shift towards a loose range of approaches labeled 'post-ANT' (Gad & Jensen 2010) or 'after-ANT' (Johansson & Metzger 2016) that extend the approach of decentering the human as the 'more-than-human' (Whatmore 2002) and as 'new materialism' (Coole & Frost 2010). These approaches build on the foundations of ANT but provide a focus on vitalism and the liveliness of matter (Barad 1998), the politics of materiality (Braun & Whatmore 2010) and ability of nonhuman entities to surprise (Bennet 2010). These approaches are important for this study since they move beyond the crude and reductive ways that classic ANT has engaged with technical devices as 'scripts' (Akrich 1992). In the post-ANT case study of the 'Zimbabwe Bush Pump' (de Laet & Mol 2000), a water pump becomes a device that has fluid boundaries that include the village communities and even national identity. This study counters the narrative of a mastermind designer that can script relations and instead highlights a distributed pattern of configuration and care by a range of entities that are all supporting and constructing the device. An important aspect of post-ANT has been the way it has engaged with anti-Cartesian philosophers such as de Spinoza (1677), Whitehead (1929) and Deleuze & Guattari (1980) to rethink the mind/matter division. A key notion is what the philosopher Whitehead called the 'bifurcation of nature' (Whitehead 1920, pp.30–31), that splits the world into two incompatible systems of reality. Latour describes it as follows:

> *"Bifurcation is what happens whenever we think the world is divided into two sets of things: one which is composed of the fundamental constituents of the universe—invisible to the eyes, known to science, real and yet valueless—and the other which is constituted of what the mind has to add to the basic building blocks of the world in order to make sense of them"* (Latour 2005*b*, p.3).

Latour and Stengers argue that bifurcation fractures nature and creates a hierarchy between objective scientific measurement of atoms, which is treated as primary, while subjective human perception is treated as secondary. Stengers illustrates this using the analogy of watching a sunset:

> *"An experience whose existential import should not be defaced, but also should not be permitted to deface the import of electro-magnetic waves. Awareness is not to be endowed with the power to evaluate and judge perception, or the knowledge that is associated with perception. Nature, as what we are aware of in perception, is a concept, the answer created to the cry 'in the same boat!"'* (Stengers 2014, p.205).

Stengers suggests that a sunset is not totally encompassed by objectively measuring its electro-magnetic radiation or by its perceived beauty; instead the technical data and experience are together 'in the same boat'. Latour and Stengers argue that since the majority of the natural sciences adopt bifurcations, science can only create incoherent accounts of the world (Latour 2004*a*). Thus the role of the post-ANT researcher is to find methods for countering these bifurcations in order to try and 'compose a common world' (Latour 2014).

Post-ANT politics

To understand the politics of post-ANT requires a historical overview of how STS relates to institutional politics and policy-making. Thoreau & Delvenne (2012) argue that early STS in the 1970s was focused on demonstrating the possibility of social change by opposing technological determinism. Later, this shifted towards the kind of science studies analysed in this review. With these detailed insights about the processes of science, the question emerged whether STS should become 'serviceable STS' (Webster 2007) and directly support institutional policy-making on science and technology matters. In contrast, researchers such as Nowotny (2007) argued that such closeness to policy would destroy the specificity of STS and its complex relationship to politics. These questions were never resolved but have meant that there are a range of different STS approaches towards politics as *"expertise, institutional participation, the inclusion of non-human others and the importance of marginalized experiences"* (Papadopoulos 2011, p.177). Post-ANT research is not attempting to 'sit in the policy room' to improve institutional participation but instead its politics is focused on the inclusion of nonhumans. Latour (2007) provides a similar taxonomy of politics that he divides into five modes (Figure 2.2).

In Latour's classification, the post-ANT approach relates to Political–1 and 2, with its focus on the formation of new associations with nonhumans and the creation of material

Meanings of 'political'	What is at stake in each meaning	Examples of movements that detect it
Political-1	New associations and cosmograms	STS
Political-2	Public and its problems	Dewey, pragmatism
Political-3	Sovereignty	Schmitt
Political-4	Deliberative assemblies	Habermas
Political-5	Governmentality	Foucault, feminism

Figure 2.2: Table after Latour (2007) describing five different meanings of politics.

politics and publics. The material politics approach is focused on the way material can become political and redefine the contours of political assemblies (Braun & Whatmore 2010). The geographer Andrew Barry describes a case study of an oil pipeline where the cracks in the metal coating became a political event that allowed the NGO to argue that the cracks were *"a manifestation of the wider forms of complicity between corporate business and government"* (Barry 2010, p.102). Barry suggests there is a distinction between the 'public politics' of the NGO talking about corrupt corporations and a 'material politics' that is based within the specific properties of the metal coating. Barry argues that it is only in specific circumstances that material can make the transition to public politics. In this case, the government did not accept that the failure of the coating was an index of a wider political failure, so the politics of the pipeline served only to build political collectives but did not translate to institutional politics. Essentially, a post-ANT politics focuses on the way material becomes the basis of public controversies *"to be in or out of politics is not a matter of the opinions that are aired, but depends on whether an actor is involved in a praxis that aims at a political object, or not"* (de Vries 2007, p.798). Thus devices and material can act politically without having to 'speak' directly to politicians. Hawkins (2009) suggests that the liveliness of material can act as a space for contested politics. She describes a study where plastic bags were institutionally deployed for *"shaping an environmentally aware subject"* (p.48). Yet staged differently, the plastic bag has the potential for *creative possibilities [that] disrupt the circuits of guilt and conscience that drive moral responses"* (p.51). Gabrys (2014*a*) emphasises the potential for 'diverging materialities' that allow a multiplicity of practices and politics to become possible. She shows that while energy meters can be use to push people into individualised energy consumption practices, artists have also managed to transform energy usage into a collective critical urban spectacle. Whatmore (2011) similarly calls for methods and devices that are intended to amplify '(inter)corporeality', 'response-ability' and the co-production of knowledge. The more-than-human literature (Adey 2015, Nieuwenhuis 2015, Feigenbaum & Kanngieser 2015) is full of attempts to create new kinds of narratives of supposedly inert entities, *"how an element like air could structure certain sets of feelings, impulses, restraints and tones"* (Adey 2015, p.61). These approaches focus on decentering established actors around environmental pollution to find new sites for intervention. In this approach, materiality is not inert and singular but becomes a performative space for generating alternative accounts of politics.

One of the suggestions of the post-ANT literature is that publics are not stable entities but that they emerge in relation to controversies as issue or material publics (Marres & Lezaun 2011). Marres talks about these publics as *"actors who are jointly implicated in an issue, but who do not belong to the same social world, so this is why they must get organised into a political community if they are to address the issue in question"* (Marres 2005*a*, p.10). She describes the link between publics and issues as 'no issue, no public' (Marres 2005*b*). Crucially, issues do not spontaneously generate publics but require material infrastructure or 'objects of politics' (Marres 2005*a*) to communicate and articulate issues. Marres (2013) proposes that publics can be purposefully constructed through devices that create connections and entanglements with issues and allow people to be affected. Latour (2004*c*) calls for turning scientific 'matters of fact' into public 'matters of concern' to become *"arenas for participants to gather"* (p.246). Stengers suggests that researchers should work on a 'cosmopolitics' (Stengers 2005) where humans and nonhumans from trees to iPods can be part of a collective political community.

Ontology and ontological politics

I offer a detailed analysis of the way Post-ANT uses the notion of 'ontology', due to the complexity of the concept and its centrality to this study. The word 'ontology' from philosophy meaning discussions about 'being' is used within the post-ANT literature not in the philosophical sense but to describe the way realities come into being. Rather than everything existing in a singular reality, Annemarie Mol suggests that ontologies are everyday practices, *"ontology is not given in the order of things, but that, instead, ontologies are brought into being, sustained, or allowed to wither away in common, day-to-day, sociomaterial practices"* (Mol 2002, p.6). Mol uses a theatre metaphor to suggest that ontologies are not natural but that they are 'enacted' and staged within situated contexts with multiple actors and devices. The key point of this approach is that it draws a difference between saying that people can have different viewpoints on the same object in which case *"the object of the many gazes and glances remains singular, intangible, untouched"* (Mol 1999, p.76), while an ontological approach can demonstrate how an object is transformed and becomes multiple. In her ethnographic work, Mol narrates the way diagnostic techniques and medical instruments enact the 'same' disease differently in different places, *"here it is being cut into with a Scalpel; there it is being bombarded with ultrasound; and somewhere else, a little further along the way, it is being put on a scale in order to be weighed"* (Mol 2002, p.77). Under a microscope atherosclerosis looks like a narrowing of arteries, while it behaves radically different in patient reports, in clinicians' observations and radiologists' visualisations. Rather than ignoring the contradictions between these enactments and continuing to suggest this is all one disease, Mol suggests that atherosclerosis is enacted as 'multiple' by the different technologies and training of the doctors. Crucially, this approach opens up a new way of narrating the impact of different enactments by devices and provides the researcher with a rich sensitivity to the complex dynamics of a case study. The concept of ontology has been adopted widely in STS and been called a 'turn to ontology'. Yet this has also been controversial and problematic:

> *"Ontology is a deliberately unstable term or category in STS. This is not only because it lacks a precise meaning or definitive qualifier but because the term itself is introduced with the intention of destabilizing seemingly robust designations of reality. The point of a turn to ontology in STS is to sharpen a contrast between alternative strategies of description"* (Woolgar & Lezaun 2015, p.463)

The aim of ontology is to reopen some of the classic problems of STS such as expertise and knowledge controversies by focusing on empirical and experimental approaches to reintroduce political focus to these problems. Mol's interest in her study are the mechanisms of coordination that try to prevent direct conflict between contradictory ontologies and shape *"what counts as the reality in a particular site"* (p.48). This choosing between different competing realities is what Mol calls ontological politics:

> *"Ontological politics is a composite term. It talks of ontology - which in standard philosophical parlance defines what belongs to the real, the conditions of possibility we live with. If the term ontology is defined with that of politics, then this suggests that the conditions of possibility are not given. That reality does not precede the mundane practices in which we interact with it, but is rather*

> *shaped within these practices. So the term politics works to underline this active mode, this process of shaping, and the fact that its character is both open and contested"* (Mol 1999, pp.74–75).

At stake in ontological politics is the way reality gets done in practice, with certain realities being enacted at the expense of others. In Mol's study the hierarchy between ontologies means that when they clash, *"in practice one of them will be privileged over the other"* (Mol 2002, p.47). For Mol the key focus of these clashing ontologies is the way they affect the care patients receive. Woolgar & Lezaun (2013) suggest that ontological politics sensitises the researcher to alternative possibilities and becomes a method for detecting *"the failed, unseen or not-yet-real possibilities hinted at by ordering practices"* (p.323). Thus Brives (2013) narrates how the tensions in her study between ontologies are not resolved and continue to cause friction. Mol suggests that the researcher should be engaging with pragmatic, normative questions such as, *"Where are the options? What is at stake? Are there really options? How should we choose?"* (Mol 1999, p.79) and, in a later text, *"which version might be better to live with? Which worse? How, and for whom?"* (Mol 2013, p.381). This normative approach shifts the researcher into politically engaged territory where they are asked to make choices and intervene in their case studies to transform them to directly improve a situation for the better. John Law proposes that *"in an ontological politics we might hope, instead, to interfere, to make some realities realer, others less so. The good of making a difference will live alongside – and sometimes displace – that of enacting truth"* (Law 2004*a*, p.67). Woolgar & Lezaun (2015) argue that an ontological approach can demonstrate that reality *"actually **is** otherwise!"* (p.465, emphasis in original), which creates a strong argument for implementing these demonstrated realities more widely.

The wish to have a direct transformative impact on one's case study is long hoped for by researchers. Yet there is not much clarity about how to do this. Woolgar & Lezaun (2013) argue that while it is common for researchers to claim to interfere via their research, they are just producing descriptions that suggest that 'it could be otherwise'. They ask: *"in what sense does this analysis 'interfere' with practices any more than any other STS analysis that points to contingency in the building of a certain entity?"* (p.326). In the post-ANT literature there are some suggestions for sensitising concepts and approaches for intervention such as Harold Garfinkel's 1960s 'breeching experiments' (Marres 2012, p.91) and Isabelle Stenger's figure of the 'idiot' (Horst & Michael 2011) and creative artistic methods (Gabrys 2014*a*). However, these are conceptual sketches that are not fleshed-out enough for researchers to adopt. Munk & Abrahamsson (2012) for example describe their struggle at trying to find a way of intervening in their case study. Woolgar & Lezaun (2013) proposed two criteria for successful 'interference', whether 'the relevant stakes and stakeholders have been articulated' and whether the constitution of the world has been changed because of the study (p.335). One of the few practical descriptions of a successful ontological intervention approach is Whatmore's case study of flood defences (Whatmore & Landström 2011). She presents an example of an ontological co-design process with an affected competency group that worked on developing new flood mitigation approaches via an experimental public mapping process she calls 'thinking with things'. The project led to an engagement with political stakeholders and further funding for developing an alternative flood plan for the area. Here the ontological approach managed to assemble a local public around the issue of flood risk and highlight *"'what' is at stake in a knowledge controversy"* (Whatmore & Landström 2011, p.585). But across the literature this is a rare example. Overall there is a wide methodological gap of how researchers can move beyond describing their site as in Mol's hospital studies and shift towards intervening and transforming it. What is needed is applied examples of 'doing' ontological politics. The next section provides an overview of design approaches that offer methods of combining ontological politics with design.

2.2 Design

This review provides an overview of design via the lens of human-computer interaction (HCI) and related approaches. It focuses on core concepts such as affordances and users, and discusses the contribution that ethnographers have made. The second part examines a convergence between design and STS to become a material method for transforming the world. The structure of this section reflects the two ways in which the study uses design, firstly as a subject within the device studies and secondly as an ontological prototyping method (section 8.2).

Design as a subject

The departure point for computer sensing devices is the discipline of HCI (Card et al. 1983) that emerged in the 1980s from computer science and cognitive psychology. Important reference points are the work of Norman (1988), Nielsen (1993) and Shneiderman (1997). Early HCI focuses on three components: a work-task, a computer and a user. The discipline became a search for universal design principles of usability and legibility that would enable these three components to cooperate. From HCI's early inception, arguments ranged between a computer science approach that argued for efficiency that could be measured, versus a holistic approach that emphasised psychological theories (Clemmensen 2006). Many of the later approaches to computing try to span across the computer and the user via notions that integrate the psychological with material hardware. For example the notion of ubiquitous computing (Weiser 1991) should make *"the computers themselves [...] vanish into the background"* (p.94) and the act of interaction take place at the cognitive periphery as 'calm technology' (Weiser & Brown 1996). Weiser's vision was extremely influential and marked a trend away from physical hardware towards the disappearance of the computer into ambient environments where the sensors are dispersed *"into the objects and the space surrounding us; as smart textiles into clothes/wearables, as smart materials into walls, floors, buildings"* (van Kranenburg 2008, p.13). This environmental formulation shifted the design of computing from a technical, hardware focused discipline towards the design of perceptual and metaphorical interaction. This opened the door towards designers that came from a broad range of backgrounds and spawned a variety of new computer design disciplines, such as experience design (Shedroff 2001), interaction design (Moggridge 2006), emotion design (Norman 2005) and service design (Stickdorn & Schneider 2010) as well as the projective design methods I will be examining. Despite the holistic approaches that try to bridge between the materiality of the computer and the psychology of the user, this dichotomy remains in the literature.

Materiality

In the HCI literature, one of the key concepts used to describe the material properties and constrains of designed objects is the notion of 'affordance'. The concept comes from ecological psychology (Gibson 1986) where it is seen as a kind of embodied resource;

"the affordances of the environment are what it offers the animals, what it provides or furnishes, either for good or ill" (p.127). When the physical and behavioural properties of the environment and animal coincide, it becomes a 'relational affordance'. The power of this notion is that it enables talking about interaction without having to divide between mind and material:

> *"An affordance is neither an objective property nor a subjective property; or it is both if you like. An affordance cuts across the dichotomy of subjective-objective and helps us to understand its inadequacy. It is equally a fact of the environment and a fact of behaviour. It is both physical and psychical, yet neither. An affordance points both ways, to the environment and to the observer"* (Gibson 1986, p.129).

In the 1990s, the notion of affordances and constraints was popularised via the work of Norman (1988), who showed how objects such as door handles need to be designed so that they communicate their push/pull physical qualities. Gaver (1991) extended the notion of affordance towards the design of computer systems with a focus on interface elements that need to be designed so that the user knows how to drag a scrollbar. However Raudaskoski (2003) argues that HCI has used the notion of affordance reductively, merely as a physical property of the object rather than as a relational possibility for interaction. She argues that HCI maintains a dualistic distinction between the mental image of an affordance and the physical affordance itself. By treating the process of interaction as largely physical, agency is assigned to the object and becomes a limited form of technological determinism. While the notion of affordance is useful for highlighting the interactional minutiae of material, it leaves the user as a generic and unspecified, shadowy hand that operates the device. It forecloses observations of complexity and unexpected interactions and Raudaskoski (2003) argues there is no need to try and distinguish whether affordances are physical or mental and instead the approach should be on empirically observing interactions as they take place. Suchman (2007) suggests *"the price of recognizing the agency of artifacts need not be the denial of our own"* (p.285) and that the researcher's role should be to trace the processes by which agency is attributed to specific entities. She gives the example of 'smart objects', where the apparent liveliness of the objects hides the labour that is involved in their construction. In these situations, she suggests, *"the task for critical practice is to resist restaging of stories about autonomous human actors and discrete technical objects in favor of an orientation to capacities for* *action comprised of specific configurations of persons and things"* (p.284). The point is that the researcher should identify the specificity of what happens in an interaction and avoid making absolutist claims that the human and machine are entirely separate or totally conjoined.

The user

Since the 1980s there has been a shift away from hardware-centred design towards the notion of the 'user'. Today the user has become an orthodoxy (Oudshoorn et al. 2004) that has led to the emergence of a whole range of new approaches such as user-centred design (Abras et al. 2004), co-design (Kankainen et al. 2012), participatory design (Kensing & Blomberg 1998) and personas (Miaskiewicz & Kozar 2011). These approaches use a wide range of methods such as interviews, focus groups and storytelling, yet there is much disagreement about who the user 'is' and how to make them 'speak'. Oudshoorn & Pinch (2006) argue that *"different groups involved in the design of technologies may have different views of who the user might or should be, and these different groups may mobilize different resources to inscribe their views in the design of technical objects"* (p.6). While the user is treated as a key actor, they are performed very differently depending on the specific design methods used to articulate them. For example, the persona approach involves the construction of fictional characters, where *"each persona has a gender, age, race, ethnic, family or cohabitation arrangement, and socio-economic background"* (Grudin & Pruitt 2002, p.160). Observing these processes of configuring the user has been the focus of many STS ethnographies (Woolgar 1990). In contrast, participatory design in the Scandinavian tradition defines itself as a shift away from designers as experts towards the participation of affected people in the process of specifying design criteria (Ehn 1988). In these different framings the notion of the 'user' variously allows the creation of better design, introduces politics or expands the range of entities that participate. Researchers have identified a variety of politics at play in these different constructions of the user. Blevis (2007) argues that by narrowly focusing on user needs this creates an 'ontological blindness' towards a wider *concern for human conditions, particular or global"* (p.504), while Wilkie & Michael (2009) argue that *"the user is a future modelling device that is key to the enactment of policy discourse and the associated micro-practices of policy persua-*

sion" (p.519). Suchman suggests a more situated understanding of the designer, user and artefact:

> *"We need to see the designer's view of the user as at once more specific and less. More in that it is specifically located within the various sites, imaginaries, exigencies, and practices that comprise professional design and less in that artifacts are characterized by greater open-endedness and indeterminacy with respect to the question of how they might be incorporated into use. The 'user' is, in other words, more vaguely figured, the object more deeply ambiguous"* (Suchman 2007, p.193).

The user and their needs are thus often not a tightly defined entity but distributed amongst a range of imaginaries and pressures. Designers have acknowledged this ambiguity and developed approaches that deliberately aim beyond the user. Chow & Jonas (2010) propose that design should build towards latent as yet unarticulated needs and create 'design projection' where one *"take[s] knowledge from one artifact and put it in another domain or context to create something new"* (p.12). In effect this design tries to address an unformed audience, it is *"design with someone, i.e. a collective and contingent practice in which the final purpose and outcome, cannot be determined in advance and becomes a result of continuous negotiation"* (Lenskjold 2013, p.3). Other designers suggest that they are designing for imminent audiences, *"we are no longer simply designing products for users. We are designing for the future experiences of people, communities and cultures who now are connected and informed in ways that were unimaginable even 10 years ago"* (Sanders & Stappers 2008, p.10). In these projective approaches, design becomes detached from commercial imperatives and becomes an exploratory practice that tries to enact new kinds of futures.

In the well-known 'probes' method (Gaver et al. 1999), playful objects are used to elicit creative responses from participants, which are then used by the designer as inspiration to create new design objects. Gaver argues that *"far from revealing an 'objective' view on the situation, the probes dramatize the difficulties of communicating with strangers"* (Gaver et al. 2004, p.5). Rather than defining the user's needs, this approach turns the user into a performative entity for rethinking the constraints of the design process. In a case study of an experimental sensor system for the domestic home (Gaver et al. 2013), the device detects air drafts between rooms and records the colour of ambient light as a portrait of the domestic microclimate. The paper suggests that while the generated data did not provide insights, the whimsical objects created long-term participant relationships with the devices and built a collective group that called themselves the 'crazy club' of domestic monitoring enthusiasts. Gaver et al. (2013) suggest that the success of the experiment was in building a new collective structure around the sensing object and argue that the devices

> *"disrupt the unitary logic of demand reduction technologies. We noted that the uncompromising narrative of ethical sacrifice becomes aversive to people tired of blame and guilt, reifies assumptions about the 'people' and 'the environment', and obscures questions of authority over the discourse they embody"* (p.3452).

Thus instead of designing for articulated 'user needs', theses devices are created to oppose a policy framing of behaviour change, where the user is addressed instrumentally by the sensing device. By creating a project using an alternative logic, the design object becomes a way of experimenting with building sensing collectives. In this example design moved from objects towards experimenting with ways of creating material publics.

While the probes approach maintains a direct relation with HCI, other related design approaches such as critical design (Dunne 1999), speculative design (Sterling 2009) and adversarial design (DiSalvo 2012*a*) exist at the intersection with art and STS. They focus on *"conceptual electronic products as a way of provoking complex and meaningful reflection on the ubiquitous, dematerialising and intelligent artificial environment we inhabit"* (Dunne 1999, p.9). Critical design aims to build 'value fictions' (Dunne 1999) that embody explicit agendas and take the form of objects that *"force a decision onto the user, revealing how limited choices are usually hard-wired into products for us"* (Dunne & Raby 2001, p.46). The intention is that by spending time with the device, the *"user would become a protagonist and co-producer of narrative experiences rather than the passive consumer of [a] product's meaning"* (ibid.). While these goals are recognisable avant-garde tactics, what is interesting is that they are packaged into objects that take the highly polished form of commercial design. In this way they reflect on and subvert the authority and seduction of design objects. Speculative design extends this approach by prototyping alternative historical or future narratives that blend social and technological change, where the design objects function as *"diegetic prototypes to suspend disbelief about change"* (Bosch 2012, para.3). The term 'diegetic' from film theory, meaning 'real sound' captures the experiential realism aimed at by these objects (Kirby 2010). Sterling maintains that this approach is not science fiction but design, since it involves and shapes material; *"it's not a kind of fiction. It's a kind of design. It tells worlds rather than stories"* (Bosch 2012, para.3). These design methods move away from commercial imperatives towards artefacts that challenge, propose alternative futures or actively try to facilitate issues. Yet there is a tension around the transformative claims of these approaches, since the resulting design objects are often confined to gallery exhibitions. While for Auger (2010) this provides freedom from *"real-world constraints"* (p.44) and a *"space for dreaming, challenging and awareness raising"* (ibid.), in contrast Disalvo (2012*b*) suggests that often, *"speculative design is spectacle alone, devoid of the content and grounding necessary to make productive critical statements or to be an instigator of public debate"* (p.120). Similarly, Kiem (2013) in his analysis of adversarial design suggests the need for engaging with the reality of the already 'designed' world:

> *"If political design is to become a concept of influence beyond the fashions of design academia I think it would need to take up a more substantial political imperative and engage directly with the problem of designing against the politics of the already designed"* (para.10).

It appears that the power of these projective design approaches is that they move away from constraining visions of the user, but their shortcoming is their lack of engagement with pragmatically contested realities.

Ethnographies of design

Ethnographers and anthropologists have been following and supporting HCI from its modern inception in the 1980s by being embedded in the workplace (Dourish 2006, Bell & Dourish 2006, Räsänen & Nyce 2006, Suchman 2011). However, these ethnographic workplace studies were often not easy for designers to interpret (Plowman et al. 1995) and raised questions about how ethnography should support HCI (Crabtree et al. 2009). Dourish (2006) argues that ethnography is a unique and reflective way of revealing relational logics beyond user needs and design specifications. Ethnography can reveal the impacts of institutional structures in which design takes place. Suchman, for example, highlights the importance of the future as a driver:

> *"The future no longer simply arrives sooner here, but rather has a kind of independent agency positioned beyond the confines, or control, of the research laboratory or even the wider Silicon Valley. And rather than being invented and*

> *propagated, this future now requires an understanding of a future that is becoming, elsewhere as well as here, and that might demand a reinvention of the Center itself"* (Suchman 2011, p.11).

In Suchman's narrative, the research lab itself becomes an 'object of design' directed towards the future. In these accounts, design becomes more than a practice of making objects but is situated within an innovation environment that is shaped by business hierarchies and institutional storytelling. Bell & Dourish (2006) similarly identify 'the future' as a key actor within the design of ubiquitous computing. They identify what they call a framing of a 'proximate future' that is always just around the corner. Crucially, this present is always deferred, preventing analysis of the current state of ubiquitous computing. In contrast, the ethnographers argue for analysing the 'ubicomp of the present' since *"infrastructures remain messy after decades or centuries, as the user of any transit system from urban subways to international airlines can attest"* (p.140). The way these ethnographers manage to work together with technologists within the research labs demonstrates a way of watching 'technology in the making' in the same way as some of the early STS science studies. Suchman suggests that the researcher should be asking *"in which specific worlds are technologies of order production generated, how do they circulate, and who or what are their subjects/objects? What or whose agendas and interests do they translate, with what effects?"* (Suchman 2007, p.205). Yet perhaps due to the complex but mutually beneficial relationship between the ethnographer and designer, these accounts seem to show a greater level of empathy and insight into the design of devices then the early STS studies within natural science laboratories. These design ethnographies thus demonstrate an engaged coexistence between ethnographic researchers and their subject that both extends the scope of design and brings ethnography into deeper engagement with its site.

Design as research method

So far, this review has focused on design as a subject of study. Yet design is also a form of research in its own terms. Fallman (2007) makes a distinction between 'research-oriented design' that focuses on improving artefacts and 'design-oriented research' that uses design artefacts to go beyond the remit of design. The strength of design-oriented research is that it can *"question the initially recognized limitations of a problem description"* (p.197).

Berg (1998) has argued that *"STS researchers venture into the lands of engineers, but the latter are not very interested in joining them on the return trip"* (p.457). However, this situation is changing and in the last decade there has been a convergence between STS and design that use the tools of design outside its traditional boundaries to intervene in public controversies and support communities. What designers bring to these topics is a specific attention and sensitivity towards material practices. Ratto (2011) observes that the existing theorisations of technology have been written by people with little practical experience of configuring technology, yet *"when one uses technologies he or she remains aware of their nuanced relationship to society, while when one theorizes about them they seem much more 'brittle' and inflexible"* (p.253). The argument is that the experience of 'making' provides a fluidity and understanding of technology that is often not captured in STS accounts. Crabtree et al. (2009) identify a tendency of ethnography to transform technical objects into 'rhetorical objects' (p.882). What a conjoining of design and ANT promises is a nuanced sensitivity and understanding of material practices and a way to intervene in the designed world (Storni et al. 2012). This shift can be seen in the emergence of the designer as ethnographer (Mette & Eriksen 2009, Wilkie 2010, Binder et al. 2011, Le Dantec & DiSalvo 2013, Kerridge 2015). The critical making approach (Ratto 2011, Ratto et al. 2014) tries to actively combine the best of these two approaches:

> *"Forms of material engagement can help overcome the ineffectual linguistic bias of traditional critiques of technoscience. On the other hand, we believe that current material practices can benefit from the conceptualization of knowledge and social organization that are foundational to [information systems] and STS research"* (Ratto et al. 2014, p.85).

Ratto et al. (2014) provide a useful overview of the state of convergence across participatory design, critical technical practice, value-sensitive design, critical design and tactical media. But the paper highlights that the main problem with these approaches is that they are short-term practices that have little structural impact:

> *"It is hard to shift from one-time practices, or single products for intervention, to structural critiques or affecting change. As we consider pathways for systemic change, how might a deeper connection with STS, which focuses on how social systems and knowledge structures become embedded in material products, help to 'scale' materiality into structural critiques, to foster new forms of knowledge production, and perhaps new practices of science, engineering and design?"* (Ratto et al. 2014, p.93)

The challenge of moving beyond the single design object is non-trivial since it extends beyond the boundary of what has usually been considered the remit of design. Yet in order to create a successful merger between design and the concerns of STS, what is needed is a specific kind of 'scaling' to practically support issues of public concern.

Infrastructuring

Participatory design has grappled with this issue of scaling by engaging with the STS concept of 'infrastructure' (Star & Ruhleder 1996). In this notion, infrastructure is seen not as mechanical but as a connective resource that links across scale between people, organisations, standards, and 'object worlds'. In this vision, *"infrastructure is fundamentally and always a **relation**, never a thing"* (Star & Ruhleder 1994, p.253, emphasis in original). Infrastructure allows different practices to coexist, for example: *"the cook considers the water system a piece of working infrastructure integral to making dinner; for the city planner, it becomes a variable in a complex equation"* (Star & Ruhleder 1996, p.113). This socially connective framing of infrastructure suggests a method of scaling between small and large by coordinating and facilitating the *"demands of multiple groups and making connections between them possible"* (Neumann & Star 1996, p.234). Participatory designers have adapted this STS concept of infrastructure into an method of 'infrastructuring' (Karasti & Syrjänen 2004, Ehn 2008, Björgvinsson et al. 2010, Hillgren et al. 2011, Björgvinsson et al. 2012, Le Dantec 2012, Disalvo et al. 2014). In this approach, designers are embedded within a community in order to build collectives and support them over an extended period of time (Karasti 2014). A particular focus has been the idea of using infrastructuring to gather collectives around public controversies (Ehn 2008). Disalvo and Le Dantec argue that design artefacts can *"expose and re-imagine constraints and parameters surrounding issues"* (Disalvo et al. 2014, p.2405). The designers refer to Marres' notions of issue and material publics (Marres 2007) and focus on designing the material objects to mediate issues and gather publics. Disalvo et al. (2014) argue that design objects can function as 'scaffolds' for the *"affective bonds that are necessary for the construction of publics"* (Le Dantec & DiSalvo 2013, p.259). Björgvinsson et al. (2012) argue that this shifts the role of the designer into actively engaging with issue controversies:

> *"The design researcher role becomes one of infrastructuring agonistic public spaces mainly by facilitating the careful building of arenas consisting of hetero-*

> *geneous participants, legitimising those marginalised, maintaining network constellations, and leaving behind repertoires of how to organise socio-materially"* (p.143).

For the designers, the focus is on gathering people together via design. However, I argue that infrastructuring has placed too much emphasis on the connective qualities of infrastructure, while overlooking the composition of structures and the way they become sites of conflict. As an example, in a case study of 'infrastructuring' a mobile phone communication system for a homeless shelter, the designers treated the staff and residents as separate publics with different issues of concern (Le Dantec et al. 2011). At the end of the project, the designers discovered that their system had highlighted an issue of accountability for the staff, whilst for the residents it had organised their household chores. I suggest that these asymmetrical outcomes were due to working within the institutional logic of the homeless shelter that treated the two groups as separate. Thus the system the designers built merely reflected the existing composition of the homeless shelter and reinforced the distinction between staff and residents. This example suggests that scaling is more complicated than simply building a collective around a design object but requires an analysis of the ontological composition of existing infrastructures.

My suggestion more broadly is that for design and ANT to come together productively, we require an ontological perspective to infrastructuring that can focus on the way design enacts realities. I turn to a concept of 'scale' taken from an early ANT text (Callon & Latour 1981) that offers an alternative approach to the structure-agency distinction between a macro-actor such as the state and a micro-actor such as an individual. Callon and Latour argue that macro-actors are not innately large and important, but that their 'size' is the result of processes of enrolling many human and non-human actors to increase their size. These processes of enrolment involve Machiavellian acts of manipulation that realign the will of all those that are enrolled, as well as the displacement of competing actors. In their words:

> *"We cannot distinguish between macro-actors (institutions, organisations, social classes, parties, states) and micro-actors (individuals, groups, families) on the basis of their dimensions, since they are all, we might say, the 'same size', or rather since size is what is primarily at stake in their struggles it is also, therefore, their most important result"* (Callon & Latour 1981, p.279).

I argue that this concept of scale adds three important perspectives to the notion of infrastructure. Firstly, it introduces the ontology of ANT to infrastructure to suggests that scaling is not a matter of making something physically bigger or working with more important institutions, but something that takes place by enrolling human and nonhuman actors. Thus 'scaling up' a design object does not have to involve working within existing institutions or problem framings, since they are themselves scaled up in the same way. Secondly, different ways of assembling an actor/infrastructure changes its composition and creates new ontological entities and realities. Finally, infrastructuring ontological entities is an intervention that creates multiple realities that can create conflicts and tensions. In this way, infrastructuring highlights an ontological politics implicit in the design of infrastructures.

Ontological design

My suggestion is that it is necessary to treat infrastructuring as 'ontological design' by bringing together ANT research and design around a focus on intervention, experimentation and interference (Law 2004*a*). Surprisingly little has been written about an ontological approach to design where devices are used to deliberately enact new realities in the sense of Mol's notion of ontology (Mol 2002). While there is literature in information systems about designing the 'ontologies' of knowledge structures (Ramaprasad & Papagari 2009), this reductive framing of ontology is not relevant to this research. A useful early reference (Winograd & Flores 1990) suggests that *"in designing tools we are designing ways of being"* (p.xi), yet the authors seem focused only on the human rather than broader realities. The most related paper (Storni 2015) calls for a focus on ontology in *"designing a multitude of elements to build an actor network"* (p.170). The aim is that *"the design process is de-centred. It shifts and multiplies its focus constantly and becomes open ended. The focus is on how things come together, how they need and reinforce one another"* (ibid.). Storni suggests mapping as a collaborative annotation process for publicly acknowledging complexity and allowing actors to recognise their place within the network. In this way, combining design and ontologies becomes a focus on the way humans and nonhumans are put together. This is highlighted by Berg (1998) who describes an ontological approach to design as *"immersing oneself in the networks described and searching for what is or can be achieved by new interlockings of artifacts and human* *work"* (p.482). Willis (2012) presents one of the few practical descriptions of ontological design in the context of environmental impact assessment, where trees were being enacted as roadside hazards or endangered ecosystems. In that case study, a political pressure group managed to shape the standards encoding these ontological categories to force a redesign of the planned project. Designing in relation to an issue thus involves changing the infrastructural composition of a controversy by trying to include or exclude certain actors. This approach chimes with Marres' call for 'experimental political ontology' that involves *"the deliberate investment of non-humans with moral and political capacities. Here objects, and by extension ontologies, have political and moral capacities 'by design"'* (Marres 2013, p.12). The value of an ontological approach to design is that it cuts through Fallman's distinction between 'design-oriented research' and 'research-oriented design' (Fallman 2007). Fallman argues that design-orientated research only creates *"unstable and unusable objects"* (p.197), while research-orientated design creates 'real' objects located in commercial realities. Yet an ontological approach to design counters this argument by empirically demonstrating how design objects actually act. Ontological design creates functioning objects that challenge the different ways of being 'real' and enacting realities in the world.

While ontological design is potentially a powerful approach for analysing controversies and being able to intervene in them, as outlined above there is a gap in the literature in terms of practical examples and methodological descriptions. What is needed is clear demonstrations of what an ontological approach to design can offer. This study aims to address this methodological gap by demonstrating an ontological design method for analysing and intervening in public controversies (chapter 8).

2.3 Participatory Sensing

This subject review covers participatory sensing across a number of overlapping literatures such as citizen science and crowdsourcing. Literature that directly uses the term 'participatory sensing' is a small corpus of largely technically focused papers while 'citizen science' has become a much broader and more heavily theorised field that has begun to encompass much of participatory sensing. For this reason, this review ranges across these fields. The review is seen through the lens of ANT and design and aims is to carry out a categorisation of different narratives and highlight patterns in the way the literature conceptualises the relationship between people, technology and environment. The review highlights an overall pattern across the participatory sensing literature of bifurcations between scientists and participants, human and machine, objective and subjective.

The popular story told by many researchers (Riesch & Potter 2014, Kullenberg 2015, Cooper & Lewenstein 2016) is that in the 1990s there were two independent 'inventions' of citizen science by the natural scientist Rick Bonney at the Cornell Laboratory of Ornithology and the sociologist Alan Irwin (Irwin 1995). The difference between these is that in the first the research is set up by scientists in which the public are allowed to be involved, and in the second the public are invited to redefine the research and change science itself. Cooper & Lewenstein (2016) labels these two approaches as 'contributory science' and 'democratising science'. Some authors have suggested these framings of science exist as a continuum or encapsulated hierarchies, where *"the democratic definition represents a larger context in which the contributory style of citizen science resides"* (Cooper & Lewenstein 2016, p.60). Other researchers frame these differences as a hierarchy of categories (Haklay 2013), where the bottom level involves the public in data gathering for science, while at the top level the public create the scientific problem definition. Generally though these categorisations frame the field as a polarity between research driven by scientists or by the public. Kullenberg (2015) similarly identifies these two categories, but adds a third category of 'citizen science as resistance' that uses scientific instruments to legitimise its actions while not being interested in contributing to the institution of science:

> *"Citizen science as a form of resistance utilises a contradiction in modern sciences, in which science is regarded as neutral and free from politics while simultaneously being the driving force in the constitution of the societies we live in. By turning to scientific methods in their political struggles, citizen scientists are able to 'short-circuit' the conventional modes of seeking political representation and use reference as a mediator in re-presenting the state of affairs that have come under controversy"* (Kullenberg 2015, p.67).

Similarly, Wylie et al. (2014) propose the term 'civic science' to indicate research *"external to the academy and where nonacademics can credibly question the state of things"* (p.118). I argue that this third narrative, with non-scientific aims, is focused mainly on the political independence of network technologies, so I describe it as 'autonomous networks' (subsection 2.3.3). Thus this review adopts three analytical categories across the literature: 'contributory science', 'democratising science' and 'autonomous networks'. My suggestion is that these three are narrative threads that run across the literature, rather than being definitive classifications that individual papers can be positioned into. Other researchers have argued that these categories are *"nebulous enough for endorsements of it often to confuse the aspirations of one interpretation to be applicable to the other"* (Riesch & Potter 2014, p.109). As I will demonstrate, it is very common for a single paper to adopt multiple narratives interchangeably. My aim is not to emphasise the importance of these categories but to use them to highlight the specific ontological entities each narrative focuses on. This is crucial in order to be able to identify the way these narratives enact specific ontologies within the empirical device studies.

Contributory science

This narrative is the most common in this area and often simply referred to as 'citizen science'. The concept is that members of the public are contributing to science by gathering data or categorising existing data. Science is framed as an ordinary and uncontroversial activity (Suomela 2014). Data gathering takes place through a division of labour where scientists plan and coordinate the research to break down the work into micro-tasks that are outsourced to the public. The epistemology of this approach is based on the notion of a discrete modularity of data that allows individual data points to be gathered by the participants and assembled into a single collective dataset for the scientists to analyse and publish. The main benefit is the ability to gather lots of data, very cheaply. Silvertown (2009) suggests that there is an *"increasing realisation among professional scientists that the public represent a free source of labour, skills, computational power and even finance"* (p.467). The contributory science approach is strongly linked to the business and computer science notion of 'crowdsourcing', coined in 2006 by Jeff Howe from Wired magazine (Letts 2006). A popular concept is the notion that the public has a cognitive surplus (Shirky 2010) that can be harvested by scientists. So researchers suggests that they can, *"skim off the people who would otherwise be playing Angry Birds and now they're going to do something that can help contribute to something meaningful"* (Ashton et al. 2013, section.3). Data gathering is typically focused on non-human entities such as animal species (Davies et al. 2013), environmental pollutants (Maisonneuve et al. 2009) or entities such as galaxies (Galaxy Zoo 2007). The process of data collection tends to be organised around clearly defined 'projects' that focus on a single species or pollutant, such as 'NoiseWatch' (European Environment Agency 2011), 'Conker Tree Science' (Conker Tree Science 2017) and 'UK Ladybird Survey' (UK Ladybird Survey 2017). For many research topics, this approach of crowdsourced data gathering is seen as the only way the research could take place, *"almost any project that seeks to collect large volumes of field data over a wide geographical area can only succeed with the help of citizen scientists"* (Silvertown 2009, p.469). This means that contributory science is fundamentally and critically dependent on the participants as well as the technologies that facilitate the contributory process. Nov et al. (2011*a*) highlight this by suggesting there are two separate elements involved, *"(1) a technological pillar, which involves developing computer systems to manage large amounts of distributed resources, and (2) a motivational pillar, which involves attracting and retaining volunteers who would contribute their skills, time, and effort to a scientific cause"* (p.68). I will examine these 'pillars' of technology and participant motivation in turn.

Technologies of crowdsourcing

While there are significant differences between technology-driven (Galaxy Zoo 2007) and naturalist projects (Davies et al. 2013), both highlight the critical importance of technologies such as smartphones for mass distributed data collection (Silvertown 2009, Kamel Boulos et al. 2011). In the participatory sensing literature, nearly every paper starts by citing statistics to demonstrate the state of global smartphone penetration (Honicky 2011, Kanhere 2011, Yang et al. 2012, Tilak 2013, Resch 2013). This is one representative example, *"there will soon be one smartphone for every five people in the world and there are already more mobile phones subscriptions in use than humans alive"* (Alfonso et al. 2015, p.1). The papers emphasise the exponential growth of smartphones and their potential to transform the world and draw a direct parallel between technological ubiquity and ecological sustainability via paper titles such as *'How Two Billion Smartphone Users Can Save Species!'* (Preece 2017). Smartphones are seen as powerful computers with inbuilt sensors such as light and sound and global positioning system (GPS) for which custom apps can be cheaply developed. Estrin (2007) has evocatively described this combination as *"imager-microphone-wireless-sensor packages that we all carry on our belts and in our pockets"* (p.3). While environmental sensing has traditionally required the researcher to develop, build and pay for expensive sensor hardware and physically deploy them, the smartphone appears to transform the whole globe into a sensor network:

> *"If all the smartphones on the planet together constitute a mobile phone sensing network, it would be the largest sensing network in the history. One can leverage millions of personal smartphones and a near-pervasive wireless network infrastructure to collect and analyze sensed data far beyond the scale of what was possible before, without the need to deploy thousands of static sensors"* (Yang et al. 2012, p.173).

The particular benefit for the researchers is that they can rely on the smartphone owners to pay for the hardware and deal with the tricky challenges of *"power management and network formation and maintenance"* (Honicky 2011, p.17). Paulos et al. (2009) argue that we are witnessing a fundamental transformation of the mobile phone from a communication tool towards a *"networked mobile personal measurement instrument"* (p.414). The smartphone is seen as a critical part of futuristic visions of smart cities where residents produce data that is fed into 'city operation systems' (Koetsier 2012). In a public lecture Picon (2014) suggests *"the most emblematic machine is not the computer or the sensor, its the smartphone. One of the reasons cities are becoming 'smart' is because of smartphones, it's as stupid as that"*. Yet this focus on the smartphone as the default sensing platform is sidelining more traditional sensing tools such as diffusion tubes that have been used in the UK since 1976 (AEA Energy and Environment 2008). These tubes consist of small plastic containers coated with a chemical reagent that after exposure are sent to a certified laboratory. The resulting data is considered to be a cheap and highly accurate way to measure urban environmental pollution, so it is striking then that diffusion tubes are hardly mentioned within the participatory sensing literature. My analysis is that participatory sensing is strongly associated with new digital technologies not just for their practical benefits but also the extensive media focus on these technologies as futuristic innovation.

The majority of the participatory sensing apps focus on the most easily accessible sensor of the smartphone, the inbuilt microphone. There is a large range of different noise monitoring apps available for download[1]. While there are apps using the inbuilt camera

[1]List of participatory sensing, noise monitoring apps: NoiseSpy (Kanjo 2010), WideNoise (WideTag 2012*c*), SoundSense (Lu et al. 2009), NoiseTube (Maisonneuve et al. 2010), Ear-Phone (Rana et al. 2010), NoiseWatch (European Environment Agency 2011), noTours (Escoitar.org 2013), The Quiet Walk (Altavilla 2011), NoizCrowd (Wisniewski et al. 2013), Recho (Recho 2014).

'Zensors' (Laput et al. 2015) and accelerometer 'iShake' (Reilly et al. 2013), these sensors are used much less frequently. Haklay suggests that the physical properties of smartphones are directing what is being sensed, *"since the microphone is the most obvious sensor and noise is an easily recognisable environmental problem, there is a proliferation of applications that deal with noise"* (Haklay 2016, p.153). Yet there is a surprising range of ways these apps frame sound pressure. While some of the apps such as NoiseSpy (Kanjo 2010), NoiseTube (Maisonneuve et al. 2010), Ear-Phone (Rana et al. 2010) and NoizCrowd (Wisniewski et al. 2013) focus on collective maps of environmental noise pollution, other apps use sound as a way to detect socially interesting events (Bao & Choudhury 2010), soundwalks (Escoitar.org 2013) or a *"rich source of information that can be used to make accurate inferences about the person carrying the phone, their environments and social events"* (Lu et al. 2009, p.1). For some of the apps, the microphone voltages represent the external environment, while for others they represent the dynamic behaviour of users. Thus it is the app software rather than the physical hardware of the phone that determines what is being sensed. Depending on which app is running, the same microphone can be sensing ontologically different things.

There is also a vast range of micro-controller based hardware devices that try to provide low cost air pollution sensing (Paulos et al. 2009, Honicky 2011, Tilak 2013). During my research I came across 25 cheap air quality sensing devices that were all developed in the last five years[2]. What is striking is how similar these devices are. Many are crowdfunded via Kickstarter or Indiegogo and cost around $150. They measure a range of gases such as nitrogen oxides and volatile organic compounds as well as particulates. They usually use WIFI, ethernet or link to the smartphone for Internet connectivity. Despite these similarities, they are usually marketed as unique and distinctive products. Haklay observes that *"participatory sensing has a strong element of 'not-invented-here syndrome', which encourages development of new applications by each developer, instead of building on the work of others through reusable code"* (Haklay 2016, p.153). My observation is that many

[2]List of participatory sensing, air quality devices: Air Quality Egg (Air Quality Egg 2012*f*), Air.Air! (Air.Air! 2014), AirBeam (HabitatMap 2014), Air Nut (IDSA 2015), AirProbe (EveryAware 2012*c*), AirSense (Dutta et al. 2016), Awair (Awair 2016), Foobot (Airboxlab 2014), ChemiSense (ChemiSense 2015), Cubesensors (KotoLabs 2016), Common Sense (Common Sense 2012), CITI-SENSE (Citi-sense 2012), Danaus (RiCiSung Technology 2015), Dylos (Dylos Corporation 2017), Frackbox (Citizen Sense 2014), Haier AirBox (Haier 2014), iKair (IKair 2013), Lapka (Lapka 2015), PiMi Airbox (Zheng et al. 2014), Plume Flow (Plume Labs 2017), SensBloks (SensBloks 2014), SensorDrone (Sensorcon 2012), Smart Citizen Kit (Acrobotic Industries 2013), Speck (Speck 2015), TZOA (TZOA 2015).

of these devices are created by developers who do not come from academic research backgrounds and were developed as commercial one-off products with a focus on novelty and with some exceptions, the source-code is not shared. In terms of approach, some of these device take a contributory science approach while many relate to the 'autonomous networks' narrative (subsection 2.3.3).

Data quality

Data quality and accuracy are seen as key issues in the contributory science narrative and are usually framed via the idea that participants introduce bias and error. Many papers discuss and compare the quality of identifications by laypeople versus experts (Cohn 2008, Haklay et al. 2009, Crall et al. 2011, Kremen et al. 2011). Schweizer et al. (2013) suggest that when participants carry out noise mapping with smartphones, they produce uneven spatial and temporal coverage. Courter et al. (2012) identify a temporal bias in the way volunteers collect data at weekends when they have free time and prefer to record *"charismatic species, such as hummingbirds"* (p.4). This unevenness is seen as a problem that can be remedied via topic specific protocols such as pairing a volunteer with an expert (Dickinson et al. 2010) or allowing skilled volunteers to count every bird, while less skilled participants are only allowed to count the most easily recognised (Cohn 2008). The participatory sensing literature proposes a range of technical methods to improve data quality such as filtering (Xiang et al. 2013), directing users to walk to under-mapped areas (Schweizer et al. 2013) or simply collecting large datasets to reduce participant error (Cohn 2008, Silvertown 2009). Yet despite the extensive focus on data quality, there are surprisingly few papers discussing the technical accuracy of the low cost sensors used within participatory sensing (D'Hondt et al. 2013, Lewis & Edwards 2016, Duvall et al. 2016, Murphy & King 2016).

My analysis is that while data quality is understandably important, the literature frames this often as participant bias, while other factors affecting data quality are given less focus. For example, in a study that uses visual observations of lichen as an NO_2 indicator and compares them with measured NO_2 levels (Tregidgo et al. 2013), the paper attributes discrepancies to the error of laypeople, rather than the fact that radically different methods are being compared. This transforms the paper into a quantitative comparison between participant fallibility versus automated gas sensors. What is interesting is that across the literature scientific expertise is often equated with technical accuracy. In this way the assumed lack of expertise of the layperson is translated into an ontological comparison between the skill of a human versus that of the machine. Wang et al. (2011) argues that *"unlike well-calibrated and well-tested infrastructure sensors, humans are less reliable, and the likelihood that participants' measurements are correct is often unknown a priori"* (p.7). There is a general narrative that assumes that machines are de facto accurate, while people are unpredictable and a source of error. It enacts a dividing line between the participant and the technologies of sensing as well as between the participant and the researcher. The result is that the participant is treated as a distinct subject that needs to be monitored, with many studies focusing on their 'reputation' (Yang, Zhang & Roe 2013).

Motivation

Since the participants are critical for gathering data, the second major topic in the literature is how to recruit people and keep them motivated to participate (Massung et al. 2013, Eveleigh et al. 2014). There are three different ways the literature engages with motivation. The first, **categorising motivation** (Boxall & McFarlane 1993, Brossard et al. 2005, Tomasek 2006, Nov et al. 2010, Raddick et al. 2010, Nov et al. 2011*b*, Rotman et al. 2012, Crall et al. 2013, Raddick et al. 2013, Iacovides et al. 2013, Nov et al. 2014, Jackson et al. 2015, Eveleigh et al. 2014, Jennett et al. 2016, Geoghan et al. 2016) consists of studies that use surveys, interviews and textual analysis to categorise participant motivation. The studies either use psychological categories or create new motivational themes such as: *"astronomy, beauty, community, contribute, discovery, fun, help, learning, science, teaching, vastness, zoo"* (Raddick et al. 2010, p.11). The second category, **applying motivation** (Sullivan et al. 2009, Maisonneuve et al. 2009, Newman et al. 2010, Wiggins & Crowston 2010, Prestopnik & Crowston 2011, 2012*a*, Roy et al. 2012, Massung et al. 2013, Kim et al. 2013, Socientize Consortium 2013, Crowston & Prestopnik 2013, Pocock et al. 2014) consists of theoretical, technical and policy papers that discuss how to apply motivation to citizen science or participatory sensing projects. In the gamefication approach (Prestopnik & Crowston 2011), the aim is to add game-like elements to make data collecting 'fun' and in the pointification approach (Massung et al. 2013) people are given symbolic rewards such as rankings and badges. The third category, of **modelling motivation** (Luo & Tham 2012, Lan & Wang 2013, Singla & Krause 2013, Thepvilojanapong et al. 2013, Tham & Luo 2013, Luo et al. 2017) focuses on game theory and notions of 'rational selfishnes' (Yang, Adeel & Mccann 2013) to create software models that simulate reward mechanisms. Faltings et al. (2014) argue their system, *"does not need to make strong assumptions about the agents' prior beliefs or updating mechanism, and is thus realistic for a practical setting."* (p.126). The typical model is a data market where users are paid for gathering data points, with the value set by a supply and demand market (Luo & Tham 2012, Lan & Wang 2013, Tham & Luo 2013). There is also a lot of interest in finding alternatives to paying participants such as gamification (Arakawa & Matsuda 2016), virtual participation credits (Luo & Tham 2012) or reputational rewards (Yang, Zhang & Roe 2013).

To theorise motivation, the literature references texts from online peer production and psychology. In contrast only a few papers examine classic socioeconomic categories such as income or education levels (Boxall & McFarlane 1993, Hobbs & White 2012, Crowston & Prestopnik 2013, Raddick et al. 2013). Many texts reference online peer production such as Wikipedia (Lakhani & Wolf 2005, Benkler & Nissenbaum 2006, Budhathoki et al. 2010) and identify single word motivators such as 'money, love, and glory' that have been imported into citizen science (Crowston & Prestopnik 2013). Secondly the literature references psychological theories such as the 'elaboration likelihood model' (Petty & Cacioppo 1986) and 'theory of reasoned action' (Fishbein & Ajzen 1975). The most frequently cited is the 'self-determination theory' (Deci 1971, 1972, Ryan & Deci 2000), which draws a distinction between intrinsic motivation that is said to come from within the self, while extrinsic motivation is an external award such as money. Deci (1971) suggests that *"one is said to be intrinsically motivated to perform an activity when he receives no apparent rewards except the activity itself"* (p.105). Much of the citizen science literature adopts this intrinsic/extrinsic distinction. Eveleigh et al. (2014) for example suggest that 'curiosity', 'competence' and 'enjoyment of a task' are intrinsic, while 'interaction with other volunteers' and 'increased status' are extrinsic. Yet it is striking that across the participatory sensing and citizen science literature, there is little agreement about motivators and the categories they fall into. Some papers argue gaming is an intrinsic motivator (Rotman et al. 2012, p.225) while others describe it as extrinsic (Knöll 2011, Eveleigh et al. 2014). Some papers suggest that 'science' is a fundamental, intrinsic motivator (Socientize Consortium 2013), while others highlight 'fun' (Prestopnik & Crowston 2012*b*). There is disagreement about where to position 'social relations'. Eveleigh et al. (2014), Crowston & Prestopnik (2013) see social connections as extrinsic, since they provide 'increased status, rewards and glory', while Nov et al. (2011*b*) suggests the participation task is inherently collective. Across the literature, the single word motivators and intrinsic/extrinsic distinction are not consistent and rather vague. The main effect of the motivation concept is that it draws a line between what the authors consider to be the core of the project and what they perceive merely as a peripheral outcome. Strikingly, this psychological framing of participation seems to marginalise other ways of framing participation. Across the literature there is little discussion about usability and design of sensing devices or contribution systems. Prestopnik & Crowston (2012*a*) identify this as a gap within the literature:

> *"In the citizen science domain, motivating participation is valued; scientists who manage citizen science projects are very interested in understanding more about motivation and participation. However, there is much less overt enthusiasm for satisfier elements such as good usability, good organization, adequate privacy controls, or responsive communication to participants. These factors are recognized as necessary, but are sometimes undervalued in comparison to more motivational elements"* (Prestopnik & Crowston 2012*a*, p.174).

The quote makes the argument that by framing the participant as a psychological entity, this forecloses a broader focus on qualities such as design usability, organisation and responsive communication that need to be in place in order to create good quality projects. My analysis is that the dominant psychological framing of the participant via reductive motivators renders them as an immaterial placeholder that lacks specificity and contributes to the lack of detail about the material practices of participatory sensing.

Humans supporting and imitating machines

The conceptual and operational models of the contributory science approach suggest that the hardware sensors and participants are very different kinds of entities. The literature uses notions such as 'citizens as sensors' (Goodchild 2007), 'humans as sensors' (Wang et al. 2014), 'people as sensors' (Resch 2013) and 'social sensors' (Sakaki et al. 2010). Estrin (2010) distinguishes between 'automated capture' of time and location stamps and 'prompted manual capture' that requires the user to actively take photos or record audio. Participants are also asked to add contextual data using sliders to provide ratings (Maisonneuve et al. 2009, Foerster et al. 2011) or add short descriptive textual tags (Zeile et al. 2015) that are correlated with the hardware sensor data. Lane et al. (2010) describe an app where users improve the automatic sound detection of the machine, *"the user is brought into the loop to confirm and provide a textual description (i.e., label) of the discovered sounds"* (p.147). In this approach the human is framed as supplementing the machine, which I call **'device support'**. Yet the literature also includes a more extreme formulation that I call **'device imitator'**. In this framing, the participant is meant to act like a sensor, *"everything will become a sensor—and humans may be the best of all"* (Herring 2010, para.1). The reason is largely one of utility since humans are considered to be 'cheaper' than hardware; *"human sensors can supplement or sometimes replace expensive and specalized sensor technology and sensor networks"* (Zeile et al. 2015, p.906). This framing of the participant leads to curious academic paper titles such as *'allowing citizens to effortlessly become rainfall sensors'* (Alfonso et al. 2015). This conceptual separation between technology and human is operationally implemented via the frequently cited notion of **MULEs** (mobile ubiquitous LAN extensions) (Shah et al. 2003, Ganti et al. 2008, Wu et al. 2009, Tseng et al. 2010, Bhadauria et al. 2011, Yang, Adeel & Mccann 2013). The term describes a diverse range of mobile platforms such as buses, animals or humans that are all considered equivalent at being able to provide mobility to the sensor hardware (Figure 2.3). In the diagram, the dotted line creates a separation between the hardware sensors that are doing the 'sensing' while the MULEs are only there to provide mobility. In this way the separation between human and machine is a structural hierarchy that is built into the design and operations of the sensing device.

From these models and the earlier discussions about data quality and motivation, I suggest that the contributory science approach enacts the human participant and the technologies of sensing as ontologically separate realities with no crossover. A significant number of papers make a distinction between objective data derived from technical sensors and subjective data generated by participants (Wang et al. 2014, Resch et al. 2014, 2015, Zeile et al. 2015). Crucially these two are placed in a hierarchy where the technical sensors generate objective data, while the human can produce merely subjective data as context. The contributory science approach thus enacts a bifurcation of nature (Whitehead 1920) that detaches 'sensing' from being a human activity of perceiving and making sense of the environment, to becoming a technological activity of quantification. Nevertheless, contributory science is fundamentally dependent on participants to support and

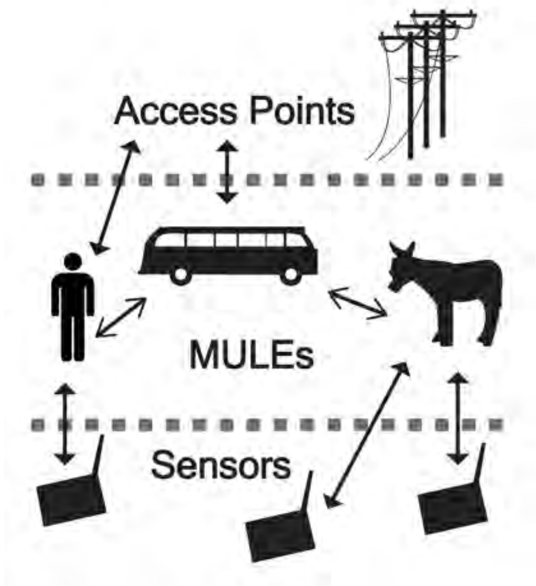

Figure 2.3: Illustration after Shah et al. (2003) showing the notion of MULEs as mobile platforms that are separated from the sensors.

imitate the machines, since without the participant, the sensing process cannot be carried out. Ellis & Waterton (2004) have observed that there is a tension in the way citizen science combines the contradictory framings of the participant as both 'data-drones' and 'nature lovers'. The result is that the participant is placed in an ambiguous and fractured position, as this study will demonstrate.

Democratising science

In contrast to contributory science, I now turn to two narratives that frame sensing as democratically empowering or enabling behaviour change. What connects them is a policy focus on the participant as involved in matters of public concern such as climate change or scientific controversies. In contrast to contributory science, these narratives are not focused on discrete 'projects' but focus on long-term processes that modulate the relationship between the public and institutions. Much of the research in this narrative comes from a social science perspective using methods of theoretical argumentation as well as surveys and interviews.

Public consultation and participation

The key feature of this narrative is the prominent invocation of the participant as a 'citizen', a focus on their relation with institutional policy and making elaborate claims about the benefits of taking part in citizen science. The narrative is premised on the notion of the 'scientific citizen' (Irwin 2001), which is a *"normative ideal concerning the appropriate form of democratic governance in a society that has become increasingly dependent on scientific knowledge"* (Horst 2007, p.151). It is a bidirectional movement of an institutional top-down attempt to include the citizen in scientific matters as well as a push upwards for the citizen to be heard. Kennedy (2016) tells a story that in the mid 20th century *"the citizen science movement took on a particular strategic goal. Instead of tearing down the institutions of power, early citizen scientists aimed to be included and recognized as legitimate experts"* (p.24). In this narrative, people counting birds is connected to policy objectives of public understanding of science as well as the advocacy of AIDS activists (ACT UP New York 2013) and environmental activists (Ottinger 2010). A key spectre in this approach is the notion of a 'deficit model', where the public are imagined as hostile to governmental science policy due to their lack of scientific comprehension. This creates a need for scientific literacy to be taught to the public for them to understand the benefits of science. This argument around expertise and competing knowledge claims between laypeople and experts has become the mainstay of STS as 'knowledge controversies' (Wynne 1992, Yearly 2000, Wynne 1996). The deficit argument and its critical alternatives have led to the setting up of large-scale public deliberation and consultation processes on a wide range of controversial scientific and technical policy topics such as nuclear power (Fiorino 1989), genetically modified food (Irwin 2006) and gene therapy (Horst 2007). Attar (2012) suggests that *"the current environment of science and technology governance is marked by a competitive struggle between the 'old' discourse of public deficit and the 'new' discourse of democracy and public engagement"* (p.5). Smallman (2016) notes a shift away from deficit approaches towards public dialogue and critique of how these dialogues are being staged, as well as more ad hoc participation activities (Stirling 2007). Structured models of participation have become enshrined into legal documents such as Principle 10 of the Rio Declaration on Environment and Development that states, *"each individual shall have appropriate access to information concerning the environment that is held by public authorities [...] and the opportunity to participate in decision-making processes"* (United

Nations 1992). This official requirement for the public to participate has resulted in governments and public bodies funding citizen science with multiple objectives such as the UK based Open Air Laboratories. In these programmes, members of the public carry out guided identification tasks of entities such as earthworms to learn about science, contribute data as well as *"explore, study and enjoy their local environment"* (OPAL 2013, para.1).

The theoretical struggle around the deficit model is reflected in the way citizen science activities are evaluated. Some studies try to establish a causal link between taking part in these projects and becoming supportive of technological and scientific progress (Brossard et al. 2005, Bonney et al. 2009) or being able to follow scientific procedures (Trumbull et al. 2000). Other studies highlight the impact of citizen science as new found awareness of ones surroundings (CAISE Inquiry Group 2009) or generating affective experiences for the participants (Lorimer 2008, Watson 2010, Koss & Kingsley 2010). However, other studies see citizen science as an opportunity to transform the epistemology of science by including local knowledge, uncertainty and 'extended peer communities' (Funtowicz & Ravetz 1997, Irwin 2001, Jasanoff 2004). As mentioned in the introduction, a key feature of citizen science is the prevalence of models and taxonomies that attempt to locate the axes of participation. Cornwall (2008) offers a historical overview of typologies of political participation starting from the 'ladder of participation' (Arnstein 1969), which divides community participation into a series of steps from 'manipulation' at the bottom to 'citizen control' at the top. There are many contemporary variations on this ladder model (Connor 1988, Fiorino 1989, Rocha 1997, Wilderman 2007, Cooper et al. 2007, Brodie et al. 2011, Haklay 2013) that highlight different facets of political and scientific participation. Many of these taxonomies map a continuum of knowledge and empowerment between laypeople and scientists along a linear scale. In this way they conflate participants engaging in increasingly complex scientific tasks with increasing levels of citizen empowerment. The discussion within this narrative focuses on power relationships between the opposite ends of the scale via questions such as, *"who really benefits the most from these developments: the amateurs or the professionals?"* (Kilfoyle & Birch 2014, para.8).

The public consultation and participation narrative foregrounds the figure of the human as ontologically distinct. While the human is seen as a complex entity consisting of expertise and knowledge, the material and practices of participatory sensing are sidelined in this narrative. In particular, what is absent are the technical 'objects' of participatory sensing as well as the reason why the research activity is being carried out such as environmental entities of pollutants, animals and plants. Cornwall (2008) argues that the dominant theoretical models of participation are inadequate and one should be examining the practices rather than the rhetoric, *"what they participate in, and, as a corollary, who participates in which activities and at which stages in the process"* (p.12). Cornwall argues for getting rid of the 'cosmetic rhetoric' that pervades this area and establishing 'clarity through specificity'. Green (2010) suggests that the problem is that participation is often approached via notions of Habermas' communicative action (Habermas 1984) within an idealised public sphere (Fraser 1990) where participation is seen as a universal 'good'. Green suggests that this theorisation means that the researchers focus on abstract advice on participation rather than carrying out empirical studies, so that *"neither proponents nor critics of participation have paid adequate attention to what actually happens when so called participatory approaches are carried out by real people in real places"* (Green 2010, p.1245). This idealisation and abstraction of participation leads to the 'citizen' featuring as a highly specified yet blackboxed entity, whose practices are largely unknown.

Behaviour change

The second framing of the democratising science narrative is the notion of changing the behaviour of the public. From World War I onwards there have been governmental campaigns to influence public behaviour in regards to health and safety concerns such as smoking (Warner 1989) and seat-belt use (Geller et al. 1990). Traditionally this has involved informational messaging backed by statistics that are communicated through the mass media. Yet in recent years, there has been a focus on trying to generate 'pro-environmental behaviours' (Defra 2008, Kollmuss & Agyeman 2002) that physically involve the public in material activities such as increasing recycling, installing insulation and more responsible water usage (Defra 2008, p.5). Proposed tactics include asking people to take pledges (Geller et al. 1990), nominate environmental champions (Hargreaves 2011) and personalised technologies such as smartphones (Webb et al. 2010, Lathia et al. 2013). There is a particular focus on sensing practices such as, *"weighing all of the office's waste, taking electricity meter readings, and staying late after work to record which appliances had been left on"* (Hargreaves 2011, p.86). In this framing, everyday activities such as printing double-sided becomes an environmental and behavioural norm. Marres (2011) suggests that this focus on pro-environmental behaviours represents a new mode of public engagement that no longer targets cognitive literacy as in the public consultation approach but becomes a form of 'material participation':

> *"These campaigns thus define public engagement in ways that deviate from more customary framings of it in terms of 'literacy': rather than seeking to increase people's knowledge about the issues, these initiatives focus on action and impact - on what people do about the issues in question"* (Marres 2011, p.511).

Hargreaves (2011) similarly identifies a shift away from appeals to morality or responsibility. The materialisation of participation has been adopted at the policy level via notions such as 'nudges.' Thaler & Sunstein (2008) that propose that people should become 'choice architects' to restructure the decision space for others. The authors give an example of a dinner lady who has to organise the layout of a canteen and needs to decide where to place the healthy food. The suggestion is that there are no neutral options and the dinner lady has to arrange the food in such a way as to nudge the children to choose the healthy option. This approach has been adopted into participatory sensing via smartphone apps. In the approach of 'persuasive design' (Fogg 1999), the mobile phone becomes the locus for behaviour change due to its intimate proximity to the user. There are apps where the, *"sensor data gathered from communities (e.g., fitness, healthcare) can be used not only to inform users but to persuade them to make positive behavioral changes (e.g., nudge users to exercise more or smoke less)"* (Lane et al. 2010, p.149). Other scenarios involve 'ambient lifestyle feedback systems' (Nakajima et al. 2008), where sensors are not passively 'sensing' but actively intervening on the user with 'negative punishment' to encourage them to do household chores. Lane et al. (2010) envisage the smartphone interrupting the user when they walk into a pharmacy to start, *"suggesting vitamins and supplements with the effectiveness of a doctor"* (p.149). The notion of behaviour change has also been adopted in environmental sensing apps (Estrin 2009, Maisonneuve et al. 2010, EveryAware 2011*a*). The NoiseTube app for example highlights not just its ability to create scientific data of environmental noise, but also its capacity to change the citizens' behaviour:

> *"Giving the possibility to any citizen to measure their personal noise exposure in their daily environment could influence their perceptions and potentially sup-*

> *port the raising of awareness of environmental issues, the first stage in the adoption of new behaviour. This is important because citizens are often – indirectly and sometimes directly; collectively and sometimes individually – responsible for part of the noise pollution they experience. Changing their behaviour could thus solve a part of the problem. With its ubiquity, the mobile phone has already demonstrated its value as a persuasion tool in several cases (education, health and marketing)"* (Maisonneuve et al. 2009, p.98).

In this quote, environmental noise pollution is framed not as a political or institutional issue, but becomes an individualised behavioural problem that the app user is made responsible for. The result is that NoiseTube is not just a sound sensor but becomes a persuasion tool for trying to influence the user's behaviour. Crucially in the behaviour change framing, the distinction between sensor and actuator becomes blurred. Perhaps more accurately, there is a shift of sensing away from the participant towards the technical system that analyses the sensory inputs and sends instructions to the 'citizen actuators' (Crowley et al. 2013). In the behaviour change narrative, participatory sensing becomes an *"activation of a human being the mechanism by which a control system acts upon the environment"* (p.109). Gabrys (2014*b*) argues that these approaches might have the effect of constraining the possibilities of environmental citizenship and turn it into a controlling top-down process:

> *"Urban citizenship is remade through environmental technologies, which mobilize urban citizens as operatives within the processing of urban environmental data; citizen activities become extensions and expressions of informationalized and efficient material–political practices"* (p.41).

The narrative of behaviour change has many overlaps with the public consultation and participation narrative in the way the participant becomes identified as a distinct ontological entity. Yet instead of treating the participant as a complex entity, they are blackboxed into behaviours. Similarly, this narrative focuses on idealised behaviours rather than providing empirical detail about what actually happens during these processes. As the analysis of the STS and design literature has identified, the agency of technology is rarely so clear and unidirectional that behaviour change will take place as smoothly as suggested. This highlights the need for more ethnographic detail about the material practices of behaviour change.

Autonomous networks

The key characteristic of this third narrative is a focus on participatory sensing activities as creating human and technical networks that are variously called 'sensor commons' (Fisher 2011), 'smart citizens' (Townsend et al. 2010, Hemment & Townsend 2013, Hill 2013, Kresin 2013), 'citizen-sensor network' (Sheth 2009) and 'sensible cities' (Resch et al. 2012). The narrative is characterised by the fluid use of terms such as 'networks', 'connectedness' and 'openness' to describe technical interoperability, free sharing of data, limitless expansion and the inclusion of people in 'open communities' (Public Lab 2013). This narrative focuses on environmental sensing where the devices are personally crowdfunded (Kickstarter 2009) and participants set up their own devices in their home to form a global sensing network (subsubsection 2.3.1.1). Hadfield (2012) argues *"the crucibles for global change will be 'open-data' cities – cities which self-consciously and collectively decide to make available unimaginable quantities of data, openly and freely"* (para.14). In these visions a wide variety of entities are generating data from smartphones to sensors embedded in metal girders and cars to create an all encompassing urban data layer that is said to transform the way the city is run. The approach is characterised by vast shifts of scale between visions of the globe covered in a universal sensing skin (Gross 1999) and hyperlocal sensing. The goal for the generated data is often left open-ended, *"we don't know what we're going to get when we arrive at a point where there is hyperlocalised data available on any conceivable measure – sound levels, temperature, rain levels, water quality, air quality, the number of cars passing a location in real time"* (Fisher 2011, para.6). Instead of having a scientific research agenda, the aim is often at creating a self-organising social and technical network. The narrative invokes cybernetic concepts from the 1970s and later internet visions such as the 'city of bits' (Mitchell 1996) where cities are inhabited by software agents as well as people.

While this narrative is related to corporate concepts of an 'internet of things' and 'smart cities' (Helmy 2014), it aims be an alternative to these visions in the form of 'smart citizens' that actively reorganise the city for themselves (Townsend et al. 2010, Hemment & Townsend 2013, Hill 2013, Kresin 2013). Balestrini et al. (2016) suggests this is a 'movement' based on *"tinkering, hacking, fixing, recreating and assembling objects and systems in creative and unexpected directions, usually using open-source tools and adhering to open* *paradigms to share knowledge and outputs with others"* (p.14). The narrative invokes hacking (Kelty 2010), DIY (Kuznetsov & Paulos 2010) as well as the Occupy movement and the Arab Spring (Hill 2013). There is clearly a political aspect to this narrative, which Kullenberg (2015) identifies as 'citizen science as resistance'. However, I suggest its main focus is on the politics of technological networks. For example, Hill (2013) argues that the main aspect of the smart citizen is the *"interesting and productive use of contemporary technology in the city [which] is here, literally in the hands of citizens, via phones and social media"* (para.24). My argument is that the politics of this narrative are largely focused on technological concerns, in particular environmental sensing. Kresin (2013) argues that *"we know how to measure ourselves and our environment, to visualise and analyse the data, to come to conclusions and take action. [...] We are ready. But, as yet, our government is not"* (para.3). The narrative is based on an opposition to existing governmental and scientific institutions and does not aim to contribute to their structures and processes. McQuillan (2014*b*) suggests citizen science can *"directly challenge orthodox science and thus establish an anti-hegemonic stance of its own"*, while Balestrini et al. (2016) suggest *"such interventions set their own goals and purposes, which may be at odds with existing regulations or procedures coming from public bodies and/or private organisations"*. The narrative's invocation of autonomy is often translated into infrastructural networks that are imagined as an alternative from existing institutions:

> *"Over the next decade, as cities everywhere struggle to maintain services, we will see a renaissance of crowdsourced public services. Going beyond mere issue and complaint reporting, these initiatives will build data-rich frameworks that connect government with loosely coordinated citizen collectives. These efforts will drive innovation in how services are delivered and funded in caregiving, education, and other non-emergency functions, and become an incubators for new kinds of public services. Lessons from online social gaming will provide ways of motivating and rewarding volunteers, by turning routine tasks into engaging civic participation"* (Townsend et al. 2010, p.5).

The key exemplar that is heavily cited in the literature is the Safecast radiation sensing community (Safecast 2011). This network emerged in response to the Fukushima nuclear disaster in Japan and was build by the maker community as low cost radiation sensing kits for the public to sense, aggregate and visualise radiation exposure. Importantly, this was not an institutionally supported project but is seen as an example of how autonomous groups need to build their own sensing networks when the governmental monitoring is inadequate. Kera et al. (2013) argues the project created a 'post apocalyptic citizenship' that *"demonstrated a whole new dimension of citizen empowerment, which goes beyond issues of data and introduces prototype building as a type of collective and political action"* (p.2). She argues that this sensing practice led to 'cosmopolitical citizenship' that is not based on *"predefined ideals of emancipation based on gender, social inclusion"* (p.4) but became an *"experiment in bringing together accessible technological possibilities with human interests and social needs"* (ibid.). The theme of the active citizen (Hill 2013) and alternative citizenship is common in this narrative, with Alvarellos (2012) proposing the need for a *"new social contract in which the rights and obligations of the citizens and the institutions will be redefined"* (para.6).

This narrative has overlaps with both contributory science in its focus on technology and data and the democratising science narrative via the focus on the citizen. Yet its uniqueness is a framing of autonomous sensing networks that are disconnected, or at a tangent, to existing institutional science and governance.

2.4 Summary of the literature review

This review has examined the corpora of STS, design and participatory sensing with an aim of trying to understand how the relationship between people, technology and environment has been theorised. The review identified a **methodological gap** (section 9.1) in the post-ANT and design literatures about how these theoretical and methodological approaches can be combined to intervene in case studies and controversies. What is missing is demonstrations of how to 'do' ontological politics by intervening in case studies while the design literature is missing examples that demonstrate ways of scaling up projective approaches. The review also highlighted an **insight gap** (section 9.2) in regard to the material practices of participatory sensing and the kinds of politics that are taking place. The review drew attention to a series of bifurcations between scientists and participants, human and machine, objective and subjective, where the participant is highly specified yet there is little empirical detail about their actual material practices. In addition the environment is treated largely as a data aggregate or topic of behaviour change and little is known about how this shapes the practices of participatory sensing.

Going forward from the review, I adopt a post-ANT theoretical approach focused on ontological politics to analyse how devices transform the world and identify the multiple realities they enact. I also adopt an ontological design method that tries to extend the infrastructuring design literature. The following methodology chapter describes how these approaches are combined and used to address the two central gaps identified.

Chapter 3

Methodology

This methodology chapter describes how the post-ANT theoretical approach is applied within research design of the study. It outlines the research questions, data collection and analysis methods as well as ethics considerations. The issue of study limitations is dealt with in relation to the findings of the study (section 9.3).

3.1 General methodological approach

This study investigates the material practices, political dynamics and potential of participatory sensing. I use a qualitative, multi-sited, mixed-methods approach based on post-ANT to focus the researcher on the liveliness of non-human actors such as the participatory sensing devices (section 2.1). In this way this study follows in the tradition of classic ethnographic laboratory studies of science (Latour 1987, 1999) and studies of technical environments such Aramis (Latour 1996*a*), Aircraft Stories (Law 2002) and Body Multiple (Mol 2002). Mol offers a very succinct summary of the role an ANT inspired ethnographer as narrating practices that connect human bodies, techniques and technologies:

> *"An ethnographer/praxiographer out to investigate diseases never isolates these from the practices in which they are, what one may call, enacted. She stubbornly takes notice of the techniques that make things visible, audible, tangible, knowable. She may talk bodies—but she never forgets about microscopes"* (Mol 2002, p.33)

The study adopts the fundamental approaches and concepts of ANT such as 'actors' and 'translation', but uses the theory largely as a sensitising approach rather than fully adopting its theoretical jargon. For example, in 'Aircraft Stories', Law (2002) tells the story of a military aircraft via technical manuals and demonstrates how a seemingly boring mathematical formulae is actually based on Cold War fears of Russian air defences. He uses the theoretical term *'heterogeneity of tellable otherness'* (p.102) to describe the sense of absence and presence of missiles. Yet what I take from this study is not the term he coined but the ethnographic sensitivity that allows him to tell a story via a formulae.

This study follows Bruno Latour's dictum to 'follow the actors' (Latour 2005*a*), with a methodological focus on 'devices' (Law & Ruppert 2013) and 'infrastructure' (Star & Ruhleder 1996). In this approach, 'devices' are socio-material-semiotic assemblages that are composed of physical material, semiotic signs and act 'socially' to assemble and arrange social relations around them. This concept is in the tradition of Foucault's *'dispositif'*, where an apparatus or device is *"literally anything that has in some way the capacity to capture, orient, determine, intercept, model, control, or secure the gestures, behaviors, opinions or discourses of living beings"* (Agamben 2009, p.14). This notion of the device has been used extensively within STS to account for the extended and unbounded nature of interactions technology, actors and methods. The device is a notion that helps account for slippages where it is hard to pin down the boundary between a physical object and its various dimensions of action and configuration. While devices often have a physical aspect, this is not a requirement; instead, they are characterised by concentrations of intensions. In Law and Ruppert's formulation devices are 'patterned teleological arrangements', meaning they have their own aims that require ethnographic analysis to identify their goals, since *"what devices are doing is not necessarily written on the package"* (Law & Ruppert 2013, p.230). Singleton & Law (2013) argue that *"devices may be found anywhere that practices embed sets of relatively repetitive and teleologically ordered strategies"* (p.260). I combine this notion of the device with Star's concept of an 'ethnography of infrastructure', where the researcher should *"attend ethnographically to the plugs, settings, sizes, and other profoundly mundane aspects"* (Star 1999, p.379). Star argues that these apparently trivial aspects of technology are the material conduits that connect actors across different scales. So when a person is bending down to plug in an electric device, they are engaging with technical standards that allow the plug to fit the socket, as well as legal and commercial relationships that allow electricity to flow from the national grid. This approach emphasises the importance of observing the usage of devices and becomes what I refer to as 'material practices', which describe the situated interactions between people, environment and technology where materiality functions as an active agent. Bruni (2005) uses the ethnography of infrastructure to make *"the software guide me through the organisation and confront me with other actors and processes, whether human or artificial"* (p.363). I similarly use this approach of letting the sensing objects bring me into contact with relevant actors and define the boundary of each case study. Throughout this study I will be referring to this ethnographic approach as a 'device study', since it places the sensing object at the centre of the enquiry and pays attention to who and what is taking place around it. This treats the objects more expansively as 'devices' (Law & Ruppert 2013) that have agendas, create practices and arrange social relations around them as well as 'infrastructure' (Star & Ruhleder 1996) that can create and prohibit structural connections across scales. While lots of entities are in contact with the sensing devices, only certain ones become actors that transform the devices and are in turn transformed by them. Transformation is not just the physical modification of the object but includes semiotic positioning in a press release or academic funding proposal.

The simile I use to describe the device study approach is like the view from a GoPro action camera. These small video cameras are often attached onto rigid objects such as bicycles, helmets or drones to show a fixed view of the world. While one sees the world rushing by in these action videos, the rigidity of the view and the surprising camera angles mean that one can never forget that this is a view from a machine. The ethnographic device studies are similarly an attempt to keep the sensing device rigidly at the centre of the view and to document the material practices taking place around it. The aim is to destabilise the prevailing assumptions in the literature about who and what is acting in participatory sensing. This approach does not aim at a scientifically objectivist view from nowhere, or a humanist perspective that would place the 'citizen' at the centre. Instead, this study aims at a situated perspective from the sensing device itself (Haraway 1988). The aim is not to create an anthropomorphic cartoon, where an object is made to speak to the reader, but to construct an object-centred ethnographic perspective that is sensitive to the properties and enactments of the device. This approach is informed by my extensive personal experience, having invented a participatory sensing device called Bio Mapping (Nold 2004) and spent a decade using it with thousands of participants across the world. Bio Mapping involved people wearing a sensor on their finger that measured their physiological arousal as an index of emotional state as well their geographical location. Together this data was visualised as spatial arousal maps that were annotated by the participants to create collective emotion maps of the local area (Nold 2006, 2007, Nold & Boraschi 2007). These projects were staged in the context of participatory art but over time morphed into alternative public consultations and urban planning. Seeing the way the practices around my device changed and were redirected by outside actors, I came to understand the disruptive potential as well as the constraints of participatory sensing. By applying a device study approach to a fresh set of devices, my goal is to create ethnographic accounts of these kinds of political dynamics from the device's point of view.

To account for the politics of devices, this study uses the theoretical notion of 'ontological politics' as a methodological focus. In Mol's words *"different enactments of a disease entail different ontologies. They each* ***do*** *the body differently. But they also come with different ways of* ***doing*** *the good"* (Mol 2002, p.176, emphasis in original). The point is that by treating the interaction around the devices as 'enactments' it is possible to demonstrate that different configurations of the device make different normative realities. The study's main methodological focus are Mol's questions of *"Where are the options? What is at stake? Are there really options? How should we choose?"* (Mol 1999, p.79), which asks how things could be done differently and invites the researcher to 'interfere' (Law 2004*b*) with the case studies. The shift from analysis towards interference is done via a design approach of ontological design and 'infrastructuring' (Karasti & Syrjänen 2004, Ehn 2008, Björgvinsson et al. 2010, Hillgren et al. 2011, Björgvinsson et al. 2012, Le Dantec 2012, Disalvo et al. 2014). In the book 'Inventive Methods', Lury & Wakeford (2012) describe the way devices such as stethoscopes and tape recorders are *"complex, and constantly changing constellations of things, procedures, abstractions, mediations, sensitivities and sociabilities in the apparatuses, configurations or assemblages of social research"* (p.9). Devices thus bring with them methods and sensibilities for collaborating and intervening in the world. Thus 'device' and 'infrastructure' become practical methods for 'infrastructuring'. Estalella & Criado (2015) describe the way they use Law and Ruppert's notion of the device as an intervention method

> *"to deploy experimental collaboration as a methodological device, a mode of assembling material and social conditions for the production of knowledge in*

> *our empirical work. Conceptualizing collaboration in terms of a device makes visible the different heterogeneous entities that have to be mobilized so as to bring into existence this relational mode in the empirical work as well as its epistemic conditions"* (Estalella & Criado 2015, p.304).

In this way, devices and infrastructures become physical prototypes that are collaboratively designed with communities to form collective interventions in controversies (Lane et al. 2011). This approach is crucial for demonstrating the alternative potential of participatory sensing and reflecting back on the other device studies.

Related research and unique contribution

There are a number of existing studies of participatory sensing that take a survey approach (Christin et al. 2011, Balestrini et al. 2016) to provide an overview of many sensing devices. Yet they offer no insights into the practices of participatory sensing and the ontological politics of the devices. The existing research that is closest to this study is Andrew Barry's study of two experimental environmental sensing devices called SMOG DOG and FEAT (Barry 2001, pp.153–174). Barry's focus is on the material politics of the device that in this study had *"an anti-political effect, serving to displace the problem of air pollution, and deflect other problematisation and their demands for other forms of action"* (p.172). Barry's study is short and doesn't offer much empirical detail about the practice of the device. The Citizen Sense project led by Jennifer Gabrys is similar in terms of theoretical and methodological approaches (Gabrys 2012, Pritchard & Gabrys 2016, Gabrys 2016) by using a new materialist approach to highlight the materiality of sensing devices as well as the affective impact of participatory sensing. One of the papers from that project also discusses the Air Quality Egg and Smart Citizen Kit (Gabrys et al. 2015), which represent one of the device studies in my study. More broadly, there is a theoretical connection to the post-ANT research of Marres (2012), Papazu & Scheele (2014) studies of the material practices of 'green' devices, as well as the Lippert (2012) study of carbon emissions using an ontological politics approach. There is also a similarity with the Ellis & Waterton (2004), Waterton (2010), Waterton et al. (2013) ethnographic accounts of new technologies that claim environmental and public impacts.

The unique contribution of this study is that it illuminates the material practices and ontological politics of participatory sensing via long-term ethnographic insights. It also demonstrates a methodological approach to combine ethnographic description of devices with the ability to craft new design interventions that can directly interfere within public controversies.

3.2 Research design

This study follows the life journeys of four devices over the period 2011–2014 as three ethnographic device studies 'Air Quality Egg and Smart Citizen Kit' (chapter 4), 'AirProbe' (chapter 5) and 'WideNoise' (chapter 6). Two of the devices, AirProbe and WideNoise, are followed through participant observer ethnography in my role as a researcher on the EveryAware research project (EU FP7) into participatory sensing. I was in the dual role of being an ethnographer and a researcher attached to the UCL team delivering the project and thus an actor in the study. As a researcher on the EU project, my role was to encourage many people to use the devices as well as evaluating this process. This overlap in tasks meant I was physically and emotionally engaged with the devices which provided me with special insights. Mackenzie (1996) describes this as 'insider uncertainty', where a researcher has access to the engineer's own questions and worries, which *"gives the analyst a way of continuing to be 'relativist' even about [a] settled area of knowledge"* (p.17). Yet these insights were not focused on the fellow researchers but the material practices of the devices themselves. The other two devices, Air Quality Egg and Smart Citizen Kit, are treated as a single device study and followed via interviews, prototyping workshops and analysis of the surrounding documentation. The ontological design intervention approach is demonstrated in a mini device study via a series of spinoff devices I refer to as the 'Heathrow Prototypes' (chapter 8).

The existing participatory sensing literature focuses on outputs such as data and empowerment but provides little detail about the design and usage of the devices. This study addresses this insight gap by specifically focusing on design and usage. Each study divides the narrative arc of the device into three stages of design, usage and outputs. The design stage describes the point where the device is configured by the funding process and organisers. The usage stage reports on the interactions and re-configurations that occur as the device comes into contact with participants and groups. The output stage reports on the device as its active life starts to dwindle and outputs emerge. This division is based on insights from the ANT literature such as the 'Zimbabwe Bush Pump' (de Laet & Mol 2000) that highlights that configuration takes place across design and usage. It is also informed by my experience with the Bio Mapping device, where important ontological shifts took place across all the stages of design, usage and outputs. The division in the device narrative is also intended to make it easier to create a horizontal comparison across the three studies. The diagram (Figure 3.1) illustrates the research design and questions.

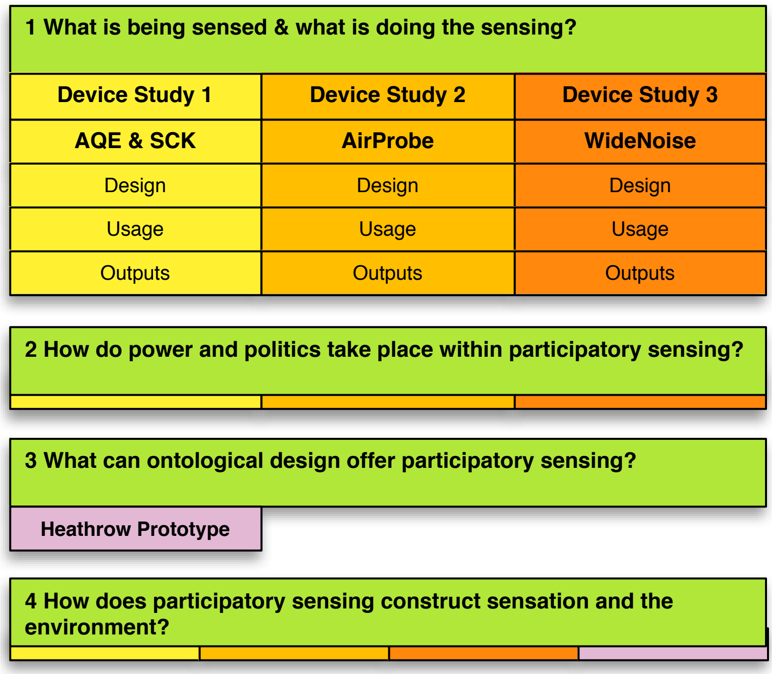

Figure 3.1: Diagram of how the four research questions (green) are answered by the empirical research. The first question is answered by the three device studies (shades of orange). The second question is answered via a horizontal overview across the three studies. The third question is addressed by the Heathrow prototypes (purple), while the final question is addressed by all the studies.

Research questions

After outlining the research question, I describe the sensing devices and explain the criteria why they were chosen as case studies.

Question 1: 'What is being sensed and what is doing the sensing?' This question aims to understand what is happening in participatory sensing. The research question is a compound question that asks about both the subject and object of participatory sensing. The question is intended to function as a kind of litmus test indicator for ontological changes in the device studies. Any changes to the answer indicate that an ontological shift has occurred, that a new kind of reality has been introduced and a new network of human and nonhuman actors has been brought together. This indicator is based on Mol's notion of enacted ontologies that have the potential to displace each other (Mol 2002). A change in what is being sensed or doing the sensing thus becomes empirical evidence of ontological politics taking place. The research question is also based on preliminary ethnographic observations of the WideNoise device where there was a surprising ambiguity about what the device was supposed to sense. This question brings together the ontological approach of the study, as well as preliminary observations from the field.

Question 2: 'How do power and politics take place within participatory sensing?' This question aims to provide a horizontal analysis across the three empirical device studies and identify what kinds of power and politics might be taking place. It revisits the answers to the first question and looks for patterns across the devices. It uses the questions from Mol as a guide: *"Where are the options? What is at stake? Are there really options? How should we choose?"* (Mol 1999, p.79). In this way the study shifts from looking at the dynamics around a single device towards making an argument about the material practices of participatory sensing itself. This question addresses the central gap in knowledge about the practices of participatory sensing. The question does not bring with it pre-made notions as to the nature of power and politics and follows the suggestion that new materialist enquiry should focus on *"what things do, rather than what they 'are'; towards processes and flows rather than structures and stable forms; to matters of power and resistance; and to interactions that draw small and large relations into assemblage"* (Fox & Alldred 2015*b*, p.407). This is reflected in the phrasing of the research question, which positions power and politics as something ethnographically observable taking place **'within'** participatory sensing, rather than power and political dynamics being something external or predefined.

Question 3: 'What can ontological design offer participatory sensing?' This research question asks about the potential of an ontological design approach for participatory sensing as well as the wider methodological potential of this method. The aim is to identify how the findings from the three device studies can be practically applied within a public controversy via a design approach. This question is addressed via the Heathrow prototypes that are described though a workshop and subsequent year-long deployment. It also addresses the methodological gap in knowledge about how to interfere and intervene using a post-ANT and design approach.

Question 4: 'How does participatory sensing construct sensation and the environment?'
This research question is intended as a summary of the three device studies in the light of the Heathrow prototyping study and addresses the methodological and insight gaps in the literature. The question addresses Gabrys (2012): *"in what ways do distributed sensor technologies contribute to new sensory processes by shifting the relations, entities, occasions, and interpretive registers of sensing?"* (para.5). It follows Gabrys in aiming to account for the broad impacts of participatory sensing on both human sensation as well as environmental practices.

Case studies

After describing the different case study devices, I outline the criteria why these devices were chosen from the many identified in the literature review (subsubsection 2.3.1.1).

Device Study 1: Air Quality Egg and Smart Citizen Kit
These devices were funded by members of the public via a crowdfunding system called Kickstarter. The hardware sensor boxes measure environmental air pollution and send the data to an online visualisation where it can be seen alongside other people's devices. Ethnographic observations were gathered at prototyping workshops, online documentation analysed and interviews carried out with the organisers. Throughout the study I refer to these devices by their abbreviations as AQE and SCK.

Device Study 2: AirProbe
This hardware sensor box and app were built by the academic EveryAware project. It measures environmental air pollution and sends the data to an online competitive game environment where participants guess air pollution levels. My role as facilitating researcher device gave me detailed ethnographic insights into the design, usage and outputs of the device.

Device Study 3: WideNoise
This app was built by a commercial company and then reconfigured by the academic

EveryAware project. The smartphone measures environmental noise and people's perceptions that are together visualised online. My role as a researcher facilitating the device and introducing it into the public controversy of Heathrow airport provided detailed ethnographic observations of the way the local actors reconfigured the device for their own purposes.

Heathrow Prototypes

This was a series of hardware devices that were designed and built in response to the controversy of noise at Heathrow airport. The prototypes are the result of a collaborative prototyping process with a collective of enthusiasts and organisations. Their design, usage and outputs demonstrate an ontological design approach.

Case study criteria

Access

Working as a researcher on a EU funded participatory sensing project gave me a clear incentive to focus on the two research devices of the project - AirProbe and WideNoise. My role as a participant observer gave me unique and definitive access to all aspects of the design, usage and outputs of the devices. I was able to trace design choices and their impacts across the whole life cycle of the devices. The issue of access was also key to choosing the AQE and SCK. These devices were seen as competitors to the two EU research devices. I also had local access to the project organisers, prototyping workshops and events, some of which was hosted by my university due to the EU research project. This intertwining and privileged access to all four of the devices made the multi-year ethnographic studies of the devices feasible.

Positionality

The overall aim of the study is predicated on taking a range of positions on the sensing devices. While I was intimately involved with the WideNoise study, I was less involved in the configuration of the AirProbe device. My position as researcher towards the AQE and the SCK were more distant, taking place through workshop observations, interviews and document analysis. The Heathrow prototypes were designed and built by myself in collaboration with a group of local enthusiasts. This diversity of positions and relationships towards the devices created different research modalities and removed potential researcher bias. With the AQE and SCK, I was not in the position to affect the trajectories of the devices. By picking case studies that created a breadth of positionality towards the devices, this also demonstrates the adaptability of this methodological approach.

Comparability

In order for the findings of this study to be generalisable, the devices had to be similar enough to be comparable. The aspect that demonstrates this comparability was that the device organisers perceived each other as close rivals. During the development, the organisers of the AQE, SCK and AirProbe were aware of the other projects and directly compared themselves towards the other devices and articulated their differences and similarities. This demonstrates that the three devices were recognisably within the same domain and suitable for horizontal comparison. At a hardware level three of the devices - AQE, SCK and AirProbe, use identical NO_2 sensors, E2V MiCS–2710 (e2v Technologies Ltd. 2008) and CO sensors E2V MiCS–5525 (e2v Technologies Ltd. 2009). While AirProbe includes additional sensors, the air pollution devices are comparable in terms of financial cost and accuracy levels. This is important for the overall theoretical and methodological approach of this study, where any differences I detect in the practices of devices will not be due to hardware differences but other aspects such as semantic, organisational or ontological configuration. Thus picking these related and comparable devices makes it possible to identify ontological differences between them.

Exemplars of participatory sensing

In order to be generalisable, it was important that the devices would be representative exemplars of participatory sensing. The AQE and SCK have in the last years become some of the most recognisable exemplars of participatory sensing and have been extensively cited in academic, mainstream media and grey literature (section 4.5). While AirProbe and WideNoise have not received as much media attention, they were created by a major EU funded research project and the results have been published in peer-reviewed academic journals (section 5.5) and (section 6.10). This demonstrates that the chosen devices are representative exemplars of participatory sensing. Furthermore the phenomena of noise and air pollution are the most definitive use-cases of participatory sensing and represent the most common category of apps and devices (subsubsection 2.3.1.1). The study focuses on both sound and air pollution and thus avoids any potential bias of only examining a single pollutant.

Scope

Finally, the range of case study devices represents the scope of participatory sensing from contributory science (subsection 2.3.1) to autonomous networks (subsection 2.3.3). As the device studies demonstrate, the devices move seamlessly between scientific research and commercial/maker culture. WideNoise was a commercial device and then became a scientific research instrument. AirProbe was designed as an academic research device and intended to be commercialised. AQE and SCK started as commercial maker culture projects and were heavily cited within the academic literature. This range of case studies thus represents the important cross-over point between academia and commercial approaches in participatory sensing.

Data collection, analysis methods and ethical considerations

Despite post-ANT and new materialism's strong focus on the impact of research methods (Savage 2013), there is surprisingly little literature that directly addresses how to carry out data collection and analysis using this approach. Typically post-ANT accounts combine a wide range of methods such as ethnographic observations, interviews and document analysis that are interspersed with high-level theoretical arguments. Yet it is often unclear why particular methods were chosen and how this contributed to the overall theoretical argument. Papers within this approach that directly address methods (Nimmo 2011, Marrero-Guillamón 2015, Fox & Alldred 2015*a*,*b*) suggest that classic social science methods are not stand-alone instruments but need to be adapted to the epistemology and ontology of post-ANT and new materialism. Fox and Alldred suggest that methods need to be seen as part of a 'research assemblage' that combines *"the researcher and the researched event, plus the many other relations involved in social inquiry such as the tools, technologies and theories of scientific research"* (Fox & Alldred 2015*a*, section.3.1). In this argument, good research involves gathering a sensitive combination of elements including the researcher, their theories and methodological tools in order to allow differences to be detected. Fox and Alldred describe the research assemblage as a 'data collection machine' that needs to be sensitive enough to detect variations within the phenomena under study as well as being able to affect them. My study adopts this approach of treating individual research methods as part of the whole device study assemblage. This means the methods of ethnographic observation, interviews, surveys, document analysis and design prototyping are used in conjunction with my own background knowledge and context to tell the narratives of the devices. I also adopt an approach to ethnography from Marrero-Guillamón (2015) who describes narrating a *"multiplicity of possible points of view; consequently, discovering and adopting such perspectives"* (p.14). He provides an example of combining interviews with different people to construct them into a singular spokesperson that can speak on behalf of an object and narrate its ontology. Figure 3.2 shows how the four research questions of the study are addressed by the research methods.

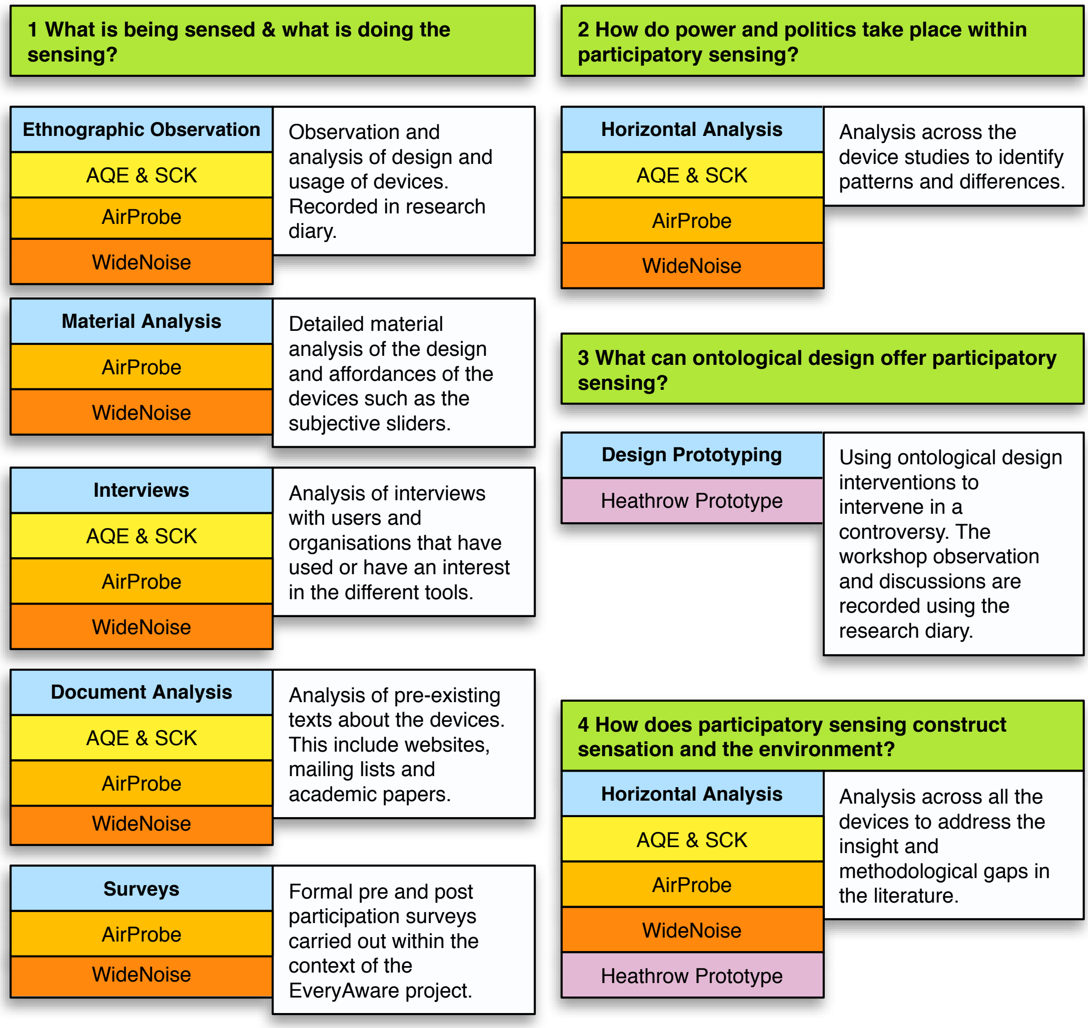

Figure 3.2: Methodology diagram showing how the four research questions (green) are addressed using a variety of data collection methods (blue) that are applied to the different device studies (shades of orange) and Heathrow prototypes (purple). The white boxes describe each method.

Ethnographic observation

The ethnographic observations were carried out during formal and informal meetings and events across the three-year duration of the EveryAware research project and subsequently during the design prototyping in Heathrow. The research question of 'what is being sensed and what is doing the sensing?' is a material-semiotic question that requires observation of material and human interactions. So the role of these ethnographic observations is to record the richness of micro narratives of the devices, whilst paying attention to my own and other people's interpretations and feelings as events are unfolding. This approach involves an awareness of auto-ethnography, but the aim is not personal experience (Ellis et al. 2011) or notions of subjectivity (Butler 2009); rather the intimate dynamics with the devices. Thus a lot of focus is on the way the devices are being configured and used and how this is reflected in the claims made about the devices. This approach is inspired by Lucy Suchman's studies where she suggests paying attention to *"how they talk among themselves and with relevant others, how they translate their own embodied courses of action into written accounts and other materializations, and how they assess the meaning and adequacy of materials created by others"* (Suchman 2000, p.312). These observations were then noted down as short first person research diary entries and stored as a series of individual text files on a laptop. The research diary entries are accompanied by multimedia material such as photos of devices being used and screenshots of visualisations. Some of the consortium events and internal meetings were also audio-recorded with the consent of the participants. Additionally material such as email communications were used to trace temporal patterns in discussions. After preliminary testing of this approach in the WideNoise study, this method of organising observations was standardised across the other device studies. Here is an illustrative entry from the research diary:

> *"Whenever I talk to [name] about helping calibrate the device, he always sends me these long complicated formulas that he doesn't seem to fully understand. When we tried to implement the formula it all seems to rely on a magic voltage level that can't quite be explained".*

An analysis of this extract highlights the way calibration acts to provide legitimacy even though the material basis is often blackboxed. Due the long duration of the studies, it was possible to track changes in these kinds of observations, such as the topic of calibration disappearing over time. These temporal patterns were analytically important for indicating that an ontological shift had taken place. These observations were then discussed with three other researchers from the EU funded project to triangulate these interpretations. Such changes were analysed using a relational mapping approach and visualised using the OmniGraffle software to identify patterns and connections between entities. The write up of the devices studies uses a ontological mapping method to illustrate the ontological relationship of actors. This technique was adapted from Fox (2017), who provides an example of mapping the connections of actors around an insulin pump, *"blood sugar – insulin – diabetes – pump – user – clinical specialist"* (p.141). This mapping method was used to analyse the ethnographic observations and clarify the structure of ontological changes across the device studies.

Material analysis

This method is focused on the material properties and affordances of the sensing devices. It involved detailed analysis of the source code of the WideNoise app in order to understand how the calibration function translated measured voltages from the microphone into decibel numbers. It also involved experimentation with the AirProbe device such as carrying the sensor box for a week to see how it affected my way of being in the city. This kind of material analysis was important for being able to understand how sensitive the devices were and how they would act within a real-life usage. This proved critical in order to have informed and detailed discussions with participants about their usage of the devices.

Interviews

The study makes use of two kinds of interviews. The first were structured interviews with participants within the remit of the EveryAware research project. For the AirProbe deployment in London all the participant groups were individually interviewed using structured approach with a fellow EveryAware researcher. These interviews were then transcribed and thematically analysed and triangulated. The focus of the interviews was on the goals of the EveryAware study such as motivation for participating and impacts of the activity. Yet these interviews were also used for my own ethnographic study and the respondents were informed prior to the interviews, that the data would be used for both of these purposes.

The second interviews carried out as part of my ethnographic study were much less structured and more responsive in terms of content and timing of interviews. As an example, I carried out an interview with a researcher of the Green team in a cafe after the final evaluation of the project, while we were waiting to catch a taxi to the airport. This responsiveness was crucial for being able to capture an immediate and emotional reflection on the AirProbe device that would have been lost otherwise. During these responsive interviews many different topics would be discussed without set questions. I saw my role as interviewer to reflexively introduce new concepts to the discussion and confront the respondent with contradictions. Whenever possible I would have the sensing objects physically present on the table while the interview was taking place, so that both interviewer and respondent would stay focused on the device and could handle and gesture at the object. This responsive and performative way of using interviews functioned within the broader approach of the device study where the researcher and context were a critical part of creating a sensitive research assemblage. Fox and Alldred suggest that in a new materialist approach *"interviews must be treated not as means to obtain subjective representations of the world but as evidence of how respondents are situated within assemblages"* (Fox & Alldred 2015*b*, p.409). Essentially, interviews are not about pinning-down people's viewpoints but about narrating the broader practices that the respondent is involved in. Here is a short extract from one of the interviews:

> **Interviewer:** *"I was watching your face when it was flatlining at zero. [Interviewer laughter]. During the demo it was recording zero. It is just sad".* **Respondent:** *"You can tell it to these guys. I was a bit surprised by the American guy, his background is in measurement".*

An analysis of the extract highlights the way the malfunction of the sensing device became an occasion for both humorous emotion and intensity that emphasises the ambiguity of the data generated. Due to the quantity of interviews, around 20 where fully transcribed, while the majority were analysed by identifying key sections for closer analysis. The coding of the interviews was carried out using a thematic clustering approach using the Scrivener software that allows textual chunks to be modularly re-ordered. I experimented with a structured coding method using ATLAS.ti, but this turned out not to be suitable since the level of close textual analysis was not appropriate for the wider research assemblage. The looser thematic coding in Scrivener allowed me to identify broader patterns that were then discussed and triangulated with fellow researchers.

Document analysis

This method is used to analyse the broad range of documents such as websites, videos, funding proposals and mailing lists that surrounded the sensing devices. Nimmo (2011) suggests that *"ANT offers a distinctive way of seeing texts which challenges the standard ethnographic view of texts and fundamentally transforms the issue"* (p.108). This means documents are not static representations but inscriptions that can act as actors in reshaping practices. This study uses this approach for documents such as the Kickstarter campaign videos of the Air Quality Egg and Smart Citizen Kit, which were critical to the success of gathering financial backers. Analysing these documents as anticipatory inscriptions provided critical insights into the intentions of the devices (Law & Ruppert 2013) in relation to issues such as accuracy, participation and distribution of sensation. The thematics of the documents were then analysed with a tight focus on the indicator of 'what is being sensed and what is doing the sensing'. These observations were then triangulated with fellow researchers.

Surveys

The study makes use of pre and post participation surveys of AirProbe and WideNoise created for the EveryAware project. The surveys were developed in conjunction with a fellow EveryAware researcher and were intended to gauge the motivation and change in environmental understanding of the participants. This thesis does not make statistical claims based on these surveys; instead, they are used as components of the research assemblage and in conjunction with the ethnographic observation method.

Design prototyping

This method involves the iterative prototyping of experimental devices to act as alternatives to the existing sensing devices. This involved the development of custom electronics and software. This method was used to revisit the Heathrow site and design a series of custom prototypes to investigate the infrastructure of the local controversy. It involved staging and facilitating workshops where the devices were explored and designed via a participatory design process. The prototypes functioned as interventions and provocations for local residents in a workshop with an aim of going beyond the existing framings of environmental pollutants. In this way, this method became a form of ontological design where a participatory sensing device could create new material manifestations and realities of noise. The discussions between participants of the workshop were recorded as audio files for transcription, coding and analysis. The overall process of prototyping was recorded in the research diary.

Ethical Considerations

When I started this research process there was no practice of ethics approval within my research department at UCL. So I used my own procedure in line with the British Sociological

Association (BSA) ethical guidelines (British Sociological Association 2002) and with an awareness of ethnographic good practice (Murphy & Dingwall 2001). I respected the physical, social and psychological wellbeing of the respondents in this study and minimised any possible harm due to this study. Most of the ethnographic fieldwork recounted in this study took place more than three years ago over the period 2011–2014. This time-delay between the fieldwork and publications lessens the 'temporal positioning of risk' (Murphy & Dingwall 2001, p.340) for the respondents of the studies, since the sensing technologies discussed have now been replaced with newer technologies.

I have anonymised all the respondents in the study in order to ensure their privacy and confidentiality. Respondents are referenced only via their role e.g. 'the resident'. The academic researchers on the EveryAware project are referenced as belonging to one of five different teams that are anonymised as Red, Blue, Green, Yellow and Orange teams. Sometimes researchers are referenced by the disciplinary context of their institution when this is critical for the argument being made.

All the respondents provided informed consent after an explanation of the goals of the research study, the research funder and how the research will be disseminated. It was made clear that people could withdraw from the study whenever they wanted. Where respondents were involved in both the EU research as well as my study, it was clearly explained to respondents that the data would be used for both purposes. This process of consent was ongoing and responsive. There was some opportunity for the respondents to challenge and clarify my analysis of events. The final text discussing the two EveryAware devices was formally submitted to two researcher from the EveryAware team for comment and clarification.

During formal interviews, the consent procedure was audio-recorded at the beginning of the interview. In collective meetings that were audio-recorded, the respondents were notified before each meeting and the microphone placed in a prominently visible position for all to see. An example of having to adapt this approach was the request from one of the EveryAware researchers that certain meetings should not be audio-recorded, which was immediately adopted.

The study does not communicate any private or confidential information and no personal email conversations are used within this study. The vast majority of the data that is cited in the AQE and SCK studies is publicly viewable on the project websites and open mailing lists.

The research data was treated as strictly confidential and handled in accordance with the provisions of the UK Data Protection Act 1998. All the data was stored on an encrypted laptop and all data backups themselves encrypted.

Chapter 4

Device study: Air Quality Egg and Smart Citizen Kit

This chapter is the first of three empirical device studies that follow a sensing device from its design, usage to output. The chapter uses a mixed methodology of participant observation, interviews with actors, document analysis and material analysis to describe the material practices of the device. The chapter addresses the research question: 'what is being sensed and what is doing the sensing?'

This chapter follows two related sensing devices: the Air Quality Egg (AQE) and Smart Citizen Kit (SCK) (Figure 4.1). The AQE is described as a *"a community-led air quality sensing network that gives people a way to participate in the conversation about air quality"* (Air Quality Egg 2012*f*) and the SCK as *"empowering communities to collect data of what's actually happening in their environment"* (Acrobotic Industries 2013). The chapter examines these devices together since they used the same gas sensors, firmware and have been described as versions of the same device, *"the SenseMakers worked on a sensor a few years ago called the Air Quality Egg, a kind of version 1.0 prototype...the Smart Citzens Kit was 2.0 version of that"* (Henriquez et al. 2016, p.78). Both the AQE and SCK were funded through Kickstarter campaigns that involved members of the public pledging money to support the projects. In addition the AQE development was supported by an IOT company called Pachube (later COSM) who paid for a community organiser to work with a network of contributors called 'SenseMakers' (Sensemakers 2015). The SCK was created by a group of people associated with the Barcelona Fab Lab. Each device was associated with a small group of individuals that gave the vast majority of interviews and created most of the mailing list posts and became the de-facto spokespeople for the device. Throughout I will be referring to these people as the AQE and SCK organiser(s).

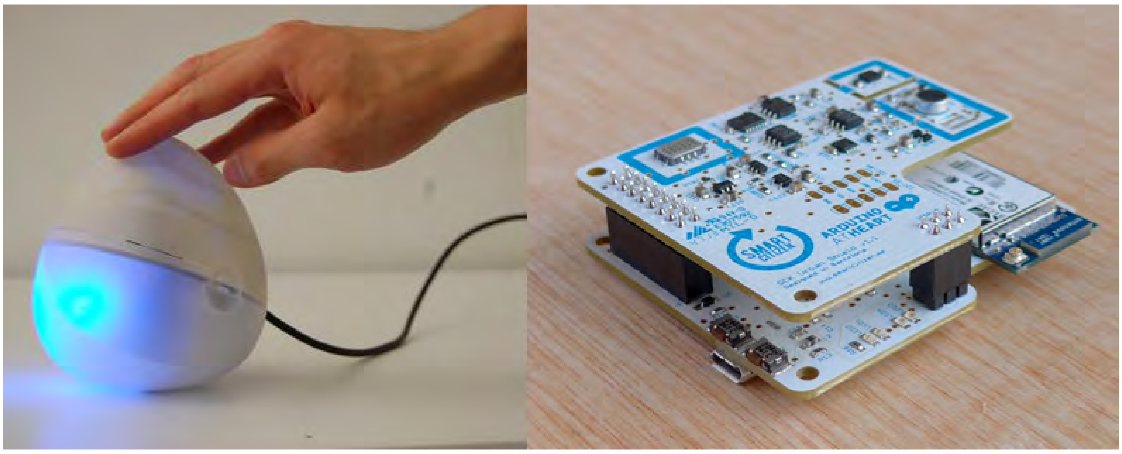

Figure 4.1: Left: Photo of the Air Quality Egg (AQE) from the project wiki (Air Quality Egg 2015). Right: Photo of the Smart Citizen Kit (SCK) from the documentation page (SmartCitizen 2013).

The AQE consists of an outdoor sensor unit and an indoor base unit. The name of the device relates to the egg-shaped base unit that uploads the data to an online data repository and visualisation. The sensor unit measures temperature, humidity, nitrogen dioxide (NO_2) and carbon monoxide (CO). The Smart Citizen Kit (SCK) is a single electronic circuit board that can powered by a battery or solar panel and uses Wi-Fi to upload data to the Internet. The device measures temperature, humidity, NO_2 and CO like the AQE, but also measures light and sound intensity and the number of nearby Wi-Fi networks. Both the AQE and SCK use the same cheap NO_2 and CO sensors that are intended to measure in the parts per million range as can be seen from the technical data-sheets (e2v Technologies Ltd. 2008, 2009), rather than parts per billion range as usually used within environmental air quality monitoring.

This chapter tells the story of both the devices from their early beginning when they gathered public interest by stringing together hardware and rhetoric to recruit a human network of backers. Yet both devices created a split between the technology that is described as high-resolution and a more vaguely articulated smart citizenship community. The issue of calibration triggered an ontological fracturing between the reality of the hardware and the rhetoric. Neither device managed to construct a meaningful instrumented network of concern that could deal with the challenge of low-cost sensors. The result was that people who were hoping to deal with air quality as a health or political concern were marginalised and could not use the devices. The devices enacted environmental sensing that does not engage with pollution as a health or political concern and cannot hold anybody accountable. Yet the legacy of the devices is that they became good practice exemplars of smart citizenship and citizen science.

The overall aim of this chapter is to narrate participatory sensing as a site of struggle between competing ontologies of the environment. The aim is to describe the mechanisms by which these ontologies are contested and identify the potential of enacting alternative participatory sensing that can create more pluralistic environments (chapter 8).

4.1 Design: AQE as movement that strings together pollution, ohms and revolution

This section introduces the AQE as being configured by stringing together rhetoric and material tinkering into a single device that could attract publicity and gather a network of backers.

In March 2012, the AQE launched as a Kickstarter campaign with each device costing $70. The campaign was extremely successful at gathering 927 backers and far exceeded its funding goal 3.5 times over. The campaign targeted people's health concerns about air pollution by asking the provocative question *"Do you ever think about the air you breathe?"* (Air Quality Egg 2012*f*) and suggesting that pollution *"affects us in ways we can see and also in ways we can't see. The Air Quality egg is a project working to make the air we breathe more visible"* (ibid.). As a solution the AQE offered *"to allow anyone to collect very high resolution readings of* NO_2 *and CO concentrations"* (ibid.). On the campaign page the AQE thus communicated itself as a measurement device that would produce data insights into one's own air pollution exposure.

The AQE first came to my attention four months before the launch of the Kickstarter via a blog post that asked people to join a grassroots movement for monitoring air quality. What was remarkable about the post entitled *'You can help build an open air quality sensor* *network'* (Pachube 2011), was the emotive language it used to make its case. The post argued that governments are *"completely useless"* (ibid.) at providing pollution data that is meaningful for understanding how much pollution is *'RIGHT. OUT. THERE. 12 inches from your face'* (ibid., emphasis in original). The post argued that there is a massive public interest in air quality and that *"the dialog online has reached a deafening roar and everyone has a cause"* (ibid.) but what is missing is *'hard evidence'*, since *"without real air quality data, people can be easily brushed aside, or worse, ignored"* (ibid.). The post argued that 'we' as a technical community can create a solution by doing our own fundraising and building a network to *"put 50,000 $100 sensors systems into a city, a collective voice which won't be able to be ignored"* (ibid.). By raising this money and deploying these thousands of sensors, this network would become *"an unstoppable movement that will re-shuffle the way issues get discussed"* (ibid.).

What is remarkable is the emotive framing of 'them' and 'us' and use of phrases such as *'brushed aside'*, *'deafening roar'* and use of uppercase letters. Together they create a dramatic call to action that directly addresses the reader to join this movement. When I discussed the post with a researcher who was examining the AQE project, they attributed this strident tone to the organiser of the project who had recently been involved with the Occupy social movement. Occupy was known for its incendiary and sophisticated use of language such as the infamous slogan: *'we are the 99%'* that claims to include the vast majority of people. Postill (2016) describes this phrase as a 'bridging frame' that creates a connection across division between working and middle class to establish a new collective constituency - *'the 99%'*. I argue that the language of the AQE post functions in a similar way as a collectivising bridge to construct a new air quality network. Here I examine another extract from the post:

> *"Nothing screams, 'Take action!' like a link to a datastream updating in real-time showing how people are being affected at this very moment. This is the next form of self-expression, a la YouTube, and it's already happening"* (Pachube 2011).

The emphasis on the data-stream and YouTube as forms of self-expression, is remarkable for the way it conflates technical platforms with human communication. The implication is that the AQE network involves a whole spectrum of human and technical entities into one all-inclusive network 'of the 99%'. This is clarified when the post argues that *"the engine* *and scale of the internet community has put what we need to solve this problem within our grasp"* (ibid.). The rhetoric of the post thus amplifies the AQE into a massive global air quality network that consists of a heterogeneous mix of physical sensors and humans. At the same time, the quote argues that this movement is *"already happening"* so all one has to do is join in, thereby recursively presupposing and using its own existence to give itself credibility. It is worth observing how much more the blog post adds to the Kickstarter campaign of the AQE by expanding the sensing object into a device (Law & Ruppert 2013) with an extensive agenda. Instead of merely selling a mundane pollution measurement object, this blog post outlines a grand recruitment drive for a new socio-techno network that will transform the world.

A few days after the Kickstarter campaign launched, I took part in a hands-on AQE workshop in London, where around 15 people each paid $70 to build an AQE prototype. The day was spent soldering up printed circuit boards and connecting sensors. In the introductory talk, one of the organisers described the AQE's pollution sensors as metal filaments that are coated with a substance that is sensitive to specific pollutants. To identify air pollution, voltage is applied to heat the filament and the resistance across it is measured. One of the organiser said, *"all we are doing is pushing power into the sensor which has 6 pins and we are sensing a change in resistance"*. I was struck by the pragmatic clarity of this description. The presentation shifted to discussing the way the US Environmental Protection Agency was trying to deal with calibration and data verification of the cheap sensors created by citizens. The presentation spliced together the problem of using a 10bit analog to digital converter to measure electrical resistance and the challenge of comparing this data with institutionally sanctioned air quality sensors. What I found exhilarating was that in the space of a few sentences, the presentation had associated and collided the physical properties of a heated metal filament with the epistemic problems of coordinating the knowledge politics of institutional and grassroots air monitoring. I felt the presentation was an amazingly concise summary of the problems of low-cost sensing, which zoomed between the micro-scale of electric filaments and macro of institutional politics. In this presentation I got a feeling of the exciting disruptive qualities of the AQE, that did not accept air quality as an institutional scientific problem but something that people could be materially engaged in. Assembling the AQE sensors and measuring the electrical resistance of the filament directly enmeshed each of the participants in the material politics of air quality. The AQE promised to shortcut the bureaucracy of air quality monitoring and turn it into something tangible that anybody can do for himself or herself. This was very different from the later AirProbe study, where the material properties of the sensors remained hidden for the participants (section 5.2).

After the workshop, I joined a small group of the workshop participants that went to the park to discuss what they wanted to do with their eggs. What was interesting was the diversity of interests. Three of the participants were interested in the AQE as an exemplar of IOT technology and community organisation. One participant was sent by their company to see how the AQE can be monetised. Another saw the AQE as an extension of the electronic tinkering they were doing with automation technologies in their home. Two participants talked about their distrust of governmental and commercial air measurements and how the AQE would allow them to check it for themselves. One of the participants talked about the AQE in relation to the Arab Spring, suggesting that it might be as transformative of power relations as the printing press. Meanwhile another participant talked about the AQE as creating a kind of cybernetic awareness between people and the environment. What I found striking was the way the AQE managed to bring together such a vast range of different understandings that made the AQE seem much **bigger** and more **exciting** than a mere electronics board with two gas sensors.

One of the key aspects of the AQE is revealed on its Frequently Asked Questions (FAQ) page, where the organisers suggest that *"it's the stringing together of all of these elements that is really special about what we are doing here* -> *funny, warm Egg visual; tactile and personal interface inside; citizen science; crowdsourcing data; community-designed"* (Air Quality Egg 2012*c*). The quote suggests that the AQE is made up of a diverse mix of elements including humour, the visual design of the device, the tactility of the hardware as well as a variety of rhetorical concepts. I suggest that the phrase 'stringing together' perfectly captures the radically combinatory mixing of electronics, graphic design and rhetorical associations. My argument is that the success of the Kickstarter campaign can be put down to the way it translated heated metal filaments into an emotive call for revolution that were packaged together into an affordable product that people could purchase. This surprising combination made the AQE into something radically different from the pedestrian topic of pollution sensing and allowed the AQE to win the best of Kickstarter 2012 award (Kickstarter 2012), before it even existed as a physical object. During one AQE meeting I attended, one of the participants asked whether the aim was to build a new society or a product, to which nobody offered an answer. The early success of the AQE can be put down to managing to keep both of these motifs in the air without having to declare for either one.

4.2 Design: AQE as high-resolution network and beacon of care

I now turn to the way the AQE splintered into a technical network of high-resolution data flows and a human community of 'care'. I argue that this bifurcation into objective and subjective networks created an ontological politics that ended up disabling the transformative potential of the AQE.

In April 2012, just as the AQE Kickstarter was reaching the funding deadline, a post appeared on the campaign page admitting that it would be impossible to accurately calibrate the gas sensors. Instead the device would only show trends that *"allow us to see, albeit cloudily, the hints of problems/anomalies that are occurring in real-time"* (Air Quality Egg 2012*g*, para.5). The post also argued that *"sensor calibration and precision is the wrong conversation"* (Air Quality Egg 2012*g*), since the *"PRIMARY purpose of this project is accessibility. Everything is based on open source designs and we are choosing the sensor components based on affordability and availability"* (para.1, emphasis in original). The post went on to argue that sensor calibration might actually be harmful to the overall AQE project, *"undermining what we are doing here"* (ibid.) since it *"inserts a dependency on someone"* (ibid.). The argument being made was that calibration requires expensive equipment and specialist knowledge that only exists in scientific institutions and involves a continuous relationship rather than just being a one-off process. The problem being presented is a political question of how the AQE project should orient itself in relation to scientific institutions. The post went on to argue:

> *"There are already scientific sensors systems available out there. They gather 'better, more reliable' data that [sic] the Egg will. But, 'better' for WHO? We are not out to contribute to the agenda of the scientific community or otherwise. We are our own community of people with our own goals, our own momentum and our own vision"* (Air Quality Egg 2012*g*, para.2, emphasis in original).

The extract makes the intriguing suggestion the AQE community should be autonomous and not engage with existing scientific standards to focus on its own vision of air quality. Yet strikingly the blog post does not clearly spell out the nature of this alternative air quality and only obliquely hints that *"this community has understood from the beginning that any single datapoint that we collect has low value while the breadth, resolution, and update frequency of the network has high value"* (Air Quality Egg 2012*f*). The suggestion being made is that 'resolution and update frequency' represent an ontologically different kind of environmental sensing that is distinct from the institutional one.

Unfortunately, this argument didn't seem to convince many of the AQE backers who focused on the perceived technical shortcomings of the device when leaving strongly worded comments on the Kickstarter page, *"if this is true, it's a bit of a shocker (my fault for assuming the sensors would be accurate)"* (comment 17). Others suggested that *"without this stability for new and aged or ageing AQE's and sensors, we have a toy and not one which one would recommend for a community to distribute, open source/access or not"* (comment 5). The point being that the backers did not see the physical limitations of the sensors as a possibility for political autonomy from science and institutional politics but rather as a material limitation on the possible scope and impact of the AQE community.

These arguments continued on the AQE mailing list, where some of the contributors started suggesting that the campaign had misrepresented the device by talking about *"very high resolution readings"* (Air Quality Egg 2012*f*). The AQE organiser responded to these criticisms by trying to clarify the notion of 'resolution' by arguing that the, *"intent of this terminology was used to primarily describe the FREQUENCY of datapoints/updates as compared to the official datasets available currently, but we also had the potential DENSITY of the sensor network as a whole in mind as well when that was written. I can see this as possibly being confused with a description of ACCURACY, which is most certainly not what was meant!"* (Air Quality Egg 2012*e*, emphasis in original). In this quote the AQE organiser suggested that the phrase 'high resolution' meant that the AQE network would be generating vast amount of data at a much more rapid pace and density than the official scientific sensors, even if if these measurements were not as accurate. Yet many of the backers and mailing list contributors seemed unconvinced and accused the organisers of obfuscation. For them, frequency and density of data points were meaningless noise unless those data points had some validated relationship. What they wanted was a firm relationship between the data and the pollutant that would create a chain of associations to make the device data comparable to an external reference and address institutional actors.

However, my feeling is that we should slow down in blaming the AQE organiser and explore this proposed notion of 'resolution' in more detail. My argument is that the disagreement about what resolution means highlights a key ontological and political conflict at the heart of what AQE was attempting to sense. If we take the organiser at their word, then the AQE's primary goal was simply to create a global network of sensor nodes. This interpretation is actually supported by my analysis of the AQE hardware. While I, and many other observers, had assumed that the multicoloured LED inside the egg enclosure changes to indicate local air quality, this is not actually correct. Using the default firmware, the LED colour is used to indicate a successful data upload to the network. If the AQE and network are both functioning well, then the LED will go through a colour cycle every minute (Wicked Device 2016). The surprising conclusion is that the AQE does not actually visualise air pollution but merely its own network status and might be more appropriately named 'Network Egg'. During the IOT assembly in June 2012, the AQE organiser described the origins of the device as wanting to build a generic global sensor network, while the concept of air quality came later. It is worth keeping in mind that the company that hosted the AQE data and paid the salary of the community organiser were using the AQE to promote their data-posting platform. Thus it doesn't seem far fetched to imagine that the project's priorities were building a global sensor network over the technical intricacies of environmental monitoring. I suggest that air pollution functioned mainly as a vehicle that would make sense of setting up this sensor network. Some of the contributors on the mailing list noticed this tension and suggested there was a conflict between measuring pollution exposure and creating a global sensor network:

> *"I'm seeing people that want to use the devices to monitor landfill fumes and people that would just like to use the devices to demonstrate 'safe and constant' internet service as interesting contrasts between Capitalist gain motivation and individual health motivation"* (Air Quality Egg 2012*h*).

My suggestion is that the AQE brings two ontologies of the environment as health impact and another as data traffic into contact with each other. Yet these ontologies come into conflict around the material property of the sensor device. Perhaps in a attempt to resolve these conflicts, the AQE rhetoric focuses on the notion of creating a community of 'SenseMakers' (Sensemakers 2015). The suggestion being that the AQE would function as a *"network that gives people a way to participate in the conversation about air quality"* (Air Quality Egg 2012*f*). To understand how this community conversation was functioned, I analyse a sign created by the AQE organising team to publicise a workshop at the Citizen Cyberscience Summit in February 2012 (Figure 4.2).

Figure 4.2: Poster announcing the Air Quality Egg workshop at the Citizen Cyberscience Summit 2012. Note the use of capitalisation to emphasise the ontological distinction between the objective nature of air quality and merely caring about it.

This international event was an important forum for the AQE and was sponsored by Pachube, the company that were supporting the development of the AQE. At the event the AQE's sign proclaimed that *"this is not a project about saying 'This is what air quality **IS**,' it's about saying 'We **DO CARE ABOUT** air quality"'* (emphasis in original). I interpret the poster as a preemptive defence against those that would argue that due to the inadequacy of the sensors, the AQE couldn't speak about the true nature of air. In effect the sign establishes a bifurcation between two realities - what air quality **IS** and **caring** about air quality. The poster suggests there is a clear hierarchy between the objective scientific properties of the world and people's feelings that are secondary. This theme was repeated on the mailing list, where the AQE organiser argued that:

> *"We don't hide the fact that these sensors are relatively shitty. But that can simply provide a platform for you to discuss and to contribute based on your own work. What is on offer here is a community of people who care, not a hardware device"* (Air Quality Egg 2012*d*).

What is interesting is that the quote tries to separate the community from the hardware to suggest that an air quality conversation can take place that is separate from the 'shitty' sensors. Yet exactly what the participants should talk about is unclear, since it is only the hardware that brought them together. On the mailing list there are hints about the intended nature of the social interaction when the organiser argues that *"every deployed Egg is like a beacon. It says, 'Hey, I care about this!"'* (Air Quality Egg 2012*a*). The quote implies that the AQE facilitates a kind of social marketing of ones own 'care'. The use of the word 'beacon' implies that the device should function like a bumper sticker that signals one's environmental credentials to others. Interestingly, the notion of the AQE as symbolic display is supported by anecdotal descriptions from people who described to me seeing AQE devices displayed prominently (yet turned off) within design studios as a kind of badge of belonging to the maker culture. It seems that the resulting community conversation was intended to signal environmental awareness and maker identity rather trying to have a more substantive impact on the reality of air pollution.

The AQE's Kickstarter campaign had been successful in rhetorically stringing together many heterogeneous concepts of air quality. Yet this assemblage was broken apart as the technical challenge of building the device to have calibration reference became clear to the organisers. The result was that air quality was bifurcated into a scientific problem of objective measurement, while people's health concerns were framed as symbolic discussions. What was lost was the possibility of enacting an alternative kind of air quality. Instead the result was merely the enactment of two flawed networks: one that creates data of its own network activity but due to its poor sensors, says nothing about the world; while the other human network symbolically declares that it 'cares' but can't materially engage with the pollution particles in the air.

4.3 Design: SCK as ambient citizenship

The SCK is physically a highly similar object to the AQE, but manages to string together an even broader range of rhetoric. Yet this also involves a fracturing between the physical properties of the hardware and the rhetoric of smart citizenship.

In June 2013, roughly a year after the AQE Kickstarter campaign, the Smart Citizen Kit (SCK) appeared on Kickstarter costing $155 plus shipping. The SCK Kickstarter was not

Figure 4.3: Screen capture from the SCK campaign video showing the sensor board arranged to sit on river pebbles to highlight its environmental credentials.

as successful as the AQE but still managed to reach its funding goal, raise $68,000 and gather 517 backers. The SCK firmware and hardware are based on the AQE and the device uses the same gas sensors but adds additional sensors as well as a smartphone app and online data platform. In order to gather backers, the SCK piggybacked on the publicity of the AQE by targeting people who already had an AQE or were interested in the device. It appears that the SCK was promoted through a campaign of posting promotional comments on around a dozen AQE related websites:

> *"I would suggest to get a Smart Citizen kit instead. They have more sensors, it is self-powered using a solar panel (included in the kit) and it is going viral now worldwide. I expect the Smart Citizen kit will have much more users worldwide in the coming month"* (Verrilli 2013).

The interesting aspect of the post is the way it emphasises that 'more' sensors and 'more' users are the main benefits of the SCK. The organised campaign of placing comments on AQE related website can be seen as a way of trying to highjack the existing AQE user community. The tone of the SCK Kickstarter campaign is also very similar to the AQE, suggesting that the SCK would be *"empowering communities to collect data of what's actually happening in their environment"* (Acrobotic Industries 2013). Where the SCK differs is that it is more evasive than the AQE about what the device actually senses. This can be seen in the campaign video that focuses on the attractive circuit board, arranged on a variety of natural backgrounds such as moistened pebbles by the side of a river

(Figure 4.3). This image is not a practical deployment since the circuit board is not waterproof and has no power-source; instead the aim of the image seems to be to create a symbolic association between the SCK and nature. This symbolic approach continues in the way the hardware is discussed on the SCK website, where the CO and NO_2 sensors are referred to as *'air composition sensors'* and the Wi-Fi chip that is used to upload the data, is referred to as a *'network sensor'*. In contrast, the campaign does not mention the accuracy or limitations of the gas sensors. When I interviewed the SCK organiser to clarify the measurement quality of the gas sensors, they argued that the SCK was better than the AQE because:

> *"Our device has extra features than the Air Quality Egg [...] One of the things is having a sound sensor in the board. Also we are using the Wi-Fi antenna as a sensor as well, so we can know which is [...] the amount of networks. We have a very good charger and our chip lasts around 30 hours"*.

It is striking the way the respondent sidestepped the issue of measurement quality in favour of highlighting additional features and sensors. It is notable that the SCK campaign and websites do not feature the word 'pollution' and do not draw specific attention to the gas sensors. Yet this raises a fundamental question of what the SCK is actually sensing. The SCK Kickstarter webpage describes the hardware as *"the Ambient Board"* (Acrobotic Industries 2013), suggesting that the SCK is sensing an non-specific and amorphous environment. In the Amsterdam deployment, the SCK was described as sensing *"the local climate in various neighbourhoods"* (Blom & Zandbergen 2015). By building ambient sensors, the SCK enacts a form of environmental sensing that is not focused on pollution as an issue of health exposure or political contestation but as something rather different. In the interview with the organiser, the conversation quickly shifted from hardware sensors towards the ambitions of the project. When I asked how the SCK would relate to existing institutions, they replied:

> *"We will have the capability of having more resolution than the government, this means at least 10% of the citizens could put sensors on their balcony. We will have a bigger amount of sensors that will give us more resolution of the data and more points of comparison"*.

The SCK thus makes an identical argument as the AQE, of having 'more resolution' - meaning more frequent data updates than governments. The organiser also argued that the project can import existing governmental data that the SCK does not have access to such as traffic information. The argument the SCK presents is that it will become a platform for constructing autonomous cities and citizens that will transcend existing institutions. The organiser argued that the SCK would extend human capabilities and support citizen science, urbanism, e-health, agriculture and facilitate neighbourhood 3D manufacturing. Yet how does the SCK manage to string together this list of ideas and combine them into a single device? The website describes the SCK as a *"node for building productive and open indicators, and distributed tools, and thereafter the collective construction of the city for its own inhabitants"* (Smart Citizen 2016*b*). The quote implies that there is an inevitable progression from sensors to the collective construction of cities. When I asked how this would happen, the organiser mentioned 3D printing technologies. The idea being that the SCK would become a universal sensing and actuation hub, where the physical world can be digitally scanned (sensed), computationally transformed and then 3D printed out to create new cities. The SCK's grand claims are thus based on piggybacking on another technology that has received vast amounts of publicity for its potential global impact. The reason the SCK suddenly seems to be much bigger than a mere electronics board is because manages to string together entities that are themselves in hype. Yet the ambitions of the SCK extend further as can be seen on the Kickstarter campaign that claimed the device will create new kinds of environmental citizenship:

> *"We are **not** asking you to eliminate your carbon footprint, nor attempting to turn you into a climate change crusader, nor claiming that the end of the world was triggered by you not recycling that can of soda last week... Experts of all kinds and points of view are working hard to tackle these problems, and talking heads add their two cents daily. Our goal is **not** to add to this chatter, but to help in the best way we know: Empowering communities to collect data of what's actually happening in their environment"* (Acrobotic Industries 2013, emphasis in original).

The quote rejects institutional framings of environmental behaviour such as recycling that are being promoted by 'experts'. Instead the SCK proposes a new form of citizenship that is based on generating and observing data. The campaign video provides some detail of what is meant by this, by showing two users talking about the way they use the SCK, *"I use my kit everyday, normally I take it in the morning just to have a global awareness of what is going on"*. The second person says, *"I check it everyday to see how the information is updated and how the data is uploaded for other people to see"*. Surprisingly there is no mention of cognitively analysing the data for its content. Instead the SCK proposes a kind of ambient data awareness that creates an affective feeling of data connectedness to a global sensing network. The SCK thus invokes the vision of the earth covered in an electronic skin of automated sensation (Gross 1999). In this way the SCK proposes a radically different notion of environmental citizenship from the classic concept of a democratic public sphere based on rational discourse (Habermas 1984). Instead the SCK offers a decentralised environmental citizenship that is based on an individualistic awareness connected to collective data flows. If we see the SCK as an example of the autonomous networks narrative (subsection 2.3.3), then we can see it offering a distinctly new smart citizenship that is different from governmental information campaigns or attempts to nudge people towards behaviour change (subsubsection 2.3.2.2).

Yet there is a striking gap between the grandeur of the SCK's visions and its material practices. While in some public presentations the SCK was described as a tool for organised environmental monitoring (Diez 2015), the website offers no guidance for how to apply the device for this purpose. During an event I attended in Amsterdam in April 2016, the scenarios being proposed by the SCK organisers were to observe the temperature change in the fridge as the door is opened and noticing the effect of next door's air conditioning. I suggest there is a wide gap between the vision of the SCK and the prosaic possibilities of the physical object. During the interview with the organiser, I was struck that when we were talking about the hardware, the conversation took place at a transcendental level, where the device seemed to be unconstrained by physical limitations. This can be seen in the way the SCK was renamed to 'Smart Citizen' by dropping any reference to the physical hardware 'kit'. The project also adopted the slogan - *'upgrade yourself with others'* suggesting a science fiction vision where humans can improve themselves by inserting new sensors into their bodies. The feeling I had was that the SCK was trying to shed the material world in favour of sensing as a techno-spiritual practice of transhuman citizenship.

Yet the result is that the SCK is very similar to the AQE in the way it enacts environmental sensing as solipsistic data generation and curation. The fracturing between the rhetorical ambitions and the limitations of the hardware mean that there is no external environment being sensed. Instead the environment is enacted as a symbolic and immaterial aesthetic that seems to offer little transformative potential. The next section explores the usage practices of this device.

4.4 Usage: AQE & SCK as technical tinkering and data confusion

By examining three usage groups that had different experiences with the AQE and SCK devices, I demonstrate that certain kinds of sensing practices were prohibited by the way the devices were ontologically configured.

One of the AQE community organisers I interviewed suggested that there were two distinct groups involved with the device; a small group of core contributors to the hardware and software who had their own mailing list and gathered at physical meetings, and a large group of backers who had supported the Kickstarter but did not have their own place to discuss the project. I also identify a third group of coordinators and participants within organised local deployments. With the AQE it is easy to follow the activities of the core group via the mailing list and technical wiki. The SCK is more opaque since the development of the device seems to have been carried out by a group based around the Barcelona Fab Lab, who did not publicly document their development process. The voices of backers appear sporadically in the project mailing lists, forums and personal blogs.

Core Contributors

The AQE was created through a network of core developers and a larger distributed network of technically inclined contributors. This group shared technical information and observations on the mailing list and organised public meetings via the Meetup platform. The researcher Ilze Black, who has been observing the AQE workshops, argues that the Meetup platform was crucial to the development of the AQE in facilitating *"the research, development and production of the AQE device (or the product), understanding the data (or information delivered by the device), and sustaining the data network"* (Black & White 2015, p.206). On the mailing list there are reports from AQE workshops where people describe their insights:

> *"We discovered that the* ***sun [i.e., heat] distorts heavily*** *NO_2 sensor measurement. It is necessary to put AQE sensor units under cover or in the shadows, to make measurement conditions stable. Otherwise we will get false positives that render data unusable"* (Air Quality Egg 2013, emphasis in original).

In another report, a participant describes the counterintuitive insight that a decrease in the numerical resistance of the metal filament may indicate an increase in gas concentration (Air Quality Egg 2012*a*). In these reports it is possible to see the contributors engaged in practical tinkering that for them opened up the device and allowed them insights into the way the sensor behaved. Yet the AQE wiki (Air Quality Egg 2013) that collates these findings, shows that these insights never translated into pollution exposure or health effects. The 'Data Quality' page on the wiki lists a large variety of technical topics such as cross sensitivity, stability and traceability, yet the page is littered with unanswered questions such as *"is this practical? How close is close enough?"* (ibid.). The page offers no conclusions and captures the insurmountable technical challenge the AQE contributors faced. There is a contrast between the electronic parts of the device that are heavily explored, while the 'Measured Phenomena' page is almost empty with just a few links to Wikipedia. This shows that the AQE contributors came to understand the electronic properties of the object, while gases, pollutants and health impacts remained unknown. There is an enormous difference between this representation of the AQE and the earlier visionary recruitment drive for a revolutionary network of change. On the wiki there is no evidence of an alternative or autonomous community vision of air quality. Instead the language and processes of engineering and environmental science are used to try to relate the device to externally validated technical procedures and metrics. The AQE represents air pollution as complex technical jargon that multiplies confusion and makes it seem like an impenetrable monolith that no community group could ever unravel. The effect is that neither the AQE mailing list nor the wiki clarify what the AQE is able to measure or make the topic of air quality more intelligible. Instead of assembling a revolutionary movement driven by the printing press, the end result is that the AQE is disassembled into its electronic component parts. Despite the argument that the project was intended to be a *"community of people who care, not a hardware device"* (Air Quality Egg 2012*d*), the attention that is evidenced within the project is only towards the hardware rather than community building. It is worth reflecting on the *SenseMakers* name that the group gave themselves and conclude that the project created a very partial 'sense' that divided air quality into objective hardware and a subjectivity of health exposure and political organisation, that the project had no language or methods to deal with. Yet it is possible to see from the mailing list that some of the AQE contributors learnt from this failure suggesting, *"given what we now know 2–3 years later, the build first ask questions later approach* *seems questionable"* (Air Quality Egg 2014). However, there has not yet been any co-ordinated evaluation of the device and these loose reflections have not been gathered together. With the SCK, the whole development and testing process cannot be followed in the same way since it has not been made public. In comparison, the DustDuino project, which is a similar air pollution sensor, has published a formal evaluation that highlights critical hardware problems as well as the impact of different funding structures and issues with internal communication (Hagen 2016).

Backers

The evidence I have about the material practices of the Kickstarter backers is from the mailing list/forum, personal websites and from individuals I met at public events. One AQE backer I met had created an online guide with software code they had written to help people create their own visualisations from their AQE. What was interesting was that the guide included two graphs of data from the device situated on the author's balcony, which triggered an extensive online discussion. One visitor wrote:

> *"As an air pollution expert I really wouldn't believe that data! I had dismissed those devices a while ago as being pretty much a complete joke – now seeing your data it looks very much like a random number generator. Is that really suggesting a trend of 400ppb – the legal average is 21ppb! Just because statistics can get a wibbly line out of it doesn't make that level of scatter credible"* (Neylon 2013).

Seeing this comment, the guide author wrote that they went and compared their data with official data and responded that indeed the AQE *"does seem pretty useless"* (ibid.). Interestingly the author's webpage then became a discussion between a variety of different backers, who began to ask questions about the quality of their AQE and SCK devices. This incident on a third-party website illustrates that the backers did not understand the data being generated, could not find any clear information and did not have a productive space for discussing their queries. This is also confirmed in a report about the SCK which states that *"users who did manage to install their SCKs also struggled to make sense of the data collected and in many cases had doubts with regards the accuracy of the data"* (Balestrini et al. 2016, p.39). The SCK forum is full of examples of confusion about the data:

> *"My SCK measures CO levels (600+ ppm) that are life threatening according to the internet: [wikipedia link]. Also my NO_2 levels seem to be way off chart: 460+ ppm"* (Smart Citizen 2014).

An SCK organiser replied in the forum that the data values were raw electrical resistance measured in Ohms and not actually gas concentrations and provided the backer with weblinks to the sensor manufacturer data-sheets. To which the backer responded *"thnx! Will have a look at these!"* (ibid.). The casual nature of this exchange and the backer's lack of anger at having been misled are striking. It suggests that the sensor data was not a major issue of concern for either the organiser or the backer. If either side thought these numbers mattered greatly then I would have expected this exchange to have a different tone. On the SCK documentation page, the topic of sensor calibration only has the phrase *'Coming soon!'* written next to it more than 3 years after the launch of the device (Smart Citizen 2016*a*). During one SCK event I attended, the organisers suggested that calibration was something that the participants should do themselves.

My own experience with an early AQE prototype that I built in the workshop was that the NO_2 level spiked at regular intervals that coincided with the heating element on the sensor board switching on and off. This suggested that the prototype was only sensing its own measurement operations. When I asked other workshop participants they confirmed this problem and similar behaviour was reported on the AQE mailing list (Air Quality Egg 2012*a*). While I was angry, the other participants seemed surprisingly much more sanguine. Based on my analysis of the mailing lists and forums as well as face-to-face meetings with backers of both devices, the lack of accuracy of the final devices was similarly not a source of anger but rather mild-mannered confusion. Many of the backers appeared to be employed in the IT industry or were academic researchers and technically able. For them the AQE and SCK appeared to be objects of personal and professional curiosity and they treated them as electronic toys that could be experimented with as prototypes of future IOT technologies. While these participants seemed to enjoy the act of generating and curating data, air quality was a matter of mild curiosity rather than a fear about personal health exposure. This meant the content and calibration of the data had relatively low importance for these backers.

However, there was another group of AQE and SCK participants: people who were directly affected by air pollution. These people are notably absent from the forums, mailing lists and websites. The main glimpse I got of these people was at the start of the AQE project, when one of the coordinators posted the public responses to a survey where they had asked potential backers to describe their interest in air quality. The survey shows a significant proportion of people writing about pollution as a direct impact on their lives and health. These people often gave significant detail about their personal circumstances:

> *"My family lives several miles from the Rhode Island Central Landfill, which was never an issue until around September of this year, when foul gas odors began emanating from the landfill and spreading far beyond the landfill's boundaries. Sometimes the smell is so pronounced and gag-worthy as to induce headaches and nausea"* (Air Quality Egg 2012*b*).

Significantly, these accounts focus on a wide range of pollutants and their effects such as mining byproducts, factory gases, radioactive phosphates and radon gas, while sensing devices are much less present in these accounts. It is crucial to note is that this list is the only place where these stories of personal exposure to pollution and accompanying fears appear. It is not clear whether these people ended up not backing the AQE or whether they could not set up the devices, which was a major problem for many of the non-technical backers. A report about the SCK acknowledges that *"around 60% of them never actually managed to set up their sensors for example, suggesting technical difficulties or that they didn't have enough time to get their sensors up and running"* (Balestrini et al. 2016, p.39). Whatever the reason, the result was that the accounts of these people who wanted to use the devices for engaged purposes are not reported on the project website. What this incident shows is that there were a significant number of backers who wanted to use the AQE to tackle specific environmental health issues. Even amongst those people who were not directly affected, environmental pollution exposure was the main framing through which people talked about the device on the forums and mailing lists.

Organised Deployments

Both the AQE and SCK have been used for organised workshops and large-scale deployments by third-party organisations. Yet many of the deployments are merely publicised without any post-event documentation. Therefore I focus on deployments where there is some significant post-event information available.

In April 2014, a journalist reported on a organised large-scale deployment of around 100 AQEs in Louisville USA (Bruggers 2014*a*) set up by the non-governmental Institute for Healthy Air Water and Soil (2016). The organisation subsidised the deployment of the devices but individual participants still had to buy the hardware devices. The town has previously acknowledged air quality problems and was the site of a Bucket Brigade action in 2003 (Bruggers 2014*a*). The stated aim of the deployment was *"to make information actionable"* (ibid.) by making the data part of the Louisville Air Map. Yet in a follow up report 6 months later the same journalist writes:

> *"The eggs do not consistently report their readings through the Internet, are not reliably accurate, and are not designed to allow comparison of pollution data from one device to another [...] Their readings of carbon monoxide — which can be deadly — are so far off, they could be dangerously misleading"* (Bruggers 2014*b*, para.8–9).

The article suggests that the AQE data was removed from the Louisville Air Map for fear of delegitimising the rest of the data set. In this deployment the AQE devices actively harmed an existing air quality project. I found evidence of another AQE deployment (Network for Clean Air 2013) and based on informal correspondence with one of the organisers, the data was similarly disappointing and not published by the organisation.

In February 2014 there was a large-scale organised deployment of 73 SCKs in Amsterdam carried out by the non-governmental Waag Society. This deployment is well documented with a documentary (Blom & Zandbergen 2015), report (Henriquez et al. 2016) and academic analysis (Nijman 2014). While the third party organisation provided the participants with instruction material and offered technical support, the documentary (Blom & Zandbergen 2015) shows participants struggling with setting up the device in their homes and only 50 out of 73 participants managed to install the SCK. The documentary also shows a public meeting where the participants are discussing their frustration at the lack of meaningful data. The Waag's own report cites one of the invited technical experts describing the SCK *"as 'rubbish technology' that produced unreliable results"* (Henriquez et al. 2016, p.25) and mentions that many participants dropped out during the project (p.72). In an independent analysis of the deployment, Nijman (2014) suggests that the actors involved realised that it was impossible to measure air quality with the SCK and that the participants held the organisers responsible for the failure to *"very explicitly state the assumptions, context and limitations"* (p.43). In particular Nijman identifies a mismatch between the goals of the participants and those of the SCK organisers who were using the participants as hardware testers. When I checked the deployment a year later, there were no more active SCK devices in Amsterdam, suggesting there was no longevity to the project. A report about the SCK admits that an older Barcelona deployment was also not very successful, suggesting:

> *"There are no actual collective citizen activities of significance linked to SCK in the city these past years, and there is a low rate of recent user engagement in the Smart Citizen forum. In addition, users often express dissatisfaction on the forum regarding how few social interactions and gatherings were facilitated or supported by the project team and instigators"* (Balestrini et al. 2016, p.30)

Observations

Both the devices seem to have created very different experiences for core contributors, backers and participants of organised deployments. AQE contributors and technically able backers had a tinkering relationship with the devices and gained insights about the hardware. Yet the usage of the devices was confined to a myopic focus on the hardware that reproduced a logic where only objective sensors define the reality of air quality. In this way the material practices echoed the bifurcation observed within the rhetorical configurations of the AQE (section 4.2). The issue was that the focus on air quality as a technical problem curtailed the development of experimental community practices that might engage with health impacts, political change or everyday citizenship. The result was that backers and participants in collective deployments, who simply received the devices as black boxes, were frustrated with installation problems and confused by the data. In addition, there is a category of collective projects and individuals that were actively harmed by the lack of accuracy and transparency of the devices that prohibited them from engaging with pollution.

4.5 Output: AQE & SCK as network monuments and good practice exemplars

I now turn to examine the outputs of the devices as global hardware dispersal and as good practice exemplars.

Both the AQE and SCK Kickstarter campaigns promised to deliver sensor hardware to backers. So when the hardware was shipped there were no other explicit goals. 6 months after the sensor boards were shipped, it is possible to see a decline in active discussions on both the AQE mailing list and SCK forum. At the time of writing in 2017, the original AQE devices are no longer supported and the company that used to host the AQE's data has been sold as a commercial entity and backers can no longer access the historical data from their own AQE device. The SCK is also in a state of decline with the public forum filled with unanswered technical queries and people asking whether the project is dead. Nevertheless, the devices are continuing both as hardware iterations and as conceptual assemblages. There is now version 2 AQE hardware available from a third party supplier with what is described as 'factory sensor calibration'. The SCK hardware is also being developed further as part of a major EU H2020 funded research consortium called 'Making Sense'. Interestingly the project's tag line *"from making sensors to sensemaking"* (Making-sense 2016) creates a direct to link to the sensemaking rhetoric of the AQE.

I now focus on the remaining legacy of the original Kickstarted versions of the AQE and SCK. I will examine the data visualisations of the AQE and SCK and citations of the projects, to analyse how they function as an ongoing legacy. When visiting the AQE and SCK websites, one is immediately presented with a world map covered in thousands of devices, (Figure 4.4). The feeling one gets is of impressive global coverage with dense clusters around population hubs. However, if one clicks on the icons, it becomes clear that the data is old, and most of the devices have been inoperable for years. The main visualisations of the AQE and SCK do not show live data but a historical aggregation of all the devices that have ever been online. On the SCK website it is possible to filter and see that only 19 out of 762 devices are active (as of April 2016). The AQE website does not provide a means of filtering out the dead devices and when I spent an hour clicking around I could not find an active device. The map page does not display the generated data but highlights the geographical locations of the hardware. To see the data requires clicking on an individual device to see the raw sensor values. While the SCK provides a more sophisticated interface, the contextual information on the sensor data is basic. The visualisation mode focuses on the solitary sensor device and does not provide a way to compare data between devices. The analogy is that each sensing device is an autonomous submarine on its own. What is absent is a visualisation that splices the data together into a single surface to provide a sense of a contiguous environment. Unless one is exactly next to the sensor device one cannot begin to see what ones exposure level might be. Clicking through the data is an emotionally flat experience of abstract numbers without comparison or interpretation.

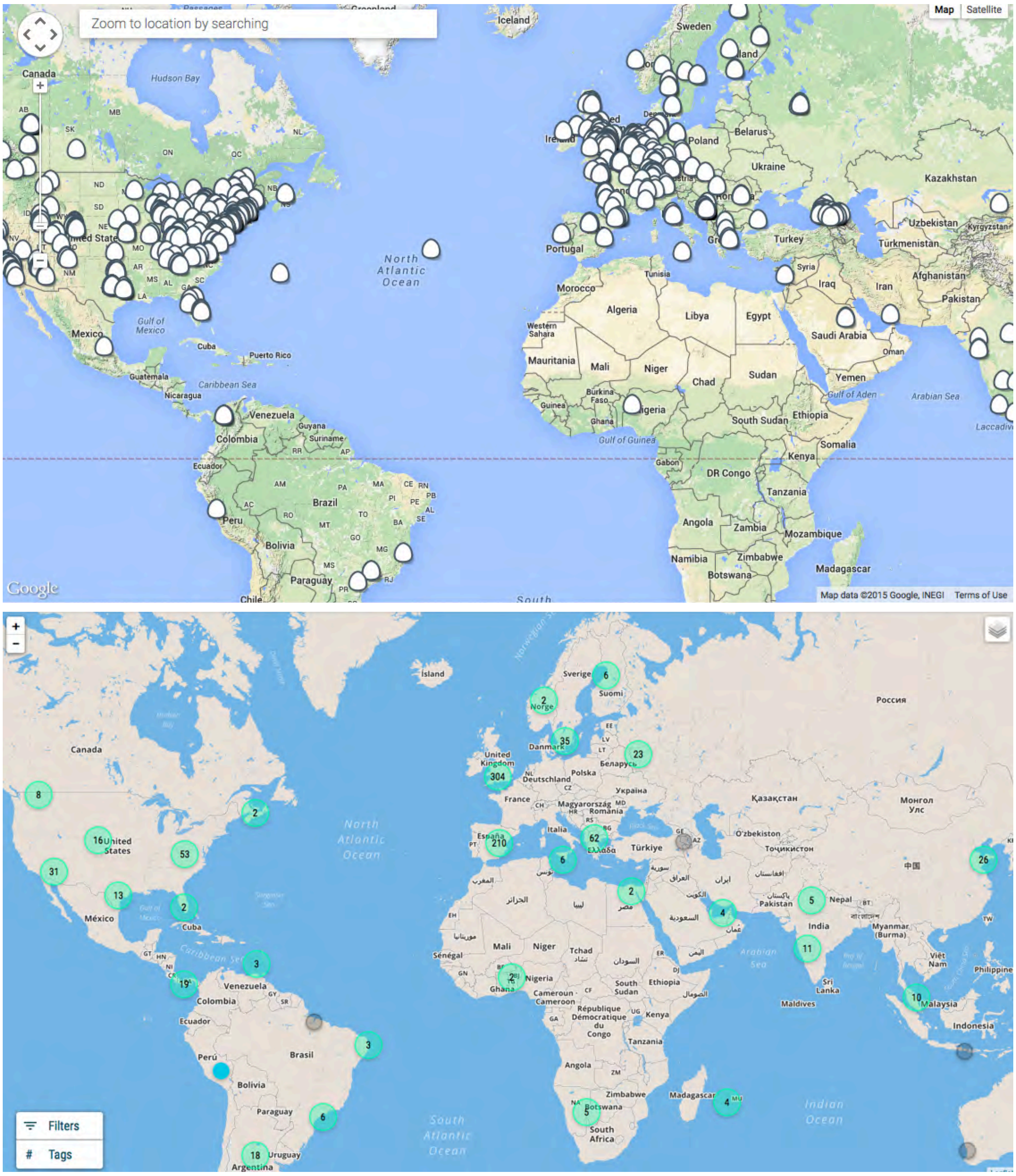

Figure 4.4: Top: Screenshot of the AQE map showing all the devices that have ever been registered. Bottom: Screenshot of the SCK map showing all the devices that have ever been registered with the numbers representing the quantity of devices at that location.

The impression I have looking at the AQE and SCK visualisation is that the sensor data is treated as secondary compared to the geographical distribution of the devices. What matters is the image of the globe covered in hardware to demonstration that the projects succeed in creating a global network. The sense is that this visualisation is intended to convey the vision of a global IOT. This symbolic quality is emphasised in a Fast Company article, which describes that *"egg icons blanket the online map in expected regions like Western Europe and the northeastern U.S., but also in the country of Georgia, between the Black and Caspian Seas, where a community group purchased 38 of them"* (Captain 2016, para.6). The article goes one to argue that these sensor networks are a *"perfect example of how Internet of Things will work in the future"* (para.8). In this way the visualisations function as a mythical monument to the possibility of creating a global IOT. These qualities of the visualisation reaffirm the AQE and SCK as solipsistic hardware networks that sense their own data throughput as vision of the environment as autonomous networks (subsection 2.3.3).

The other important legacy of the AQE and SCK has been as citational good practice exemplars for the IOT, smart cities and citizen science. Salim & Haque (2015) describe the AQE as an example of *"citizens using and deploying IoT systems themselves"* (p.34). Fernandez (2013) use the AQE to claim that *"the smart city becomes real when people can deal with open technologies to build their own public infrastructure for environmental monitoring"* (p.44). The European Commission's 'Digital Social Innovation' report describes the SCK as an awareness network that enables sustainable behaviour and *"empowers citizens to improve urban life through capturing and analysing real-time environmental data"* (Bria 2014, p.2). The Nesta report 'Rethinking Smart Cities from the ground up' gives extensive coverage to the SCK as an exemplar of a *"people-centred smart city"* (Saunders & Baeck 2015, p.9). McQuillan (2014*a*) describes the SCK as creating *"sensor citizenship"* (para.3). Capdevila & Zarlenga (2015) use the SCK as an example of a grassroots initiative that can *"report to local city governments or to raise awareness of issues that matter to the local community"* (p.277). The European Commission report on environment policy uses the AQE as an good practice case study of a *"global citizen science project"* and describes the device alongside projects by IBM and the US National Oceanic and Atmospheric Administration (Science Communication Unit University of the West of England 2013, p.19). Finally Verrilli (2013) suggests the AQE is an example where *"the public won the tug-of war"* against science about what people need.

What all these citational uses of the devices have in common is that they describe the AQE and SCK devices as a good practice exemplars of grassroots community participation in technology and scientific governance. They are trying to combine the democratising science narrative (subsection 2.3.2) with the autonomous networks narrative (subsection 2.3.3). Yet these reports and papers fail to acknowledge the material problems of the devices, the failure to support community organisation or the fact that the projects defined themselves specifically in opposition to institutional cooperation. Almost none of the reports raise any questions about the real-world impacts of the devices and they are unreflective about using the devices as good practice exemplars. How was it possible to separate the rhetorical success of the devices from their material failure? To understand how these exemplars function, I examine one citation by Kumar et al. (2015) from the peer reviewed journal Environment International:

> *"There are also community-led sensing networks in operation (Air Quality Egg, 2014), allowing the general public to participate in discussions on air quality. Compared to analytical instruments for measuring air pollutants, the sensors which are currently available are several-times less expensive and are easy to deploy, operate and manage. Retrieving data from the sensors is straightforward and their automatic operation allows for wide-spread deployment in the built environment. The use of sensors in this way provides granularity, which better informs the identification of pollution sources and helps support more conclusive studies on the effects of air pollution on socio-ecological justice and human quality of life"* (p.201).

The quote mentions the AQE only very briefly and uses it to string together a wide-ranging argument about socio-ecological justice. While the text creates only the loosest of associations with the device, the fact that the AQE exists discursively as a citable exemplar means that it provides legitimacy to the author's otherwise unsubstantiated argument. It does not matter that the actual material practices of the device do not support the argument being made by the author. In this use of the device as rhetorical exemplar, these material practices are absent. I would like to describe this as a 'minimal exemplar', since it creates only the most minimal connection to the device in order to make its rhetorical point. My suggestion is that the AQE and SCK are largely used as these minimal exemplars across mainstream media, grey literature, academic publications and European Commission reports.

An insightful analysis of the AQE and SCK devices has been carried out by the anthropologist Dorien Zandbergen who argues that the devices are 'storytelling' devices, that are *"told regularly at Smart City conferences, in books and on websites"* (Zandbergen 2015). She argues the goal is to promote smart city agendas while deliberately avoiding talking about the friction, contestation and negative impacts of the technologies. She argues the storytelling about the devices involves a highly selective narrative that *"smart cities are currently being built by 'smart citizens', working with cheap, accessible sensor technologies and free data platforms, creating and freely sharing data for their own purposes, commanding significant changes in their environment"* (ibid.). She suggests these narratives aim at a kind of 'astroturfing' that make it appear that smart city technologies are being created as bottom-up processes rather than being imposed on the public. I observed many AQE contributors and device backers making these same arguments. My suggestion is that the imposition is not necessarily in terms of physical technology but in the way it brackets particular realities of environmental sensing where 'matter' no longer matters. The effect is an ontological politics where the rhetorical reality of minimal exemplars and storytelling becomes separated from the material practices of the devices and thus unaffected by their failure.

The dramatic impact of this can be seen in a report published by the Waag Society about the Amsterdam deployment of the SCK (Henriquez et al. 2016). The report consists of two parts, with the second part outlining the significant problems of the SCK deployment. While the first part is full of aspirational rhetoric such as, *"citizens can become smart, engaged, and illuminated through mastering the technologies that help them express themselves, connect to others, share their resources and thoughts so they can decide the best course of action"* (p.17). What is striking is the way the two parts of the report seem to contradict each other. It is as if the rhetoric of smart citizenship and the problems of the deployment exist as ontologically separate realities that run alongside each other but do not interface. The report quotes an expert as saying that the Amsterdam deployment is merely a beginning, while in the future the sensors will work properly (p.25). What is important here is that the reality of the material problems exists merely in the present, while the rhetoric of smart citizenship exists as a future that is treated as totally separate. In this way participatory sensing seems to be largely a future gazing practice that Bell and Dourish have described as 'proximate futures' (Bell & Dourish 2006), where technologies are deferred into the future and don't need any analysis of the current reality. My argument is that this anticipatory rhetoric provided the strength for the AQE and the SCK to gather publicity but it also brought with it an ontological politics that meant it could not analyse its own material practices.

4.6 Summary of the AQE and SCK device study

This chapter has identified what was being sensed and what was doing the sensing in the design, usage and outputs of the AQE and SCK (Figure 4.5). At least initially, both devices managed to successfully string together rhetoric and hardware of heated filaments, concerns about air pollution, revolutionary change, smart citizenship and anti-governmental ideas into well-supported Kickstarter campaigns. Both devices were highly effective at translating the usually mundane topic of air quality into an emotive call for action and the creation of new techno-social networks.

AQE & SCK	
Actor	**What is being sensed and what is doing the sensing?**
AQE organisers	Community 'care' & hardware network
SCK organisers	Smart citizenship & hardware network
AQE contributors	Technical tinkering
AQE & SCK backers	Electronic toy
Pollution affected	NULL
3rd party deployments	Setup problems and arbitrary data
Researchers & Media	Exemplar of IOT, citizen science and smart citizenship

Figure 4.5: Diagram of the different actor's ontologies of what is being sensed and what is doing the sensing with the AQE and SCK.

Yet the problems with the AQE started as it became apparent that the sensor hardware could not be calibrated and the organiser started obfuscating the properties of the device. This created confusion amongst the core contributors and backers about what the device could actually sense. The inability of the AQE organisers to solve the issue of calibration triggered a bifurcation where they argued that air pollution is only measurable by objective scientific instruments. This resulted in the AQE being enacted as a dualistic device of rapid data flows and a human network of 'care'. The SCK used the same gas sensors as the AQE and while it didn't claim to measure pollution, it had even more hyperbolic rhetoric attached. Despite their stated goals of developing autonomous visions of air quality, neither device managed to create new practices of citizenship or ontologies of sensing that could convincingly make 'sense' of the low quality sensors. The problem was that the framings of high speed data networks, beacons of 'care' or smart citizenships did not appear to articulate the environment in a meaningfully way for the participants. The resulting usage of both devices was confined to electronic tinkering, while those people who had hoped to engage with health issues or political concerns couldn't use the devices or were marginalised. Yet despite these major flaws, both devices have a continuing legacy as good practice exemplars across the academic and policy literature where they are used to demonstrate smart citizenship, citizen science and IOT. In this usage as minimal exemplars, the devices continue to enact the same ontological politics that bifurcates between rhetorical promises while ignoring the material practices of the devices.

Chapter 5

Device study: AirProbe

This chapter is the second of three empirical device studies that follow a sensing device from its design, usage to output. It uses a mixed methodology of participant observation, interviews with actors, document analysis, surveys and material analysis to describe the material practices of the device. The chapter continues to address the research question: what is being sensed and what is doing the sensing?

This device study examines how AirProbe was designed by the academic EveryAware consortium as a research tool for monitoring air pollution and behaviour change of participants. AirProbe was one of the two devices that emerged from the EveryAware project that was active between 2011 and 2014 and funded by the EU as part of the 7th Framework programme. The consortium consisted of five teams: a Green team of environmental scientists, a Blue team of physicists focused on social dynamics modelling, an Orange team of electronics and software engineers, a Yellow team of computer scientists and the Red multidisciplinary team focused on action research with communities.

AirProbe is a complex system that combined a hardware sensor box, calibration model, smartphone app and online gaming platform (Figure 5.1). The usage section of the chapter describes the way AirProbe was used as a competitive mixed reality game where teams of people gathered pollution data in the city and guessed pollution levels in the online game. The main output from the device is an academic paper that suggests that AirProbe increased the participants' environmental awareness and learning.

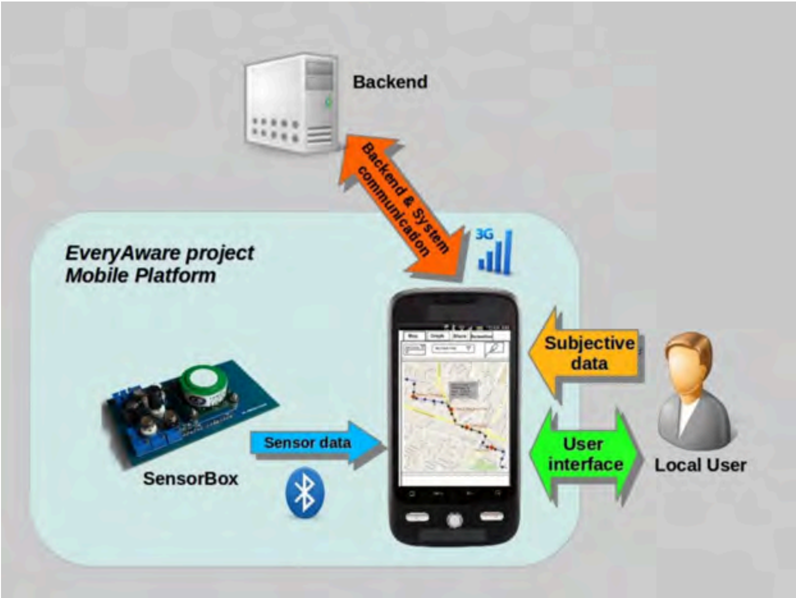

Figure 5.1: Diagram of the AirProbe system (EveryAware 2014). The smartphone app receives sensor data from the sensor box and 'subjective' data from the user. Not shown are the calibration model and the online game.

This chapter tells the story of AirProbe as a device that started off sensing tiny cancer-causing particles, but which suddenly shifted to sensing people's environmental awareness while air pollution as a health issue disappeared. The chapter describes how this ontological shift took place through a combination of design, diagrams and rhetoric. The chapter focuses on the properties of the AirPin slider and accompanying notion of AirPin Difference (APD) as the key sites of ontological politics where the experience of participants and health framings of air pollution were translated into concepts of behaviour change and societal modification. The nature of this identification is important because it moves responsibility towards the bifurcation of nature and the material configuration of systems.

Together with the other device studies, the role of the chapter is to articulate participatory sensing as a site of struggle between competing ontologies of the environment. The aim is to describe the mechanisms by which these ontologies are contested and identify the potential of enacting alternative participatory sensing that can create more pluralistic environments (chapter 8).

5.1 Design: AirProbe as academic funding application

I start my investigation of AirProbe by examining the successful funding proposal of the EveryAware project (EveryAware 2010) as an artefact to identify its declared aims. While each of the partner organisations also had implicit goals, this proposal is a useful marker against which the material practices of AirProbe and WideNoise can be compared. I argue that the proposal strings together a loosely defined mix of hardware sensors and rhetorical entities of motivation, awareness and behaviour change, which will later become important actors that affect the AirProbe and WideNoise devices.

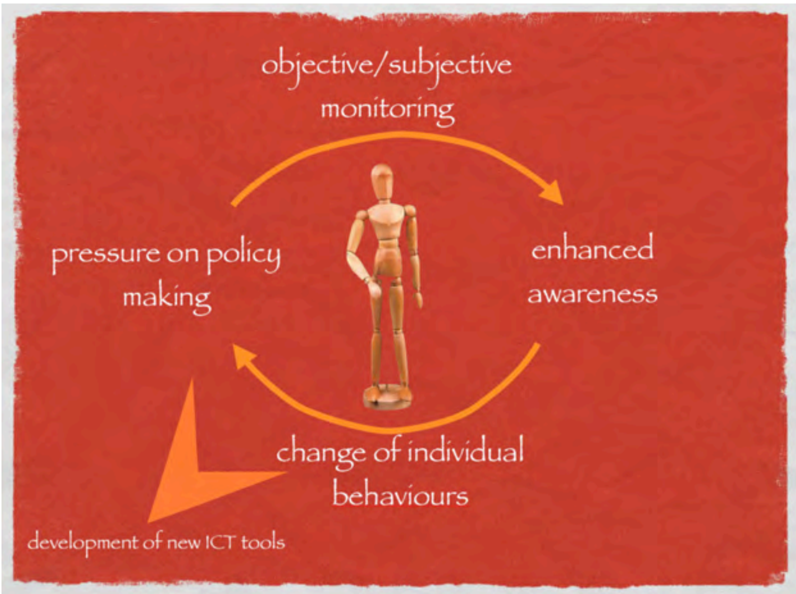

Figure 5.2: Diagram showing the human at the centre of a 'virtuous loop' that will increase the participant's environmental awareness, change their behaviour as well as connect them to policy-making (EveryAware 2011*b*).

The proposal describes the goal of the research as using computer technologies to support environmental sustainability. The aim is to create an 'end to end methodology' of developing environmental sensors, recruiting participants and then studying their behaviour and making this accessible to policy by relating it to environmental legislation such as the European Noise Directive (European Parliament 2002). The research intends to be technically innovative in the development of new pollution sensors and systems to aggregate environmental data, as well as uncovering what motivates people to participate in participatory sensing.

The proposal suggests that the innovation of the research is its focus on the awareness and behaviour change of the participants. The text argues that, while physical interventions to deal with sustainability are useful, *"it is only when people become fully aware of their actual environmental conditions and their future consequences that the much needed change of behaviour will truly happen"* (EveryAware 2010, p.4). The proposal positions itself as a policy tool that allows environmental data to be used to create awareness and behaviour change in the wider public: *"the project intends to stimulate fundamental shifts in public opinion with subsequent changes in individual behaviour and pressure on policy makers"* (p.3). The proposal was to use smartphones to gather environmental pollution data and then immediately present the participant with 'personalised environmental information' as feedback of their actions in order to change their behaviour (Figure 5.2). The proposal suggests that the unique element of the research proposal is *"the seamless integration of participatory sensing with subjective opinions"* (p.5). The idea is that it is this combination of objective sensor data and subjective opinions will change the participant's behaviour. While the proposal provides the example of reducing one's water and energy consumption, it does not articulate what a behaviour change in relation to pollution data might consist of. Crucially the consortium did not include any psychology expertise on the notions of awareness and behaviour change. Instead, behaviour change was seen as something that would be identified through data analytics. In particular, the notion of subjectivity was treated as an operational category that *"must not require a strong effort from the users in order to encourage the voluntary data supply and, at the same time, be structured enough to be analysed by a software application"* (p.18). Nevertheless, the proposal suggests that the main innovation was the combination of the new objective sensor hardware with the capturing of subjectivity in the form of engagement, motivation, awareness, subjectivity and behaviour change.

I analyse the proposal as trying to go beyond the scope of traditional environmental monitoring focused on physical pollutants. By focusing on the 'subjective', this represents a recognition that the causes of environmental pollution are complex dynamic 'human' issues. Thus the project's goal of combining objective and subjective data should be seen as an attempt to connect the external world with the internal mind to deal with the causes of pollution in a more cohesive way. Yet crucially this framing of objective and subjective is premised on the idea that these entities are divided in the first place. Thus the proposal is fundamentally based on an ontological bifurcation of nature (Whitehead 1920) that treats the objective and the subjective as separate realities that need to be treated differently. The proposal merely references the concepts of awareness and behaviour change without defining how they might be materialised in the research. Yet I argue the funding success of this proposal can be put down to the way it goes beyond measuring pollutants to string together hardware sensors with expansive policy rhetorics of motivation, awareness and behaviour change.

5.2 Design: AirProbe as public health instrument, behaviour change or community concern

There were three ontologies of air quality in the consortium: as public health policy, as behavioural change indicator and as situated community concern. This section explores how the conflict between these ontologies was eventually resolved in AirProbe via the design of a competitive game that enabled only one way of enacting air quality while prohibiting the others.

Despite being a small portable object, AirProbe was built like an aircraft over a period of years from components distributed across the whole of Europe. The electronics of the sensor board and smartphone app were produced by the Orange team, the Blue team created the online gaming platform and software model, the Green team worked on pollution calibration, the Yellow team handled the data management platform and the Red team was responsible for the recruitment of participants. Across the development period, the consortium partners presented their work in compartmentalised ways that meant, that for most of the project, there were multiple AirProbes that consisted of discussions about deliverables, diagrams and data models. It was only in the last 6 months of the 3 year research project that AirProbe became a tangible object. Yet, even then, AirProbe continued to be a complex device that measured gases, to act as a tracer for particles that were an indicator for other particles. The sensor box contained eight gas sensors that measured CO, NO_x, O_3, VOC and two meteorological sensors for temperature and humidity. Most of the sensors were cheap (€5), except for one sensor that was expensive

(€180). The NO_2 sensor E2V MiCS–2710 (e2v Technologies Ltd. 2008) and CO sensor E2V MiCS–5525 (e2v Technologies Ltd. 2009) were identical to the crude sensors used within the AQE and SCK devices. However, the EveryAware team had examined the AQE and scornfully suggested that AirProbe would be much more accurate. The premise of AirProbe was that by using a neural-net calibration model, the limitations of individual sensors could be compensated and combined to form a high quality sensor. The gases that Air Probe measured are in themselves not harmful at normal concentrations, but could be used as a tracer for black carbon. Black carbon is tiny soot particles that are created by car exhausts during combustion that are so small that when we breathe them in, they enter our lungs and bloodstream to cause direct health effects such as cardiorespiratory events (Janssen et al. 2012). The AirProbe calibration model was trained using a μ-Aethalometer reference device that sucked in air and deposited black carbon particles so that they could be optically measured. The reason AirProbe used gases as a tracer for black carbon rather then directly measuring the particles was one of cost, with the AirProbe sensor box costing €200 versus €2000 for the μ-Aethalometer. Importantly, European pollution guidelines focus on a category of tiny particles called PM2.5 of which black carbon is a subset. Experiments have shown that black carbon can act as a tracer for PM2.5 (Air Quality Expert Group 2012). Thus AirProbe was a highly complex device that sensed gases as a cost effective tracer for black carbon, which itself functioned as a tracer for PM2.5, which is a policy instrument for public health legislation.

The main tension within the consortium was the challenge of calibrating AirProbe and the question of what accuracy level would be good enough for the research project. The Green team, who were environmental scientists conceived air pollution as a very difficult entity to measure. The team emphasised that air pollution is extremely localised, where the physical position of a cyclist in relation to a car exhaust would radically alter that person's exposure. Over the course of the development period, the Green team showed hundreds of technical diagrams that emphasised the complexity of the measurement and calibration tasks. The diagrams showed how the sensors were affected by temperature and humidity and the way the individual sensors caused interactions amongst each other. The sensors were also constantly ageing, drifting and diverging from the model. Calibration involved the researchers going on trips through the city carrying the AirProbe sensor boxes as well as the μ-Aethalometer over a period of weeks to gather enough local data that could be sent to the Green team to create a special calibration model for that geographical location, since each city had its own unique mix of petrol and diesel engines. Then each sensor box had to be configured using a unique model for that box, which would only be valid for a period of weeks before the tenuous relationship between AirProbe and the reference device would break down and the object would become useless again. AirProbe was thus an extremely complex and unstable experimental device that relied on a complex neural-net model to create a temporal relationship to the reference device and involved an enormous amount of institutional support for the device to exist. If one was to map the boundaries of the device, then it would extend across the whole of Europe and involve five different teams of researchers and innumerable man-hours over the three years of development.

Throughout the multi-year collaboration there was a continual conflict amongst the consortium about the nature of air pollution. The Green team argued that AirProbe would need to have *"some kind of reality"*, which meant that it had to be able to identify roads with the most car traffic, as well as produce useful data for air quality modellers who were creating environmental models as a public health policy instrument. For the Green team the calibration model was critical for translating the arbitrary gas data into cancer causing exposure levels that related to public health policy. Without the calibration model, AirProbe would not be able to create this relationship and thus be useless. For the Green team this meant that AirProbe required constant attention and supervision from the researchers and could not function as a standalone product. In contrast, the Blue and Yellow teams wanted AirProbe to generate data for behavioural analysis. This meant the sensor box had to be a stable data generator that could be deployed with little effort and be scalable for future commercialisation. In this ontology, air pollution was something blackboxed within the device that didn't need to be thought about after it was built. For these teams, AirProbe had to demonstrate that new information would lead a person to change their travel routes in order to minimise their own personal exposure. In this ontology, what mattered was being able to demonstrate that behaviour had been changed, while the quality of the gathered pollution data did not matter so much. Meanwhile, the Red team had an ontology of air pollution as an issue of community concern. For them, AirProbe had to support existing communities worried about air pollution and help them to tackle their local problems. While there was an overlap with the Green team in terms of a focus on pollution as a health problem, it differed in the way it imagined local communities as the main stakeholder and was less concerned about feeding data towards governmental policy. This ontology demanded that AirProbe should be easy to use and interpret by participants.

These three ontologies were in conflict in the way they interpreted the device as well as the way they tried to materially reconfigure it. Throughout the whole development period the Blue and Yellow teams were in conflict with the Green team of environmental engineers, arguing the device 'didn't have to be 100% accurate' and just needed to be available as soon as possible. In an interview, a researcher from the Green team suggested *"it has always been ambiguous, do we want to do proper air quality monitoring or not? Or is this just a vehicle to do some sort of social sciences and social analysis?"*. For the respondent air quality was something much 'more down to earth' then the behavioural concept that the Blue team focused on. The researcher suggested that there are *"a lot of steps in between making a measurement and awareness, let alone behavioural change"* and that by using an unstable sensor to make this behaviour argument the project was on *"utterly shaky grounds, [in regards to] behavioural change"*.

For the Red team, the problem was that they were never certain what AirProbe would be able to sense since the device was in constant flux, with new firmware updates that radically altered the function of the hardware and measured pollution values. During one discussion, I described the Red team's position as, *"we are zookeepers but we don't know what kind of animal will arrive. We don't know if it will be an elephant or a frog"*. The Red team felt they had to understand the object in order to start recruiting participants,*"how are you going to pitch and try and encourage people to participate is going to depend on what is required of them"*. For the Red team the participants were a critical component of sensing and their needs had to be designed for. Yet one of the Green team told me, *"all you need to know is that the device has a button to turn it on and off"*. This tension was graphically illustrated during one of the consortium meetings when one of the researchers picked up an early AirProbe prototype, which was the size of a shoe box and held it next to their arm to see how it would look when attached there. As a joke, I suggested that they should mount the box on their head, which they did and triggered laughter from the consortium as they saw the ridiculousness of the situation. What became clear was that the participants were not being treated as meaningful stakeholders of sensing but merely as operational components that would add mobility to the sensor box. The approach was directly adopting concepts from the participatory sensing literature that treated ‘people as sensors’ (Resch 2013) or MULEs (Shah et al. 2003) that the consortium aligned themselves with in the consortium book (Loreto et al. 2017). In the Green team’s ontology of environmental monitoring, sensing was something that had to be deliberately separated and shielded from the human participant who could only introduce bias to the technical sensor platform. The result was that throughout the three-year development process the measurement quality and potential of the device were expressed as statistical measures of R^2 coefficients of determination and Cohen’s kappa of agreement that described the fit between the measured data and the reference device. Throughout the process these statistical measures went up and down yet remained abstract without any descriptive metaphors for the pollutant. Interestingly, the μ-Aethalometer tests strips showed black carbon particles as a disgusting smudge of dirt that created a direct sense of cancer-causing particles in the lung (Figure 5.3).

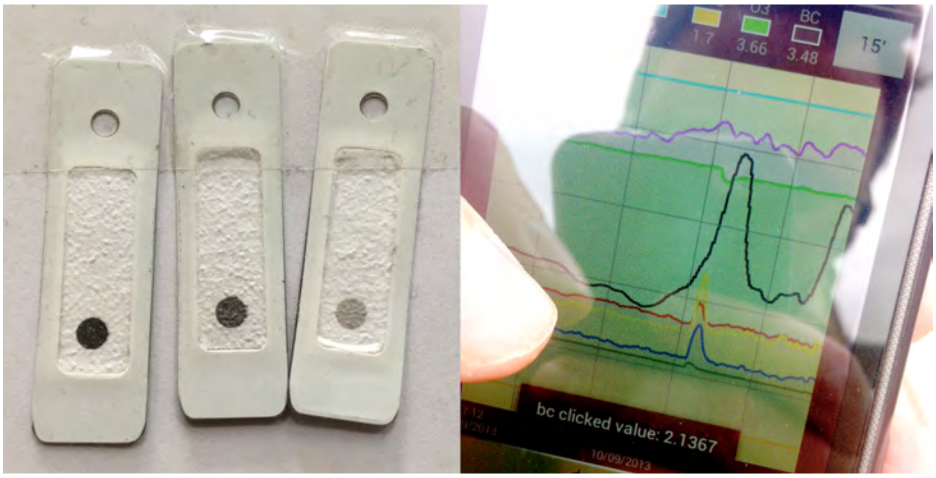

Figure 5.3: Left: Three μ-Aethalometer strips showing the black carbon exposure for each day. Right: The AirProbe app showing a numeric black carbon value.

Yet this material sense of pollution was lost in the abstract numbers generated by AirProbe. The closest the project came was when a member of the Green team drew a diagram of urban air pollution (Figure 5.4). In this image the curved cushion shape represents background air pollution due to living in a city, while the little spikes on top indicated localised variability.

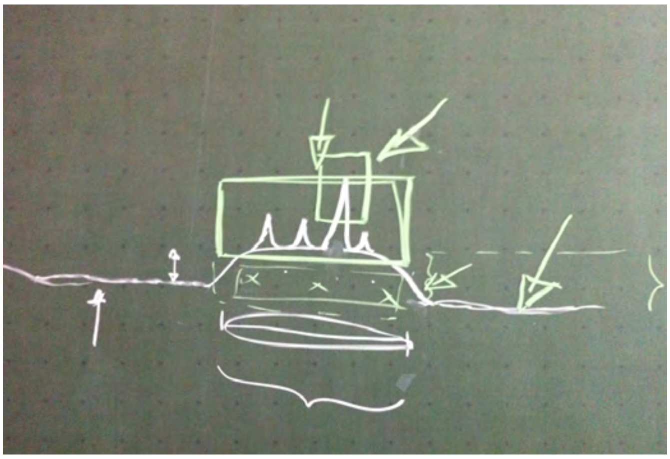

Figure 5.4: Diagram from the 2012 consortium meeting. The cushion shape represents the background pollution due to living in a city, while the spike in the small box represents the localised pollution that might be avoidable.

The diagram illustrates the extent and limit of a person's agency in reducing their own pollution exposure. It was these spikes that the Green team was hoping to measure with AirProbe. Unfortunately it was never clear whether AirProbe could detect these little spikes and become a useful device. The single-minded focus on data quality had meant that the usage, visualisation and interpretation of the data by participants had not been considered. In desperation the Red team organised an emergency nighttime meeting at a bar where the consortium teams were made to sit together to brainstorm how AirProbe might be targeted towards different user groups. The result were scenarios for groups concerned about air pollution, such as young mothers and cyclists who would need the sensor box to be mounted on a pram or bicycle and require custom visualisations. Yet these scenarios didn't have any noticeable effect on the design of AirProbe or lead to any collaboration with these groups. The myopic focus on data accuracy meant that the participant's understanding and usage were not considered as relevant components of the device. This incident demonstrates the impact of the literature's ontological separation between the participant and the researcher and the participant and the device. By framing the participants as MULEs (Figure 2.3) who do not need to be designed for, the resulting sensing objects end up being suitable for no-one.

As the project was coming to an end, the consortium was under pressure to demonstrate the promised 200–300 sensor box users, but the AirProbe device was not ready for deployment. My experience in using a prototype was that standing next to a car exhaust often resulted in no reaction or only a tiny blip, while entering a shop made the black carbon levels shoot up dramatically as a false positive. My feeling was that AirProbe was unstable and unreliable. It was only at the end of the project that I gained certainty about the measurement quality of AirProbe. Before the final project evaluation, one of the technical team members was setting up two sensor boxes, one of which measured 0–1 μg/m^3 while the other showed 18 μg/m^3. The technician didn't seem surprised by this enormous discrepancy and the other team members started joking about the measurement quality of the sensor boxes. I realised then that the majority of the consortium team didn't trust AirProbe. After this final project evaluation I interviewed a researcher from the Green team who with frustration described the calibration fit of the sensor box as *"weak, it is weak, it's weak"* and suggested that the measurement quality was so low that the sensor boxes merely identified that *"sometimes [it's] a bit higher and sometimes it's bit lower and we captured that in some cases"*. From the Green team's perspective the device was a failure since it would not be able to support policy work.

Nevertheless, to meet the EU deliverable deadlines, the sensor boxes had to be ready to use, no matter their measurement accuracy or whether it prohibited the setting up of community projects. The Blue team had an online game platform that they had been wanting to use within the project, so during a consortium meeting a proposal surfaced for a 6 week long game called the AirProbe International Challenge (APIC). The game would take place simultaneously in four European cities with the idea that the cities were competing against each other in a mixed reality game. Participants would walk the city with the sensor boxes while there was also an online game environment where people could gain virtual rewards for guessing the correct pollution levels and demonstrate that their behaviour had changed. The Red team talked with a community group concerned with air pollution about taking part in the game, but the group were very negative about the gamification of pollution and mentioned that they felt this approach insulted their genuine health concerns and chose not to participate. The Red team felt embarrassed by the incident and never mentioned the APIC game again with an engaged community group. The Green team wanted more time to improve the measurement accuracy of the device but due to the looming deliverable deadline conceded their demand.

Throughout the three-year development process of AirProbe there had been three ontologies of air quality: as a public health policy instrument, an indicator of behaviour change and as situated community concern. While it might have been possible to design a deployment of AirProbe that allow these ontologies to coexist, the particular way in which the game was implemented as a competition and without providing enough time to have functioning sensors meant the only ontology of air quality the game would support was one of behaviour change. In my research diary I noted the speed with which this game concept was adopted by the consortium without any explicit consensus having been formed about the overall goal and audience of AirProbe. It seemed like the material design of the game platform settled these competing ontologies.

5.3 Design: AirProbe as sensor of subjective opinion

The AirProbe International Challenge was a complex mixed-reality game that took place in three square kilometre target sites in four cities. These locations did not have any explicit pollution issues but were central locations that were chosen for their accessibility. The concept of the game was a multi-level competition at city level as well as between the different teams within each city about trying to achieve the best temporal and spatial data coverage, which would be rewarded with prizes. The game was premised on the EveryAware organisations recruiting students to form teams of 'Air Ambassadors' whose role was to take outdoor measurements using the sensor boxes, as well as recruiting participants as 'Air Guardians', who would play an online game where they had to guess pollution levels. From the researcher's perspective the game was a behavioural experiment that allowed them to feed the participants with targeted pieces of information and then track their behaviour over the duration of the game to see if it had changed.

The game had a three-phase structure:

- Phase 1 - Air Ambassadors and Air Guardians play online game to guess pollution levels;
- Phase 2 - Air Ambassadors walk the target area with the AirProbe sensor box, while Air Guardians continue playing the online game;

- Phase 3 - Air Ambassadors and Air Guardians continue but the game now includes data from the sensor boxes. The online players can now buy 'AirSquares' to see small rectangular areas of pollution data to base their guesses on.

The concept of the online game was that players would log into the system every day to improve their estimates of pollution in order to keep earning revenue, unlock achievements and compete for their city and team. The game adopted a growth metaphor from the Facebook game FarmVille (Zynga 2016) where players plant and harvest crops to earn revenue. FarmVille and other games in that genre are often described as repetitive and shallow yet somehow addictive (Liszkiewicz 2010). The key reinforcement mechanism of these games is a timed interval economy that forces the user to log in regularly to receive their income and use people's social relationships to help promote the game to others. The APIC online game consisted of an aerial view of the target area with an overlaid interface that showed that the player had $1000 of in-game currency to spend. A player could click on the map to purchase an 'AirPin' and make an estimate of the pollution level at this location by moving the AirPin slider to indicate their guess. Overnight each AirPin would then generate in-game currency for the player based on the accuracy of their estimates. If a player failed to log in they would lose their income for the day. Any pins that were not producing any revenue were coloured red to alert the player that their pollution estimate was wrong. There were also in-game achievements that triggered when a player reached the necessary requirements such as spending money to earn the 'Junior Investor' achievement. The game showed a detailed ranking system that compared the player's income against other individuals, teams and the four competing cities.

The AirPin slider was a remarkable piece of ontological design that reconfigured what AirProbe sensed. Before the development of the game, AirProbe was fully focused on measuring the external environment as accurately as possible, yet within the game, the device switched to sensing the behaviour of participants and became a sensor of subjective opinion. By overlaying the AirPin graphic onto a geographical location, the slider became a conduit between the user's mind and urban pollution data that exists within the game. The slider thus materialised the goal of the EveryAware's funding proposal, to bring together objective pollution and subjective opinion (section 5.1). Furthermore, the slider turned the abstract concept of subjectivity into an operationalisable entity. When a participant is moving the slider, they were creating 'subjective numerical pollution' that became directly comparable to 'objective numerical pollution' and could thus be tracked over time. For the researchers the innovation of the AirPin slider was that it bridged the impossible chasm between the internal and external world and flattened it into numbers that were ready for statistical analysis. Yet at the same time this piece of ontological design instigated a hierarchical politics that played out within the practices of the device.

There were two major issues with the design of this behavioural experiment. The first was that the design of the AirPin slider was misleading for the user. In the consortium there had been a disagreement about whether players should guess a relative value of pollution from 1 to 10 or an absolute black carbon concentration such as 1.3 μg/m^3. These two concepts are conceptually and visually very different. A relative indicator uses its boundaries to delimit extremes and the middle indicates an average, while an absolute indicator does not provide any guidance of this sort. Yet the team who implemented the slider were nervous since *"each choice would have been a bias"* (as stated in an internal power point presentation). There was a discussion amongst the consortium and the AirPin design was changed from a relative slider towards an absolute slider. The problem was that the final design is a hybrid that used absolute concentrations of black carbon from 1 to 10 μg/m^3 as well as a relative indicator gradient labeled 'low pollution - high pollution', (Figure 5.5). The result is that the slider is a muddle between a relative and an absolute indicator. The key confusion this introduced was that it suggested that a value of 5 μg/m^3 black carbon positioned in the middle of the bar, represented 'normal' pollution level, while anything less than 5 μg/m^3 would represent low pollution. This issue was compounded by the second problem that involved changes to the economy of the game without the player's knowledge. During phase 1 and 2, the revenue that players received from the AirPins was not actually based on pollution values but a spatial average of other people's guesses. So a player whose estimates were in-line with the consensus would be rewarded, while those outside of the consensus were penalised. This created an echo chamber effect where players simply confirmed each other's guesses, while still being totally unrelated to any external environmental reality. But in phase 3 the revenue calculation was suddenly changed to use the actual measured data from the sensor boxes. As the interviews in the next section demonstrate, the effect of this was that most of the player's guesses were now marked as wrong because they had overestimated the pollution level due to the misleading design of the slider. As the interviews demonstrate, this led to confusion amongst the participants who failed to understand the logic of the game economy.

Figure 5.5: Two design iterations of the AirPin slider. Top: the older relative slider where one guesses between low and high pollution as indicated by the gradient bar. Bottom: the final slider indicating absolute values of black carbon ($\mu g/m^3$) as well as a gradient bar suggesting relative values.

My suggestion is that this flawed implementation of the slider and muddled game economy were caused by the way the participants were framed as abstracted immaterial placeholder. Throughout the whole of the three-year development process of AirProbe there had not been any direct contact with potential users or outside user testing. Much of this can be attributed to the motivation and behaviour change literatures where the participant is framed as a blackboxed entity to be engaged by gamification features while basic usability design issue are neglected (subsubsection 2.3.1.3).

5.4 Usage: AirProbe as urban exploration, game economy and confusion

I now turn to examine the experiences and practice of the participants within the game. This section is based on interviews with all of the ten London APIC teams with a focus on what was actually being sensed during the game.

When asked, the reason the participants gave for getting involved in the process was due to a general curiosity about air pollution. For some this was a personal interest in their pollution exposure while cycling. Others joined because the topic was related to their studies or because they felt a sense of duty to support scientific research. Many thought that APIC would have wider benefits that might 'improve the environment' and raise the public's awareness of air pollution.

The majority of participants took part in using the AirProbe sensor box as well as the online game. The participants enjoyed using the sensor boxes to gather outdoor pollution data whilst being part of an urban game that allowed them to experiment with for example, comparing bus exhausts with park areas. The participants also tried to establish the effect of going out at different times of the day and different weather conditions. Some tried repositioning the fan of the sensor box by making it face forward or backward. The main observation was that air pollution didn't seem to vary much between places or proximity to obvious sources of air pollution such as car exhausts. Yet most interviewees observed dramatic reactions to temperature and humidity, *"it seemed a lot higher ratings when it was damp and it felt muggy as opposed to at night when the air is really clear"*. The participants were not sure if the weather was affecting the actual pollution in the air or simply generating measurement false positives. A significant proportion of the interviewees reported that roads showed lower pollution levels than parks: *"in a big road they were very low and in the park it would be very high"*. One participant explained that they deliberately set up an experiment to compare the pollution in empty park with an extremely busy road, *"in a park where I was alone in a very big area the values were suddenly increasing. But then when I was going to bed and the traffic was crazy it went really low"*. The participants who had these counter-intuitive results reported that due to this experience they now realised that *"[pollution] it's not where you think it is"*. Another participant explicitly stated that this experiences with AirProbe had transformed their awareness and perception of pollution stating it is *"quite a change in the awareness and the usual general perception"*. Yet a different participant was more suspicious of the measured data and did some online research on the distribution of black carbon and said, *"I just thought the box wasn't really working properly"*.

Interestingly, the participant who identified that their sensor box was not functioning commented, *"I thought the design of the devices was amazing, and I really thought that it was impressive how measurement could be done in such an easy way"*. On the whole, the participants were surprisingly casual about the perceived accuracy or inaccuracy of the sensor boxes. The explanation seems to have been that for many of the respondents the pollution data was simply one aspect of the mapping activity. While walking most participants used the map page of the app rather than the gas sensor graph. This meant they could focus on the geographical area their team needed to map to receive in-game revenue rather than looking at the level of pollution. A number of interviewees talked about creating a system where one team member prepared printed maps that showed the area that other team members should cover during their sessions. Many of the Air Ambassadors were exploring the city while thinking about the logic of the game in order to maximise their spatial coverage as in this quote, *"if I walked down the left hand side of one street and then the right hand side of the other street, that's two 10 x 10 squares"*. Some participants described the experience like a mixed reality game where the algorithm creates a performative experience that transformed their way of being in the city: *"if I walk that street and then come back half an hour later and do the other one, you know, like it's got quite interesting in that sense which was purely the game side of it"*. Yet another participant reported that the imperative of data coverage created awkward incidents where they had to enter a street and immediately reverse back out again, which drew unwelcome public attention to the respondent. Some participants mentioned exploring the unusual architecture of the Barbican area and its multi-layered walkways. The participants emphasised that the walks allowed them to explore hidden aspects of the city that they had never seen, *"places that I've really passed by many times in my life in here and you just go beyond"*. For one participant this was their first month in London, so the project was their first experience of the urban city. Another participant described that the walks helped them understand the connections between locations:

> *"The thing I really loved the most is London. I live in the area. I used to live in Old Street. I used to live in Barbican and I just clicked places I never thought about before and I loved it. I really really really loved it. That was awesome!"*.

A number of participants reported positive social interactions with people in the street that recognised them as they passed on separate days and talked with them. One participant even received free food from someone they met this way. Many of the interviewees talked at length about their observations while exploring the city and described it as their favourite part of APIC.

In contrast the participants were divided about the online game, describing it as *"dreadful, absolutely awful"* while also describing themselves as 'obsessed' by the game. There was a sense that the game was easy to play and required no intellectual or physical effort. At least two of the interviewees were embarrassed by how involved they got in playing the game despite finding it boring. One participant described playing the game whilst wearing pyjamas and explained that the game was a way for them to procrastinate. The aspect that kept them playing was the competition facilitated through the rankings. Interestingly, this competition seemed to be an end in itself. While the participants understood that the aim of the game was to guess pollution levels, they were confused about the game economy and the way the AirPin functioned. Most assumed that the slider was supposed to indicate a relative scale, *"I didn't have any understanding what a specific numeric value might represent. So for me it was like from 1 to 10. If I think that it's kind of an average level of pollution it's going to be 5. If it's an acceptable level it's going to be below 5"*. Another interviewee used this logic to decide which areas would have low or high pollution, *"this area of trees there, is maybe 3 out of 10, whereas the road is probably 7 out of 10"*. Since the revenue feedback in phase 1 and 2 was based on other people's guesses, this reinforced this relative conception of the slider. But most participants mentioned suddenly noticing that from one day to the next all their AirPins stopped producing revenue: *"one day I woke up and had lots of red pins"*. During the interviews the participants mentioned that they had not understood the crucial change-over to the sensor box data in the 3rd phase and were shocked when we explained this. They had assumed that they had always been guessing pollution. The participants were baffled that their estimates were suddenly labeled as wrong and responded by changing their AirPin guesses, but did this in order to *"win more money[1]"* and not because they now understood the environmental pollution value. One participant described how they were initially careful about the placement and estimates of the values but after a while started to set an average pollution level on all the AirPin sliders, *"because I just didn't have the patience to go through and actually think about every individual flag"*.

Many respondents described the game as a self-referential system with investment strategies that didn't have any reference to the external world, *"there was just me and the pins"*. One participant talked about flooding their map with so many AirPins that in phase 3 they never had to purchase any of the measured sensor box data. They simply used the AirPin feedback colour as a kind of financial sensor for finding the slider position that would give them the most revenue. Another participant got their team members to send screen-captures of their AirPin values, which they entered into a spreadsheet to reverse-engineer the game's revenue algorithm. When asked to reflect on the kind of activity they had been engaged in, one participant said, *"I was playing the game, to play the game. I'm not really sure beyond that what my engagement was"*. The online game did not provide the participants with any contextual information about black carbon as a pollutant such as its health effects or safe exposure levels. Thus some participants went out and searched for information about black carbon, yet others said, *"I didn't really know where to go to see what it meant or anything like that"*. These descriptions suggest that the online game did not provide the participants with any genuine understanding about black carbon as an environmental pollutant. One participant said *"I haven't learnt anything about air pollution from this at all. I think because you know a figure of 3.76 PM10 or whatever, it doesn't really mean anything to me"*. The quote refers to PM10 units of pollution that were not ac-

[1] The respondent was referring to virtual in-game currency rather than actual financial benefits.

tually used in the project. Thus the quote doubly reinforces that the game did not provide the participants with any insights about air quality.

Yet the game did have an impact on participants. One participant talked about how annoyed they were that the game was a 'social experiment' that was testing the participants rather than focusing on the gathered pollution data. Another respondent described APIC like a reality television show, a *"stupid TV program watching people walk around London"*. Another participant raised doubts about the usefulness of the experiment and emphasised its lack of clarity: *"there was no way to clearly explain what the game was or why we were playing it, or what happened with that data. It just was kind of – there are some scientists there who wanted to see how your understanding and behaviour changes through simulation"*.

Based on these interviews with all the London teams, it is striking how the mixed reality game acted to scatter and dissipate air pollution as an issue of concern and tangible pollutant with health effects. Instead of coming to understand pollution exposure, many participants seem to have picked up false insights from using the participatory sensing device. In terms of the online game, they were enrolled into a surprisingly addictive, yet meaningless game that made some of the participants feel like test subjects in a social experiment.

5.5 Output: AirProbe as academic publication

By the time of writing this study in 2017, AirProbe is no longer being supported or developed any further. The consortium's initial plans to commercialise the device were abandoned due to the lack of measurement accuracy. Thus the only legacy of the device is a series of academic publications (Caminiti et al. 2013, Becker, Mueller, Hotho & Stumme 2013, Sîrbu et al. 2015*a*, Loreto et al. 2017) and EU deliverable reports and documentation of the project created by the European Commission (Digital Agenda for Europe 2014, European Commission 2014). This section examines the main legacy of the AirProbe device in the form of the collective EveryAware paper with 20 authors called *'Participatory patterns in an international air quality monitoring initiative'* (Sîrbu et al. 2015*a*). The paper was published in PLoS ONE, a prestigious open access peer-reviewed journal for science and medicine.

The structure and argument of the paper are very similar to the other consortium paper about WideNoise (section 6.10). The AirProbe paper starts by discussing the need for systematic monitoring of air pollution due to the extensive health impacts such as respiratory diseases. After this introduction, the topic of pollution and health are replaced by an argument that data gathering can be outsourced to citizens which could *"facilitate learning and increase their awareness of environmental issues"* (p.2). The paper makes the argument that *"at the beginning of the challenge the general perception was that pollution was higher than in reality, perceptions changed in time indicating increased knowledge of real pollution levels"* (p.4). The paper builds this argument by creating a distinction between 'objective' data, meaning measured air pollution from the sensor box and 'subjective' data, meaning the positioning of the AirPin slider. At the same time the paper creates a new ontological entity called 'AirPin difference' (APD) that is meant to represent the numerical difference between machine and human perception. The paper's arguments are based on diagrams of changes in this APD value across the three phases of the game. The researchers suggest that in phase 3, the participants lowered their slider guesses as the real sensor box data was introduced and that this demonstrates that participants *"are able to reduce the 'errors' in the annotations, by learning the true values"* (p.14). The paper also claims to identify *"inertia in changing the old opinion structure"* (ibid.) and *"resistance of subjective opinions to objective results"* (ibid.). The paper makes the recommendation that participatory sensing can function as policy tool for delivering awareness enhancement and that, *"this could result in better adoption of policies towards decreasing pollution"* (p.1).

Surprisingly, the paper does not discuss the suitability of the experimental design. In particular, it does not discuss the critical issue of the AirPin slider design and game economy change that may have accounted for the pollution guesses going down. Also, the critical stability issues with the sensor device are not spelled out despite the 31 pages of technical detail about sensor calibration. The key issue of how suitable AirProbe is for environmental sensing, is given just a single sentence: *"the performance obtained was enough for the purposes of our project, i.e. participatory mapping of pollution with multiple devices, for enhancing environmental awareness"* (Sîrbu et al. 2015*b*, p.6). The implication of the quote is that since the purpose is 'only' environmental awareness this means the sensors do not have to be accurate. As the interviews with participants demonstrated the sensor boxes produced misleading and counterfactual readings, which are confirmed by the technical data that identifies a London R^2 value of 0.407 (Sîrbu et al. 2015*b*, p.9), and which the researcher from the Green team had described as a 'weak' relationship. Yet the whole of the paper's argument relies on the slider and sensor box being an accurate and stable reference against which human perception can be judged. It is only by enacting the experimental setup as de facto 'objective' that it can detect the 'subjective human'. If the paper were forced to engage with the material problems of the sensor box and the ambiguity of the slider, then it would be impossible to separate the hardware error from participant behaviour. The researcher from the Green team was highly critical of the experiment and the way it was being interpreted, suggesting that one should ask *"did we consider that all these sensors might have drifted?"*. The point is that the instability of the experimental setup might be so large that it would be impossible to bifurcate the human as an ontologically distinct essence from the messy material practices of the device.

Surprisingly, the paper also does not engage with the central issue of how improving guesses might lead to a reduction in environmental pollution. The paper vaguely mentions 'learning', 'knowledge' and 'awareness', yet does not define these concepts or offer external references. The paper assumes that it as self-evident that an increase in guess accuracy will lead to a better environment. Yet during our interview a member of the Green team raised the issue that even an accurate sensing device can create undesirable behavioural changes:

> *"The individual optimum is not the social optimum. You might decide based upon [seeing] some results that it's better to drive the car instead of cycling through this traffic. So I am exposed to all this so I will take my car. It is not obvious what kind of behavioural change [will happen]"*

The quote suggests that a sensing device could actually show someone that they can reduce their own exposure by driving their car, thereby making pollution worse for everyone else. This highlights a fundamental ambiguity about the kinds of individual and collective behaviour changes that might result from sensor practices. However, the paper blackboxes the participant and their practices and does not engage with the morality and ethics of different kinds of environmental behaviour. Furthermore, the paper does not analyse the actual pollution data gathered during the experiment. The only mentioned purpose of the pollution data is to act as a baseline against which behavioural shifts can be monitored. Yet the paper's introduction had framed the goal of the experiment in relation to legislation about public health impacts of air pollution. What is going on? My interpretation is that the paper is not actually interested in air pollution as a health problem. Instead it seems to perform a task of stringing together hardware, data and pollution rhetoric into a message that is directed at policy makers to demonstrate the benefits of participatory sensing to policy. If we engage with the AirPin slider as a 'patterned teleological arrangement' (Law & Ruppert 2013), then we can see it as a material-semiotic instantiation of the deficit model (Sturgis & Allum 2004), which is premised on a gap in knowledge between the public and science. In this mythical mode, the participant becomes a representative of the public and the sensing device becomes a stand-in for scientific knowledge. The slider thus becomes a sensor for measuring how wide this knowledge deficit is, as ADP and crucially promises to act as a societal actuator for closing this gap. My suggestion is that the paper presents AirProbe as a very literal policy instrument for making the public more environmental by making them more accurate. This framing of AirProbe translates the behaviour change rhetoric into something tangible that can be measured by sensors. In this way it provides a body and reality for the ungrounded rhetoric. In this way, behaviour change becomes materialised as an 'empirical effect' (Marres 2011) while participatory sensing is expanded into a powerful societal actor for instigating large-scale changes.

There are clear indications that the paper's framing of participatory sensing is very closely aligned with EU research policy and not an isolated outlier or a result of the EveryAware project's contingencies. This can be seen in the way the European Commission chose to document the EveryAware project in the form of an extended article (Digital Agenda for Europe 2014) and press release with video (European Commission 2014). The title of the article, *'measuring your way to a healthier environment'* (Digital Agenda for Europe 2014), suggests that the act of measurement itself will create a better environment. Notably, neither of these EU documents presents any empirical evidence from the EveryAware project, suggesting that *"it is still too early to draw any conclusions"* (European Commission 2014). The video has a curious chameleon-like quality of addressing different audiences and framings of air quality. One minute it seems to address potential participants by asking *"can you imagine knowing how much pollution you are exposed to at* *every step of your journey?"* (Digital Single Market 2014), while later suggesting *"you can use the web as a sort of lab into which you can bring people virtually in order to complete specific tasks and basically to run experiments"* (ibid). The 'you' in the later part of the video shifted towards researchers, with citizens acting as subjects for the scientists. The form of address is to a multi-headed 'you' of citizens, policy makers and researchers, asking them all to get involved. Instead of presenting empirical evidence, the video feels like a Kickstarter campaign that tries to recruit backers for financial support at the start of a project. In this way the video has a similar tone to other European Commission videos of parallel project such as the Citizen Observatories (European Commission 2013). This suggests that the EveryAware consortium's way of doing environmental sensing is directly in line with the European Commission. In this framing, participatory sensing is not interested in pollution as a health problem, but the environment becomes an associative vehicle for stringing together financial, technical and policy agendas into a public practice of socio-technical change.

5.6 Summary of the AirProbe device study

This chapter identified what was being sensed and what was doing the sensing in the design, usage and outputs of AirProbe (Figure 5.6).

Air Probe	
Actor	**What is being sensed and what is doing the sensing?**
Green team	Attempt to build instrument for public health policy
Blue & Yellow teams	Usage data translated into behaviour change
Red team	Attempt to support situated community concerns
APIC participants	Game dynamics, urban exploration, pollution confusion

Figure 5.6: Diagram of the different actor's ontologies of what is being sensing and what is doing the sensing with AirProbe.

The device managed to raise academic funding by stringing together gas sensors with rhetorics of motivation, awareness and behaviour change. Yet the design of AirProbe became a site of ontological struggles between competing realities of air quality as a public health policy instrument, an indicator of behaviour change and situated community concerns. The chapter suggests that these competing ontologies of the environment were not resolved by consensual agreement but through displacement by material design.

The game and AirPin slider became the key sites of ontological politics, since they only enabled an ontology of air pollution as a baseline for behaviour change of participants, while public health policy and community concerns were sidelined. Within the game context, the participants didn't learn anything about pollution and acquired false insights from the poorly calibrated sensing device. The online game proved to be surprisingly addictive, yet futile in the way it encouraged the participants to compete in a self-referential system that had no meaningful relations to the external world. Finally, the academic paper makes the claim that the participants increased their environmental awareness. Yet this claim was only possible by blackboxing the physical limitations of the sensor box, the complexities of the participant's experience and the environment itself. The end result of this process was that it became progressively less clear what AirProbe was sensing, as it became a policy actuator and associative vehicle for stringing together a wide variety of institutional agendas.

Chapter 6

Device study: WideNoise

This is the last of the three empirical device studies. Like the previous chapters, it uses a mixed methodology of participant observation, interviews with actors, document analysis, surveys and material analysis to describe the material practices of the sensing device. The chapter continues to address the research question: what is being sensed and what is doing the sensing? Versions of this study have been published as a peer reviewed book chapter[1] (Nold & Francis 2016) and conference proceedings[2] (Nold 2013).

This device study examines multiple versions of the WideNoise smartphone app. WideNoise is a free app for iOS and Android that allows the creation of geo-located sound measurements and collects data about the user via sliders and textual tags. The sound level data is viewable on a local map within the app, as well as on a global online visualisation that shows the aggregated measurements. Version 1.0 and 2.0 were created in 2009 by a commercial company called WideTag (WideTag 2012*d*). In 2011 the app was licensed and redesigned as version 3.0 (later renamed WideNoise Plus), for use by the scientific research project EveryAware (Figure 6.1).

The WideNoise study is the most complex of the device studies since it involves many different actors. Thus I start by outlining the structure and trajectory of this chapter. The

[1]Nold, C. & Francis, L. (2016) Participatory Sensing: Recruiting Bipedal Platforms or Building Issue-centred Projects? In: Vittorio Loreto, Muki Haklay, Andreas Hotho, Vito C.P. Servedio, et al. (eds.). Participatory Sensing, Opinions and Collective Awareness. Springer International Publishing. pp. 213–235.

[2]Nold, C. (2013) Mapping Disagreement around Smart City devices. In: D. Charitos, I. Theona, D. Dragona, H. Rizopoulos, et al. (eds.). Subtle Revolution 2nd International Hybrid City Conference. 2013 Athens, University Research Insitute of Applied Communications. pp. 133–140.

Figure 6.1: Left: WideNoise version 1.0/2.0 created by the WideTag company in 2009. Right: WideNoise version 3.0 as licensed and redesigned for use in the EveryAware academic research project in 2011 (EveryAware 2012*a*).

five design sections explore the way the device was designed multiple times by different actors and using different means. The birth of WideNoise was with the company WideTag and was later adopted as a scientific research device by the EveryAware consortium. The device was then redesigned by testing the accuracy of the app, which changed the way the actors related to it. The device was also reshaped by the insertion of concepts of motivation, engagement and behaviour change from the EveryAware proposal (section 5.1). The final design section describes the extensive reconfiguration of the device by the Red team as it encased the app within a campaign targeting the controversial issue of Heathrow airport. The four usage sections discuss the deployment of WideNoise within the different ontologies of the Heathrow residents, a local pressure group, a local council and finally the consortium teams. The two output sections analyse the multi-author academic paper produced by the consortium as well as a council report and experiential map of noise impact.

This device study demonstrates the capacity of a participatory sensing device to sense entirely different entities as it enacts different ontologies. The chapter identifies accuracy, subjectivity and intentionality as key sites of ontological politics around the WideNoise device. The nature of this identification is important because it moves responsibility towards the material and ontological configuration of devices. Together with the other device studies, the role of the chapter is to articulate participatory sensing as a site of struggle between competing ontologies of the environment. The aim is also to describe the mechanisms by which these ontologies are contested and identify potential for enacting an alternative participatory sensing that can create more pluralistic environments. This chapter is followed by a horizontal analysis across all the device studies (chapter 7).

6.1 Design: WideNoise as green object, demo and prototype for transcendence

The WideNoise app was publicly announced to the world in 2008 at a new media technology conference, where it promised that *"in a kind of retro interface you can use the iPhone's microphone to pick up the environmental noise which can be of course, people* *speaking and nothing else or a party, it can be traffic on the street, or you, or a baby sleeping"* (Orban 2008*c*). The presentation also introduced a forthcoming feature, the *'Cool-o-meter'*, which with a swipe gesture will enable the user to indicate *"whether you think that the place or the event you are participating is cool or not"* (ibid.). While the *'Cool-o-meter'* never made it into the released version of the app, WideNoise was communicated as a holistic app that *"will help you to better understand the soundscape around you & live a healthier life"* (EveryAware 2012*d*, para.1). These descriptions make WideNoise sound like thousands of light-hearted lifestyle apps such as the iBeer app that use the iPhone's inbuilt sensors to simulate the drinking of a foamy pint of beer as the user tilts the smartphone towards their mouth. However, unlike these toy apps that eventually disappear from the App store, WideNoise managed to gain extensive publicity on Reuters and CNN as well as Italian TV and receive a major accolade from the New York Times, being named one of the 'Top 10 Internet of Things Products of 2009' (MacManus 2009). To understand what made WideNoise so successful requires looking at the company that built it.

The WideTag company was founded in Italy in 2008, and later moved its headquarters to California, where according to an industry website it became one of the *"main movers and shakers in the emerging Internet of Things"* (Postscapesllc 2014). WideTag were heavily involved in trying to communicate their visions of futuristic technologies creating new kinds of human/machine sociality. In Wired magazine, the founder of WideTag argued that:

> *"By 2050 I imagine the Internet of Things will have become a reality. A wider and deeper internet than Web 2.0, on a planetary scale, capable of taking on GAIA, the Earth, and enabling both humans and their 'machines' to become part of social networks"* (Orban 2010*a*, para.2).

WideTag employed their own chief evangelist David Orban (Orban 2008*b*) who made proclamations based on ideas from technological determinist authors such as Vernor Vinge (Vinge 1993), to argue that artificial intelligence will lead to technological transcendence and leave humans behind. In 2010, at a lecture given in the Second Life virtual world to an audience of blue and green alien avatars (Orban 2010*b*), WideTag's chief evangelist outlined the concept of 'spimes[3]' (Sterling 2005). Orban describes spimes as a new category of 'sensing objects' that sense and transform the environment:

[3]Spime is a neologism of a technical object that is trackable in space and time.

> *"The role of the sensor in a spime is [what] makes the object aware of the world around it. This awareness is the key. And there are more and more objects, and systems formed by them, whose value greatly derives from this awareness, and the object's capability of building on it, acting on it"* (Orban 2008*a*, para.2).

The idea is that these technological entities are autonomous are will grow exponentially until they vastly transcend humans in terms of number and intelligence. Orban suggests that humans will have to learn to adapt and develop ways in which they can be part of this world.

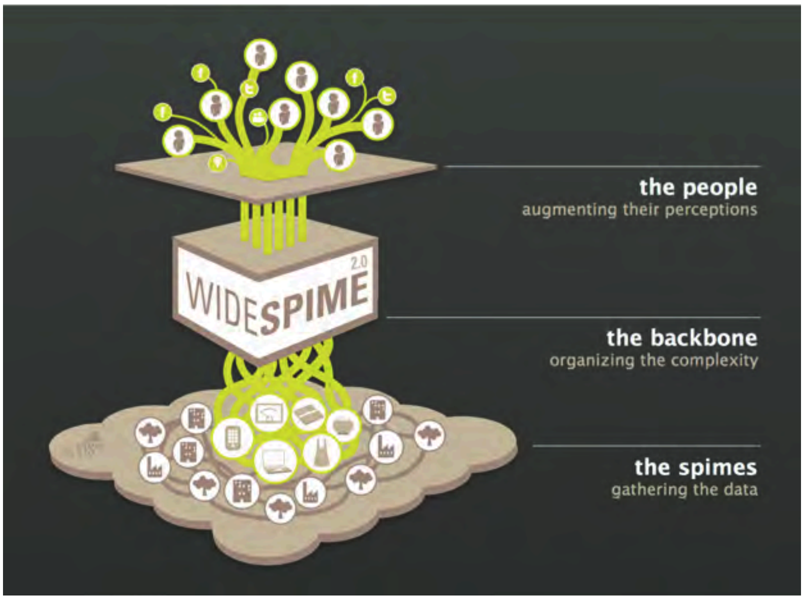

Figure 6.2: Conceptual model of the WideSpime platform from a WideTag presentation (WideTag 2010).

Yet for all of WideTag's futuristic swagger and rhetorical power, spimes and the IOT did not exist yet. Bruce Sterling argued that there are technologies that show the way towards spimes, but *"there are no things as true spimes yet - these are still speculative, imaginary concepts"* (Sterling 2005, p.13). However, as a company, WideTag tried to piggyback on these future visions and turn them into a commercial reality by building the first spime. They realised that if they could demonstrate a spime then this would generate lots of publicity and differentiate them from other IOT companies. WideTag thus created a data management platform called WideSpime (Figure 6.2) that was intended to function as the universal backbone for hosting millions of spimes and people and distributing data between them. WideNoise was created as an exemplar of a spime to demonstrate the capabilities of the WideSpime platform. On the company website, WideNoise is described as *"a very simple application that could be scaled efficiently and do some load on our WideSpime infrastructure"* (WideTag 2012*c*). In my interview, the designer of WideNoise described the role of WideNoise as

> *"the visible part of the underlying platform. If I come to you and say we have this huge amazing platform that is able to collect millions of data-points per second, you will say ok, what does that mean? If I come to you and show you a software application, and the iPhone is in hype, it helps a little bit. I show you the application. I measure the data. I see a data point on the map [...] So for us the first version was really a proof of concept. This is the kind of thing our platform allows us to do on a global scale"*.

The extract suggests that WideNoise was created as a technical demo for generating data load and thus demonstrating the platform's global reach and resilience to large quantities of data. WideNoise was intended to be a commercial demo to impress potential clients as well as a revolutionary spime object to gather media publicity. To build a spime would mean building something that could sense and then send the data somewhere else. WideTag realised that building their own hardware and distributing it would be difficult, so they chose to focus on smartphones that come with inbuilt sensing and communication capabilities, while the user provides the hardware. The design team asked themselves:

> *"What kind of sensor does the phone have? Well the light sensor, it's not really easy to get. So the only really one that was feasible, was the sound, the microphone. Well we tried first of all if we could build an add-on to measure CO2, that was still way too expensive"*.

What is striking in the extract are the priorities that directed the choice of what to sense. There was a pragmatic focus that meant working only with the inbuilt capabilities of the phone, and as well as a focus on a sensor that was easy to access. This pragmatism dictated that WideNoise sensed sound rather than becoming 'WideLight' or 'WideCO2'. This pragmatism continued into the interface design. The designer described that in creating the interaction flow of the app, the priority was to make the interaction quick and easy and thus maximise the amount of data generated:

> *"It was really, take a sample, measure it, you get the number and we fire it to our server [...] That was designed in this way because we wanted as much data as possible, as many data-points as possible, because our platform was exactly about that"*.

The designer described that this approach created a trade-off between quality and quantity of data. If a user tries to take a measurement with WideNoise and the GPS location has not been acquired yet, the app doesn't make the user wait but creates a data entry regardless, because *"we get a large amount of data. Yes, some data is not as good as others but we still get a lot of amount of data and as a user you get immediately the information you want"*. What becomes clear from these design choices is that the central goal of WideNoise was to generate vast flows of data to WideSpime, while the content of the data was not important for WideTag. This arbitrariness is most clearly visible in the lack of calibration of the smartphone microphone. The WideTag team only carried out a crude sound calibration where they played pink noise (similar to white noise but with equal energy per octave) and hardcoded numeric decibel steps into the app. During the interview the designer defended this approach as good enough, since the app was only intended to be playful. Indeed, the WideTag website mentions this approximate level of calibration and that the app is not intended for professional measurement. Yet this raises the question: what was WideNoise was for?

For the designer, the important part of WideNoise was the visual design and the expressive icons, such as the roaring dinosaur, which visually communicated sound intensity. They argued that the success of these icons was demonstrated by the fact that people on the app store used the language of the icons to talk about sound: *"when I read these comments I know I did something good, because they were not talking about the number, they were saying it is not a cat sleeping, it is not a car noise level"*. For the designer this shift away from decibel numbers towards iconic representations is an indicator of success. I asked what would happen if WideNoise totally removed the decibel number from the interface and they responded that the app would still work very well. This discussion showed that the app was deliberately designed to distance itself from environment pollution as scientific measurement. Instead the aim was to sense an affective environment that intertwines technology and human into collective connectivity. The designer mentioned that *"a friend of ours used it [WideNoise] as a measurement for how the crowd was clapping at the end of the presentation so he measured that to get some data points"*. In this quote sound pressure come to represent the intensity of the audience's feelings, which are then with a social network. The intended effect of looking at the map of the collective sound data is the realisation that *"you start looking around saying wow, we are connected"*. WideTag were not trying to measure sound as a pollutant, but to use it as an index of socio-technical connectivity and intensity. A review left on an app download site echoes this sentiment suggesting, *"I love this tiny APP because is 'Social' and allow me to share something that it could be mentioned [sic] as 'pollution' as well as 'Music"'* (SensorTower 2016, emphasis in original). The comment is striking for the way it blurs the app, social media, music and pollution all into one. WideNoise aims to enact a new kind of transhuman environment that fuses sound pressure, social connectivity and data load into a flow of intensity. The designer suggested this notion might be very different to what people are familiar with, so the environmental framing of WideNoise was used as a deliberate 'anchor point' or 'bridge' to teach people about new kinds of spime environments:

> *"Because spimes or internet of things and all these kind of concepts are still hard content, people do not get them. So we were designing this to be a kind of bridge. We were saying use this application because you are a green person because you are curious to understand your soundscape because for reasons that are very near to you, because these might be things are already interest you are already a passionate about. By doing that we will show you what is then possible, what is just a little bit ahead of it. If you start off straightaway talking about spimes people will simply not get it"*.

The extract demonstrates that WideTag deliberately deployed the notion of 'greenness' as something that people could recognise and relate to. The designer argued that, *"on average people only grasp simple things that they can relate to [...] To get cultures to shift to make this kind of movement, you still need this kind of anchor points"*. In the extract, the app is used to pull people from an environmental framing into a spime world. This stringing together of 'greenness' with futurism is captured in WideTag's description of the app as a *"social environmental noise spime"* (WideTag 2009, p.1). The phrase shows the way WideTag connected together a mix of trendy elements from social media, parties, environmental pollution and future transcendence without making any specific claim to measure environmental pollution. What is striking is the blurring about what the app sensed; nevertheless, this seems to have appealed to some users as illustrated in this review:

> *"This app is the future of digital products: collecting mobile data and aggregating it in real-time with everybody else's! Can't wait to see more apps like this. BOOM!"* (SensorTower 2016).

The designer mentioned that in the first two years the app had 100 downloads per day and managed to reach the global top 10 app charts. WideNoise functioned as a snowball that grew bigger and more impressive as it gained publicity, won international design awards and got more people to download it. I argue that this success was due to its combinatory rhetorics that were materialised as an app that anybody could download for free.

But in March 2011, the WideTag website announced that the company was winding down due to having focused too much on 'research' and not enough on making money (WideTag 2012*a*). The problem seems to have been that WideNoise was largely a publicity object that didn't generate any income. As WideTag went into a process of shutting down as a commercial entity, WideNoise still remained available for public download and became an orphan app.

6.2 Design: WideNoise as instrument for pollution and behaviour change

In 2011 WideNoise was redesigned into a scientific research device and designated as an instrument for sensing air pollution and behaviour change. As described in the AirProbe chapter, EveryAware was an EU research project focused on creating new sensing hardware, participatory recruitment methods and studying behaviour change (section 5.1). At the start of the research process, the consortium didn't want to spend time building its own sound sensing device and wanted to use an existing one. A number of smartphone apps were examined including NoiseTube (D'Hondt et al. 2013), which was an established, open source app calibrated for use in environmental monitoring, but it was rejected and the consortium decided to purchase an exclusive license for WideNoise. The data generated by the app would now flow to the EveryAware server while WideTag maintained ownership and creative control over the app. As part of the licensing deal, EveryAware paid WideTag to make a number of changes to the app and release them as version 3.0. Existing WideNoise users would receive a notification on their phone that a new version was available for download, but for the participants there was no clear indication that their data was now part of a EU research project. A major change was made to the communication of the app, with the EveryAware website now referring to WideNoise 3.0 as an *"instrument to address the issue of noise pollution that allows the compilation of reliable* *pollution maps as well as the monitoring of the evolution of people's awareness about environmental issues"* (EveryAware 2012*a*, para.4). The next paragraphs analyse the changes that were made to the app in order to transform it into a research instrument.

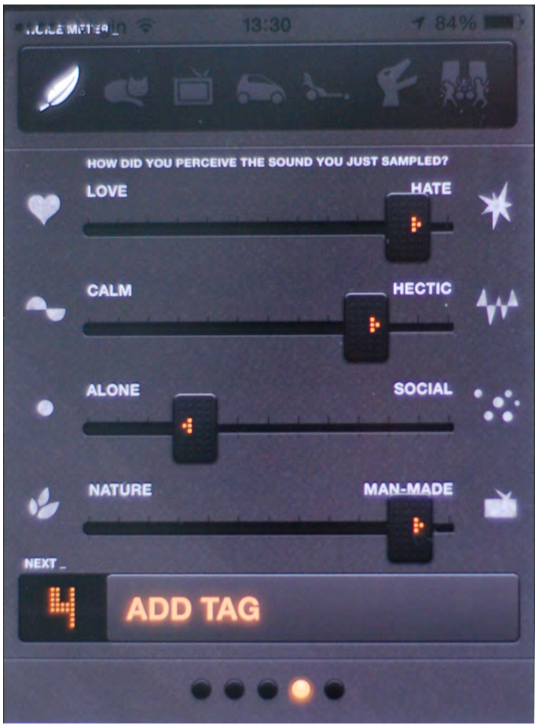

Figure 6.3: The 'experience sliders' allow the user to qualify the sound measurement by moving the sliders to the left or right.

In order to sense environmental awareness and generate 'subjective' data, the EveryAware team had asked WideTag to add a text entry box that allowed users to add textual tags to the measurement they made, as well as a number of interface sliders that would collect data from the user. I joined the Red team of the EveryAware project in September 2011, just as the transfer of WideNoise to the consortium was in progress. On my first day of joining the consortium, I was told that I had a few hours to decide the labels for the 'experience sliders' that people would use to qualify sounds. I agonised over these labels since they seemed crucial in deciding what the app would be sensing and I didn't feel confident that I understood WideNoise or that they would communicate to users. After a conversation with a colleague, we came up with the axis labels, 'love-hate, calm-hectic, alone-social, nature-man-made' (Figure 6.3). I felt I had been given a weighty responsibility without any clear guidance. However the label choices were immediately approved and implemented without any further discussions. The feeling I had was that for the other consortium teams the data labels were not important.

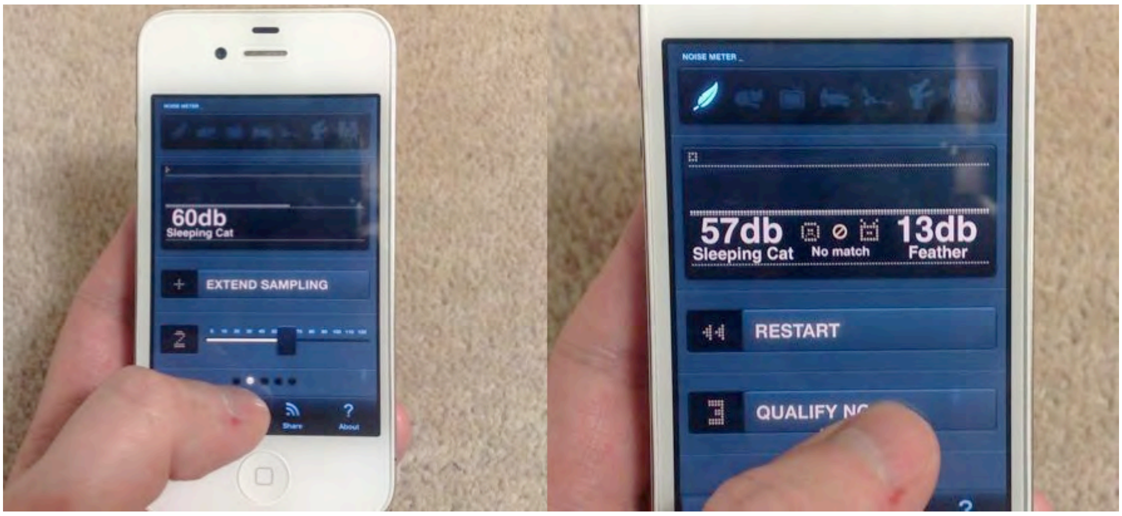

Figure 6.4: Left: The guess slider has been used to set an estimate of 60dB. Right: After the five second delay the screen shows 'No match', since there is a large discrepancy between the 'subjective' guess of 57dB and the 'objective' measurement of 13dB.

The other addition to WideNoise 3.0 was a 'guess slider', where users are meant to drag an onscreen slider to estimate the sound amplitude while the measurement is taking place (Figure 6.4). At the end of the five second measurement period, the user is shown their 'subjective' guess versus the 'objective' measurement from the app's microphone. If the numbers are close, the word 'Good' is displayed, while if there is a big discrepancy, the screen displays 'No Match'. I was told this function was intended as a game and to teach people the correct decibel level. When I tried the app myself I found the feature confusing and not very entertaining. The app didn't force the user to make a guess and showed their guess as '0dB' and 'No Match', even if they didn't move the slider. The Red team organised formal usability testing with a group of university students that described this feature as 'very confusing' and most people ignored it. My recommendation was that this feature should be removed since its purpose was unclear and poorly implemented, yet this was rejected and only later did I discover that this slider would become the most important 'sensor' of the WideNoise app (section 6.10).

In terms of making WideNoise more accurate for measuring sound pressure, the consortium requested that WideTag make the app send the raw audio recordings directly to the EveryAware server, so that they could perform additional calibration on the server.

However, WideTag argued that this would violate user privacy and create data transfer problems, so could not be implemented. While calibration seemed to be an important issue for a while, I noticed the way the topic seemed to peter out on the consortium mailing list with the suggestion that calibration would be added as part of a future version of the app. The result was that the consortium's version 3.0 app maintained the same crude calibration as the old one. Nevertheless the EveryAware website suggested that WideNoise would *"support the generation of highly detailed pollutant models for the test areas and permit the validation of these models against existing approaches"* (EveryAware 2012*a*, para.5). I took a look at the WideNoise 3.0 source code (Widetag 2011) and saw that the decibel calculation consists of a basic look-up table that translates measured voltage level from the phone's microphone into hardcoded decibel values. When I showed this source code to one of the people involved with building the NoiseTube app (D'Hondt et al. 2013), they were shocked and argued that this was a naive approach that didn't use the established decibel formula for noise measurement. The only change that was made to make the app more 'professional' was a visual one. The WideTag website describes that they were asked to remove the steampunk visual style of the app to *"make it more like a professional tool, with a sheer metal surface and orange lights"* (WideTag 2012*b*).

It is worth summarising what changed and what didn't change as the app was transferred from the company to the research consortium. By implementing the sliders and tagging function, the consortium had added a series of additional 'sensors' to the device that were intended to capture the context and subjective experience of the user. The visual style was changed to make it look more 'professional', even if the underlying sound calibration algorithm was not improved.

6.3 Design: WideNoise transformed by testing

This section describes the way evaluating WideNoise did not result in any physical changes but emotionally transformed the way the researcher related to the app, suggesting that calibration is largely a way of building and mediating relations.

The Red team had committed to evaluating WideNoise for the consortium with the idea that the test data would allow the calibration to be improved. I made an appointment to use an anechoic chamber and invited a technical member of the team to make sure we were correctly carrying out the procedure. We had brought different smartphones to check how the app would behave on different hardware and operating systems. Before I arrived at the lab, I received a text message from the scientist who ran the facility, asking me to buy AA batteries for powering the main reference meter. I had imagined the anechoic chamber would be a hygienic white space, but instead we were led into a small dusty chamber with a broken office chair hanging from netting. The speakers in the chamber didn't work, so the scientist propped a single large speaker in the corner of the chamber and told us that we would have to generate our own calibration audio from our laptop. We taped the smartphones onto a wooden board using duct tape that was precariously balanced on the office chair that was swaying in the netting. The door of the chamber could not be sealed since we had to leave the laptop outside and run an audio cable to the speakers in the chamber.

The setup of the chamber felt primitive but we tried to follow a rigorous test procedure laid out by D'Hondt et al. (2013). The problem was that there was no clear measurement standard that we could use to associate the app with the reference meter. The app claimed to measure decibel but didn't specify any psychoacoustic weighting. We tried using unweighted decibel, dB(z) but the discrepancy to the reference meter was huge. After some experimentation, it became clear that WideNoise had actually been calibrated against dB(a) weighting without this being stated in the app or documentation. Once we used this standard, the app and reference meter became relatable. The second issue was that the smartphone microphones were extremely directional, making the positioning of the hardware and speakers very tricky. Turning a phone a millimetre to one side or the other would radically alter the measurements. This directionality would make it hard to create accurate readings in a real world context. We repeated the testing procedure but each time a few devices fluctuated wildly and we had to create an average of the readings. The graph we produced (Figure 6.5) shows that WideNoise responded very differently running on the different smartphone hardware with strong discrepancies as large as 20dB(a) with quiet sound. To put this in context, an increase of 3dB(a) is considered to be twice as loud for the human ear, meaning that some hardware measured values 6 times louder than others. Above 50dB(a) the difference between the hardware was lower but below that threshold the measurements fluctuated unpredictably. Crucially the two identical hardware phones had very similar readings. This suggested that the measured data was not entirely random and that it would be possible to create a hardware profile for the different smartphones and thus calibrate WideNoise. This multiple profiles approach had already been successfully demonstrated by the NoiseTube app (D'Hondt et al. 2013), where it had allowed high quality noise measurements. The evaluation in the chamber demonstrated that the WideNoise app used a crude calibration algorithm but also that it would be possible to make WideNoise more accurate by implementing hardware profiles.

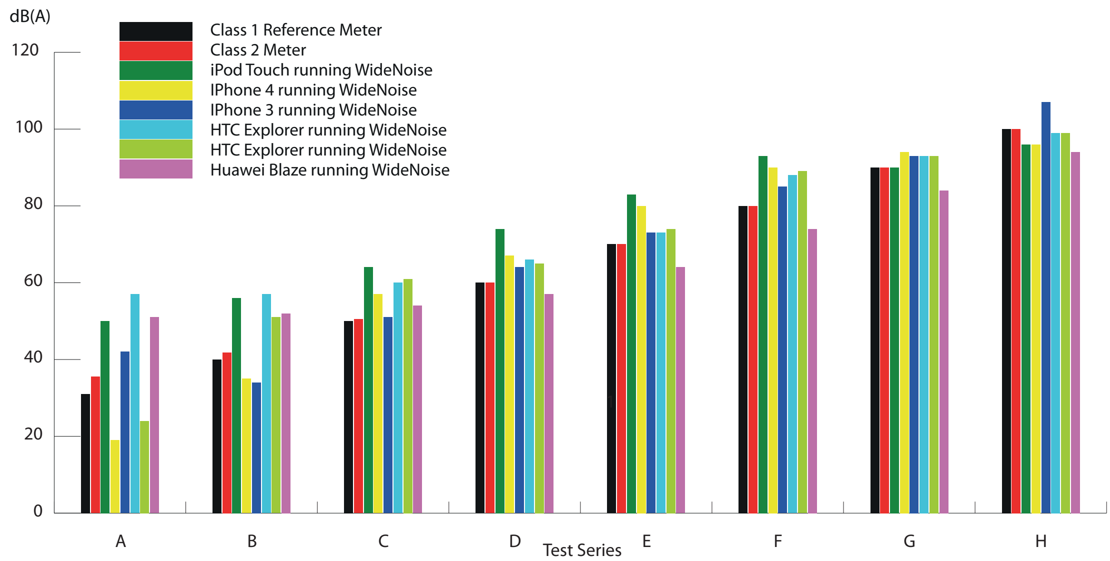

Figure 6.5: Test data comparing the WideNoise app running on a variety of smartphone platforms and hardware against a Class 1 reference meter (black bar). The eight set of results (A-H) show the response at different sound pressure levels.

When we presented these results to the EveryAware consortium, we proposed that the app could be improved by adding hardware profiles. However, none of the consortium teams wanted to take charge. One of the team leaders explained that graphical changes to the visualisation of the data were easy but that calibration was difficult since new smartphone hardware would keep being released, meaning that new profiles would continually have to be created. It is interesting to compare WideNoise with the AirProbe device. There the calibration process involved thousands of man hours spread across years of development and involved the whole consortium in detailed discussions about the minutiae of calibration (section 5.2). So why was calibrating WideNoise not deemed important? The key difference was that the Green team felt responsible for air pollution and AirProbe, while none of the consortium partners felt any ownership of WideNoise. As the AirProbe study showed, the Blue and Yellow teams were focused on behavioural data, which meant that calibrating WideNoise to comply with environmental noise standards was not crucial. When I confronted one of the researchers from the Blue team, they suggested that calibration only mattered for participants in as far as it demonstrated that the researchers 'care about this problem', yet they didn't think it was important. During a consortium meeting when the decision not to calibrate was taken, the question was framed as:

> *"We as a project need to make a decision whether it is worth the effort or whether we can take a more realistic approach, understand we have an error and communicate it"*.

The researchers understood that calibration mattered to participants but that it would take a lot of effort for the researchers to implement. In this way the decision to communicate the level of error rather than fix it can be seen as a tradeoff that indicated the consortium's priorities. I suggest it was a choice between different environmental realities: one was a distant and abstract reality where WideNoise might be meaningful for some participants and an academic reality where the app was simply a research object and not so important. This made it easy for the consortium to choose the 'realistic approach' of least effort and not calibrate the app. While the consortium released additional versions of the app with minor changes, the calibration algorithm itself was never improved.

While the surreal ritual in the anechoic chamber did not result in any physical changes to the app, it had transformed the assemblage of the device. The consortium members had suggested that they were not surprised by the test data, saying, *"we knew that. There is no calibration being done by WideNoise"*, nevertheless showing and discussing the data with the consortium had an emotional effect on the way the teams related to WideNoise. Some of the members seemed pleased when we presented the test data, suggesting that WideNoise had finally been calibrated. For them the procedure in the chamber had 'calibrated' the app even without making any actual improvements. Others, on the other hand, were frustrated by the poor test results. During one informal chat I had with one of the researchers from the Green team, they described WideNoise like a crude electronic birthday card with an inbuilt sound chip and proceeded to sing me a deliberately tuneless rendition of *'Happy Birthday to you'*. At the final consortium meeting, when the teams were preparing the microphone and speaker setup, there was some screeching feedback.

When the harsh noise died down one of the team members joked that the noise had been 'WideNoise' to which others responded with laughter. Showing the test results seemed to allow the consortium to talk more openly about the app. By evaluating it and forcing the consortium to take an explicit decision on the calibration issue, the Red team had made the priorities of the consortium explicit and made the app more transparent. In my field notes I described the evaluation as an active transformation of the app:

> *"We are actually building the device by adding a whole new level to WideNoise that from now on will not be removable. It now has an error margin attached to it, even if the technical testing procedure was ridiculous"*.

The Red team felt a surprising sense of relief, since the evaluation had confirmed their concerns about the app and transformed it into a known and predictable entity. A member of the Red team argued that WideNoise is *'arbitrary not random'* meaning that while the app data does not relate to any noise standard, it could be used to indicate low, medium and high sound levels. The evaluation thus became a way of ontologically redesigning the device by setting new expectations amongst the consortium and the Red team about which sound realities the app might be able to sense.

6.4 Design: WideNoise as engagement, motivation and behavioural sensor

This section examines the way WideNoise was made to sense engagement, motivation and behaviour change as human properties, which created conflicts about the consortium's refusal to acknowledge the physical limitations of the app.

When I joined the Red team, I was told that our role within the consortium was to deal with the engagement of participants, monitor their motivation and behaviour change. The Red team was expected to recruit large numbers of participants. Numbers between 1,000 and 10,000 participants were mentioned at consortium meetings. The expectation was that the Red team would promote the app via social media and that this would make it 'go viral' to gather these participants. The Red team felt these numbers were unrealistic and joked that we were expected to enrol 'a million participants'.

The team had been assigned two research questions: *'What motivates people to participate in community-based activities such as the sensing processes underpinning this work?'* (EveryAware 2012*b*, p.2) and *'Does access to appropriate personalized sensor information lead to changes in behaviour?'* (ibid.). These questions presented multiple problems. The first was that the terms 'motivation' and 'behaviour change' were never defined in the project proposal (section 5.1) or during the process of the research. They were so vague that at a consortium meeting 8 months before the end of the project, the whole consortium spent an afternoon brainstorming about what the term 'behaviour change' might actually mean and how it might be demonstrated with the sensing devices. During the meeting one researcher stood up and read aloud that the proposal had promised to *"stimulate fundamental shifts in public opinion with subsequent changes in individual behaviour and pressure on policy makers"* (EveryAware 2010, p.3). Listening back to what they had promised, there was tangible emotional shock in the room and one researcher joked that they must have been on drugs when they wrote the proposal. For more than two years, the consortium had been building sensor hardware and carrying out research without clarifying what was meant by behaviour change. For me, this revealed that these terms had been used in the proposal to reference academic discussions and policy objectives, in order to legitimate the project and get funding, yet there had never been any clarity as to what they might mean in practice.

These concepts had the most tangible impact on the Red team who were assigned the aforementioned research questions due to the team's supposed expertise with participants. The Red team felt that they had been designated the 'people people', who had to deal with these concepts as 'people issues', so that the rest of the consortium could focus on the technology. The main issue the team faced was that the concept of behaviour change as articulated in the literature didn't seem to fit with the properties of WideNoise. Behaviour change campaigns on topics such as seatbelt use or smoking start with clear definition of what are considered high-risk practices and beneficial behaviours (subsubsection 2.3.2.2). Yet the WideNoise app didn't seem to relate to any explicit environmental agenda or define pro-environmental or anti-environmental behaviour. The app had physical properties that were radically different from any other object the team had ever encountered. While the design requires the user to make a deliberate choice to take a measurement, it provides no guidance or context of what to measure. The app couldn't act as a meaningful noise meter due to lack of calibration and it was not a game. The advertising agency we hired to promote the app said they didn't understand the purpose for using it, saying: *"I sort of felt - is that it? Its has gone off somewhere but I have no understanding what I have participated in"*. The students and conference delegates who had been asked to test WideNoise echoed this and said the app wasn't interesting or meaningful to use. The Red team wrote a report arguing that the app needed to be redesigned before it could be used with real world participants, suggesting *"going back to the WHY and HOW somebody might want to use [a] sound recording/sharing tool"* (emphasis in original). The problem was that the Red team had been assigned questions about universal human motivation and behaviour change that were premised on the idea that WideNoise provided *'appropriate personalized sensor information'* (EveryAware 2012*b*, p.2). Since the consortium considered WideNoise to be 'appropriate', no changes were made to the app.

This approach of blackboxing the physical design of the app can be directly attributed to the academic crowdsourcing literature (subsubsection 2.3.1.3) that the consortium chose to align themselves with in the EveryAware book. The book includes two chapters (Kostakos et al. 2017, Riahi et al. 2017) that focus on motivation as a psychological property where the 'human sensor' is thought to be driven either by intrinsic desire or extrinsic rational greed that is rewarded through payments. Yet, crucially in this framing, the context of the sensing task and the material properties of the devices are *a priori* excluded from being the reason why a task is carried out. Yet the Red team felt this framing of motivation was unsuited to WideNoise especially since it would be the poor design and lack of purpose that would stop it being used rather than the psychology of the participants. One team member said, *"I don't have any belief in the application. And I feel it's dishonest to use a tool that can't really be used to help them. It's unfair to them and I feel uncomfortable"*. Nevertheless, the consortium tried to force the Red team to analyse people's behaviour whilst not being allowed to discuss the appropriateness of the device. In this way the consortium enacted a reality where the rhetorical concepts from the academic literature were made more 'real' than the material properties of the app. An analogy might be like an air accident investigator that is only allowed to report on the behaviour of the pilot, whilst being prohibited from mentioning the flaws in the material structure of the aircraft that resulted in the wing falling off. This led to numerous heated exchanges with emotional language being used, and behaviour change being described by the Red team as a 'noose' that was hovering above our heads. One of the Red team tried to downplay these concerns by saying *"you do this rubbish, so that it allows you to do this other thing"*, the suggestion being that in order to get funding, one has to play along with these framings. But in practice this attitude did not make these entities disappear. One of the Red team described the quality of 'behaviour change' as follows: *"I can't take it apart. I can't stick it together with anything. I can't couple it to something else to give us choice"*. What is striking in this quote is that a rhetorical concept that was largely undefined within the consortium became as tangible as a crushing piece of granite that acted to constrain the research.

The result was that the Red team refused to study the participants in terms of psychological motivation or behaviour change, but came to an informal truce where as long as the team would carry out a limited recruitment campaign and get participants to generate data with WideNoise our role in the consortium would be met. To fulfil the research deliverables, the Red team tested different recruitment and engagement strategies by hiring an advertising agency to create a media campaign that compared online banner ads, newspaper adverts and a mobile billboard van in terms of being able to recruit participants. The campaign allowed the agency to track how many people downloaded the app via the different advertising channels. The Red team also used an international conference to email every delegate every day to encourage them to use WideNoise. This led to WideNoise data being generated between conference sessions and on the evening walk to the conference dinner. Neither of these deployments created any meaningful environmental monitoring, but they provided the consortium with data that could be reported in EU deliverables as engagement and motivation patterns.

This episode showed that the notions of motivation (subsubsection 2.3.1.3) and behaviour change (subsubsection 2.3.2.2) from the participatory sensing literature were not ephemeral discourses but powerful actors that actively created ontological conflicts within the project. The main effect was that they forced the creation of tokenistic engagement practices that most of the researchers felt were not meaningful, but had to be carried out to reference the existing literature and fulfil research deliverables.

6.5 Design: WideNoise attached to an issue of concern

The most dramatic transformation of WideNoise occurred as it was attached to a public controversy. This allowed WideNoise to be used by a range of new actors who used the app to support their own ontologies of noise and sense different entities. This section demonstrates that it is possible to deliberately translate the ontology of what is being sensed by a sensing device, through organisational and publicity work as well as hands-on configuration and support.

As part of the EveryAware consortium, the Red team was obliged to deliver a large-scale study using WideNoise with many participants and lots of data. Based on the early recruitment experiments, it was clear that promoting the app as a stand-alone object would not engage many people or create meaningful usage. The Red team wanted to fulfil their obligation but also their own ethical imperatives and so tried to find a way of repurposing WideNoise as action research. Thus we encased WideNoise within the framework of a collective campaign targeting an environmental issue of public concern. It was our view that it would be easier to attach WideNoise onto an existing issue that already had people gathered around it and would provide a reason for participants to take measurements and make sense of the data. We chose Heathrow Airport in London because it was a major topical controversy in which noise pollution played a crucial part.

Heathrow is the world's third largest airport, with 73.4 million passengers passing through Heathrow every year (Heathrow Airport 2015), making London the city with the highest aircraft noise exposure in Europe (Mayor of London 2013). In spite of this, there have been many calls to expand the air travel capacity in the south-east of England, and in 2013 the Airports Commission was set up to establish which of the three London airports should be expanded. In 2015 the commission recommended the expansion of Heathrow with a third runway, which was expected to generate £147 billion in additional Gross Domestic Product over the next 60 years (Airports Commission 2015). Expansion was expected to bring more flights and road traffic, and more people would be affected by aircraft noise. The issue of the airport's impacts is highly emotive and is being kept in the public eye via on-going media reporting of studies on noise and air quality impacts and economic benefits. In many of these studies, the issue of Heathrow noise is framed in terms of a trade-off between addressing the, *"annoyance and disturbance suffered by some local residents as a result of aircraft noise, while at the same time continuing to maximise the social and economic benefits that the airport delivers to the local community and the country as a whole"* (Heathrow Airport Limited 2013, p.7). The political controversy is that local residents feel there is an unequal distribution in the environmental pollution affecting them, while the economic benefits are going to others. The Red team had existing contacts with an organisation called the 'Heathrow Association for the Control of Aircraft Noise' (HACAN) which is the largest voluntary organisation in Europe for people suffering from aircraft noise (HACAN ClearSkies 2015). The organisation are focused on campaigning but do not carry out organised noise monitoring. This meant a collaboration with the Red team on monitoring noise might be a mutually beneficial way of attracting participants to use WideNoise and afford the issue of Heathrow greater visibility. In 2012, when the Red team started the collaboration with HACAN, the Heathrow noise issue became more important due to the creation of a governmental commission that would report on which airport should be expanded. While HACAN initially argued that a third runway at Heathrow was unlikely, this changed during the multi-year noise collaboration and became an imminent threat, making the collaboration more important.

By associating WideNoise with the existing Heathrow campaign, the Red team hoped to provide an ontological answer as to 'what' WideNoise should sense. A third runway would greatly increase noise for local residents and give the monitoring campaign a clear focus. While the Red team did not dictate that participants should monitor aircraft noise, by targeting that geographical area of London with a sound app, it invariably became connected to the threat of a third runway. This created a shift from an ontology of sound as scientific vibration or behaviour change towards sound as causative i.e. having a source and having the potential to affect entities and thus having an emotive and political dimension. While the lack of calibration prohibited the use of WideNoise as a scientifically accurate evidential instrument to combat the airport, HACAN and the Red team felt that the device could be used within an engaged context where the emotional and political qualities of sound mattered. This constructed a motivation for using the app. Rather than retrospectively studying the motivation of participants, we were pre-emptively designing WideNoise into a campaign. Motivation thus shifted from something individualistic, internal and psychological as imagined in the participatory sensing literature, towards something collective, that is engaged with an issue, pollutants, sound metrics and a measuring device. The next two paragraphs analyse how this ontological shift in sensing was achieved through practical configuration, organisational labour and publicity.

Figure 6.6: Noise Map campaign poster created by the Red team, showing noise emanating from a plane flying overhead.

In order for the collaboration with HACAN to function, the Red team raised additional third party funding to be able to hire a member of HACAN as a community officer for the duration of the campaign. The community officer was highly engaged with both the politics of Heathrow airport and the local community. Their local knowledge, contacts and access to the HACAN mailing list of members were crucial in organising the series of well-attended participatory workshops. The Red team created 200 posters and leaflets that were placed in local shops to publicise the campaign and invite people to the workshops (Figure 6.6). The collaboration between the university and HACAN as local partner worked well in getting extensive television, radio and newspaper coverage for the campaign (Figure 6.7). The launch of the Noise Map campaign was attended by the chairman of HACAN and a local politician as well as 40 local residents. In total, 80 people attended face-to-face workshops around Heathrow and due to the media coverage a total of 252 people took part in the Heathrow campaign and created 6666 measurements in the area (Nold & Francis 2016, p.230). For the EveryAware consortium this deployment was sufficient to treat it as a successful large-scale case study and cover the Red team's commitment. Crucially it also opened up a variety of surprising ontological appropriations of the app by local actors such as the residents, HACAN and Windsor and Maidenhead council.

Figure 6.7: BBC coverage of the campaign in relation to the Heathrow noise issue.

After meeting local residents at the campaign launch, it became clear that most of the participants were retired and few had suitable modern smartphones that would run WideNoise (Figure 6.8). Amongst those that owned a smartphone, few were comfortable with the interface or had ever downloaded an app before. Training and supporting the Heathrow participants involved creating a support network around the app that involved designing a printed manual that explained how WideNoise functioned and described its calibration limitations. The manual suggested a loose usage protocol, *"use the application where and when you like but please do so outdoors so that we can combine the data to make the communal noise map"*. The support network involved the community officer being available for weekly face-to-face meetings at a pub in Isleworth and offering email support to all the participants. In the meetings the Red team would restate the calibration issues of the app to trigger conversations about how this affected the monitoring campaign.

Figure 6.8: Promotional photo of the Noise Map campaign launch with participants holding up smartphones.

Most of the smartphones owned by the participants were too slow to run WideNoise, so to create a larger monitoring campaign, the Red team purchased new smartphones to lend out to the participants. The aim had been to buy twenty identical smartphones, but due to 'security concerns' UK shops only sell a few phones in a single purchase which meant visiting multiple shops to buy all the hardware. A side effect was that the phones were locked to different network providers that required a variety of top-up vouchers. Setting up a single phone involved unpacking it, changing the battery, inserting the Subscriber Identity Module (SIM) and adding credit. Then the extraneous interface icons had to be removed, the Internet connection set up which required multiple Short Message Service (SMS) exchanges with each network provider. Then WideNoise had to be downloaded and installed on each phone, which required a valid Google account in order to access the Apps Marketplace. This required that we either create individual Google email accounts for each phone or use a single account on all of the phones. For simplicity, we opted to use a single account to sign into all of the phones, but this skewed the number of user downloads. Setting up WideNoise also required a registration process with email address validation that turned out to be difficult, and some participants tried the process a dozen times and still failed. In addition, a number of the smartphones failed and the hardware had to be swapped amongst the participants. This meant that we ended up with phone number and registration mismatches between users, user accounts, and phone hardware. Overall these multiple levels of intricate interdependent registrations made it extremely difficult to administer the project and keep track of the data generated by individual users.

The central issue was WideNoise's fundamental reliance on specific smartphone hardware that forced the device to be part of commercial, technical and legal frameworks of network and hardware manufacturers, platform providers and government legislation. It is simply not possible to use a smartphone to sense the environment without being locked into an infrastructure (Star & Ruhleder 1996) of entities that regulate and shape the way the device can be used. The underlying problem we encountered was the socio-technical assumption that each smartphone is owned by a single person who will also be the end-user of the device. This assumption meant the phones involve nested chains of logins, registrations and personalisations that required the entry of inordinate amounts of information to be provided just to initialise the device. To our knowledge, there is no administrative system that would have allowed for centralised setup and ongoing management of smartphones for participatory sensing. WideNoise and the data-management platform of the consortium all relied on the concept where the hardware identity represents an individual person. This assumption makes it very difficult to use smartphones for collectivised participatory sensing where devices need to be lent to multiple people or a group of people use the same device at different points in the day. In this study, the smartphones did not save the labour of the researchers or participants but actually generated huge amounts of hidden labour that is unacknowledged within the rhetoric of the contributory science model of cheap and efficient crowdsourcing (subsection 2.3.1).

This episode showed that it was possible to make up for some of the shortcomings of the app and radically reconfigure what it was sensing. But this required extensive organisational and publicity work as well as laborious hands-on configuration and support.

6.6 Usage: WideNoise as metric of experiential and political impact

I now explore the way the Heathrow participants created a specific way of using WideNoise based on their ontology of noise as an experiential and political issue.

The Heathrow participants did not treat WideNoise as a scientific instrument for dispassionately measuring vibration but a political tool that would document their reality of noise at Heathrow. They did not trust the official noise metrics, suggesting *"there is almost certainly technical hocus-pocus - some technical bullshit in all this"* and instead wanted to *"document actual noise levels rather than the theoretical ones that BAA[4] provide"*. Many participants were frustrated that the airport was mainly modelling noise dispersal rather than empirically measuring it and felt that they were misrepresenting the impact of noise on the Heathrow community. Taking part in the noise monitoring campaign would *"make politicians realise what we suffer"*, exert political pressure to *"raise the bar for politicians thinking about the 3rd runway"* and *"add weight to the argument against Heathrow expansion"*.

The participants asked detailed questions about the calibration of WideNoise and understood that it was not a sophisticated instrument that would be directly comparable to the official measurement devices. The important thing for the participants was that *"it's got to stand up in debate ... and taken into account by 'us' rather than a weakness used by 'them' to attack us"*. Accuracy was thus not a scientific goal in itself but mattered only in as far as it created a strong or weak political negotiation position in relation to the airport debate: *"if we can't back it up then it means nothing when it's presented to the consultation and the experts will take it apart"*. This meant many participants were concerned whether WideNoise would be 'good enough', but there was no obvious threshold point at which measurements would be accepted or dismissed by the airport. This ambiguity meant that WideNoise still offered some potential within the political context. Nonetheless, many participants suggested the need for a static, calibrated measuring device that would be able to accurately contest the airport's claims. After the EveryAware

[4] British Airport Authorities were the commercial owners of the airport now called Heathrow Airport Holdings Limited

research was complete, this request became the basis for a range of custom prototypes beyond the EveryAware research remit (section 8.2). Nevertheless, while the participants were frustrated by the accuracy limitations of WideNoise, it was the only tool they had access to and they suggested that using WideNoise gave them *"some satisfaction of 'doing something"'*.

The participants tried to use WideNoise to capture the noise from individual overhead flights and made significant efforts to measure each overflight as well as possible. When people were home and heard an aircraft approach they described rushing into the garden to take a measurement with the app as the plane was overhead. Others used the app during daily activities, such as a woman who described cycling to and from work and stopping to take measurements whenever a plane flew overhead. Many of the participants were concerned that they were taking the measurements correctly and emailed the community officer, asking: *"how does my 83.48 dBs stack up anyway? What do I realistically need to accomplish to hit the bell rather than let the side down?"*. This suggests that the participants were not just trying to determine their own exposure but saw their sensing practice as part of a joint campaign to establish collective impact of noise. During a workshop, one participant demonstrated to another that the best time to start a WideNoise measurement is while an aircraft is still at a distance in order to capture the noise peak as the aircraft starts coming overhead. Another stated that the 'extended sampling' function of the app was useful for capturing the full duration of an overflight and get a higher reading. A number of people started discussing a more rigorous usage protocol, such as this suggestion from a participant during a workshop:

> *"I think for the future it would be much more important to have the rigour [that] we will not average readings. And secondly, there should be an encouragement for people not to record less than 75, or 70 or whatever it is. Because to influence the people to whom this applies, it seems to me they are not interested in the fact we have taken 5000 readings and the average is 76. What's going to influence them is that 10% of the readings were above 85 or whatever and if we cut out all the smaller readings the data that they will get will get bigger and bigger and bigger"*.

The participant describes the WideNoise data as a form of communication with *'the people to whom this applies'* in order to influence them. The participant makes the argument that the campaign should focus on numerically high readings in order to increase the political and public impact so that the campaign will continue to expand indefinitely, *'get* *bigger and bigger and bigger'*. Another participant said, *"I didn't bother sending anything less than 75 decibels"*. What is clear from both these descriptions is that the participants were making deliberate choices to capture and maximise the experiential, political and publicity impact of an aircraft. Many of the participants were extremely knowledgeable about the academic literature and legislation around noise management at Heathrow and they stated that they wanted to avoid the averaging of the noise levels. The reason was that the official Heathrow noise metric is based on averaging sound events across 24 hours, which doesn't adequately account for the disturbance caused by the loud but short noise of aircraft overflights. In a lecture, a noise campaigner provided an analogy of letting off a gun every night next to somebody's ear, which when averaged out over day using the sound metric would become as loud as a gently murmuring stream (Weise 2014). For this reason the Heathrow participants desperately wanted to avoid averaging the WideNoise data and said, *"I was going to take some quiet ones [measurements] and but don't want them to just pull down the average. I wanted to stress the loudness. That's what Heathrow already has is averages. I thought we were trying to say in reality the loud noise that we are in"*. What is striking in this quote is the conflict between the reality of the official metric and the 'reality of loud noise we are in'. By using WideNoise to measure the loudest and most disturbing planes, the residents were trying to better communicate their experiential reality than the current noise metrics. Crucially, the participants did not see the selective submission as manipulation of scientific data but as adopting a rigorous experiential and political protocol. The participants mentioned many times the care they took in avoiding measuring non-aircraft noise, for example people said, *"I didn't take anything when there was wind, the measurements were meaningless"*. The point is that they were not creating exaggerated 'fake' data but that they were highlighting the 'real' high numbers that were actually occurring but being swamped by the averaging properties of the official metric. By selectively submitting the data from planes that annoyed them, they were adapting the design of the app as a communicative 'hack' to create a better representation of their reality of noise.

In contrast the participants were confused by the 'subjective' sliders of WideNoise saying *"I still don't understand the Alone - Social axis. What does it actually mean? That I was alone when I recorded it? That the noise was created by a single aircraft? Or what? It does seem rather odd"*. For the participants these sliders made no sense in the Heathrow context; they described them as *"really meaningless"* and questioned *"does accurate completion of that section every time matter?"*. The residents who did use the sliders did so *"because we were supposed to"* and mentioned arbitrarily moving the sliders to the right or left extremes. The tagging function was used to some extent to indicate whether the plane was landing or taking off or to describe being woken by the noise. The general consensus though was that the prebuilt 'subjective' features of the app were too generic and that the selective submission of the decibel data functioned as a much more powerful way for the residents to articulate their subjective reality of sound.

During the launch of the WideNoise campaign a local councillor suggested that WideNoise, *"will enable people to [Pause] real people to record, real noise, not what Heathrow or what anybody else says it is - real people, record real noise and put it on a map"*. The significant part of the quote is the repetition of the word *'real'* in relation to both people and noise, which suggests that the residents are engaged in a fully fledged ontological battle about the reality of noise at Heathrow. Rather than rejecting the concept of a metric as encompassing their sensation, the participants were strategically searching for a new metric that they could deploy to represent their reality to themselves and project it towards others. The selective submission should be seen as a 'hack' of the official noise data that the residents feel have been adopted for political reasons to delegitimise their experience. By using the app's selective submission affordance the residents enacted a protocol that both **represented** and **contested** the representation of their experience and political role. WideNoise data became an alternative metric that became an index of physical, experiential and political pressure. Large numbers were simultaneously representing vibration, pain and causing greater institutional pressure for stopping the third runway. The residents thus denied a division of noise into an objectively measurable artefact or a subjectively felt entity. The result was that the residents became an integral part of the WideNoise data that could not be removed from it.

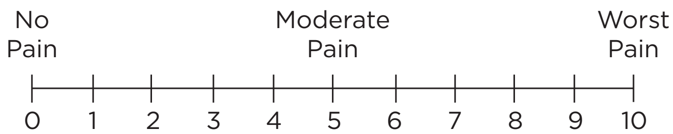

Figure 6.9: Pain scale used within medical contexts for patients to indicate changes in pain over time.

A useful comparison might be the pain rating scales (Jensen et al. 1986) that are used within medical contexts to establish an intersubjective language between patients and doctors as part of pain management programmes (Figure 6.9). The device mediates the relationship between patient and doctor and it would make no sense to use the scale without the patient being involved. The comparison highlights the way the residents' enactment of WideNoise was a way of including themselves 'within' noise, in order to build a new triangular relationship between themselves, noise and the airport. This example suggests the possibility of developing new relational tools that would better articulate the experience of the residents in their dealings with the airport. I felt very engaged by this approach and it inspired a range of prototypes towards supporting ontological multiplicity (chapter 8).

6.7 Usage: WideNoise as mass demonstration

I now turn to explore the way HACAN enacted WideNoise as a mass demonstration where 'who' was doing the sensing mattered more than 'what' was being sensed. This illustrates that WideNoise could be enacted politically without making any use of the generated data.

The pressure group HACAN were enthusiastic about the noise monitoring campaign because it refocused public attention on the issue of noise at Heathrow, and the association with the EU research project added legitimacy to their campaign. While HACAN were actively contacting their members to get involved in the WideNoise noise monitoring campaign, there was a sense that the organisation were using the app differently from the residents:

> *"Certainly, the app is popular [respondent pauses]. Clearly people feel a need to measure the noise themselves because there is a lack of trust in BAA and the authorities. Even though BAA have got a lot better in measuring the noise - it's probably pretty accurate [but] that is not people's perception. They are grabbing this tool as something to give a result. Certainly there is a need out there, people are wanting it"*.

The argument is that the airport is not hiding the measurable level of noise and that WideNoise would not uncover anything because there was nothing untoward to discover. In the interview with the representative of HACAN, I mentioned that many of the residents were collecting data to give to the authorities and they responded, *"I think that example you gave, that is somebody not thinking like an activist. That's somebody saying if I have some data, I will give it to a politician to do something about it. Well actually, that's not how things would work"*. The representative argued that it is unrealistic to imagine that giving data to the authorities would have any real impact. From this perspective, the goal of the WideNoise campaign was not to 'speak truth to power' via the data but to demonstrate a shift in 'who' is doing the sensing. A press release from HACAN argues that, *"the fact that residents are measuring the noise themselves will put added pressure on BAA to get it right"* (HACAN ClearSkies 2012). The extract stresses that it is now residents who are 'measuring the noise themselves' not the British Airport Authorities (BAA). For the HACAN representative it was the switching of 'who is doing the sensing' that would create political pressure on the authorities rather than the data itself. The suggestion is that the impact of WideNoise is the inclusion of people in a symmetrical process of keeping a watchful eye on the airport. Notably none of the HACAN press releases about WideNoise make any explicit mention about how the gathered data will be used. In these press releases HACAN deliberately shifted the focus away from the hardware and the data towards the people and their activity of measurement that is being presented as a performative political action.

In the interview, the representative argued that this approach emerged from the experience of activists during the anti-roadbuilding campaigns of the 1990s, where they realised that official government enquiries couldn't be won by activists. Out of hundreds of public enquiries into the road building program, only one was ever won by the activists and they concluded that the system was strategically loaded against them. The activists learnt that they had to win in terms of public opinion before an official deliberative public enquiry could take place. This meant staging large-scale demonstrations of public opposition: *"you build up your massive demonstrations. You show politically it's going to be so difficult to build a road or build the new runway that actually the authorities ... they back off"*. This is how HACAN were using WideNoise in relation to the threatened third runway as can be seen in another HACAN press release:

> *"The number of people logging readings and the passion of those contributing at community meetings demonstrates how people are worn down by the noise from Heathrow"* (HACAN ClearSkies 2012)

HACAN used WideNoise as a collective demonstration and expression of public opposition to airport expansion. While a widely distributed group of people creating readings with smartphones is not the same as a physical street demonstration, the press release translates the act of using the app into a protest. In this translation, the mass of participants taking measurements becomes an index for their passion about the noise issue. Using the carefully worded press releases, HACAN managed to enact WideNoise as performatively projecting emotive power that did not require analysis of the WideNoise data. The goal was to demonstrate enough anticipatory political opposition to airport expansion before an official process could be instituted. In this activist approach 'who' was doing the sensing mattered, while it wasn't important 'what' was being sensed so the accuracy limitations were not an issue. The HACAN representative confirmed that even if WideNoise had been more accurate, they would have likely used the app in the same way.

6.8 Usage: WideNoise as community annoyance

This section discusses the way the Royal Borough of Windsor and Maidenhead (RBWM) council re-configured WideNoise as sensing community annoyance. In this way the data could be used as key evidence for their response to the UK government's 2013 Airports Commission (Airports Commission 2013*a*). The section highlights a politics around ontological arguments about whether using WideNoise demonstrates enough intentionality to count as annoyance.

During the WideNoise campaign, the Red team was contacted by the RBWM council because one of their local residents had experimented with the app and then encouraged the council to collaborate with the WideNoise campaign. The council have long been opponents to airport expansion and officially endorsed WideNoise describing it as an *"important evidential tool"* (Windsor & Maidenhead Council 2013, para.5) since it *"provides affected households an independent opportunity for using their own hands-on device to record their complaints or experience"* (Gould 2013, p.4). The council created their own local campaign in Windsor and Maidenhead called 'Raise Your Voice', which called *"for volunteers to step forward and help implement the roll-out of the WideNoise mobile phone app"* (ibid.) with the goal of giving the data *"to government as part of the on-going (and very imminent) deliberations into future aviation proposals for Heathrow"* (Nash 2013, p.1). The council promoted the campaign via their website, social media, magazine and e-mailed 8,000 residents and got media coverage in local newspapers as well as on the web-sites of the two main political parties. They also created their own 'how-to' guide for the app and organised public workshops where they taught residents to use WideNoise. The council was very satisfied with the campaign and used the resulting WideNoise data as the central component of the official RBWM response to the UK government's Airports Commission that makes the recommendation on future airport expansion (section 6.11).

Here I focus on the way WideNoise was translated into a legitimate local government tool, by focusing on an internal discussion amongst the RBWM team that I was invited to attend. The discussion took place at the critical point where RBWM had to decide whether they should give official council support to the WideNoise campaign. A junior team member introduced the app, suggesting:

> *"The database is not of noise levels that we can use to beat the DFT [Department for Transport] or Heathrow round the head with. It's more the number of complaints generated, so the number of people that physically take themselves outside to log the problem. The decibel level or whatever that is created as a result of that action, whilst it's not irrelevant, it's not the overall outcome of that exercise. The outcome is the actual [respondent paused] the noting of a noise source"*.

However a senior member of the team disagreed: *"the fact that you've registered noise at this stage, undefined in terms of level, is not an annoyance. It's merely the fact that you have picked up a noise that you have identified as an aircraft"*. The junior member responded, *"no, it's a statement. I'm feeling annoyed"*. What was at stake in this argument was the ontology of WideNoise, i.e. what the data consisted of. For the junior member, each data point was created as a deliberate human complaint that had representative power to say, *"I have been affected by this problem"*. In contrast, the senior member argued that a data point was merely a sound event without demonstrating human intentionality. The difference either legitimates or delegitimates the data within the framework of Heathrow legislation. The key issue was wherever WideNoise could be used in relation to the ANASE study (Le Masurier et al. 2007), which had been a major study on community annoyance and had concluded that Heathrow residents were annoyed by much lower levels of noise than had previously been thought. The study had been rejected for procedural matters and many of the local councils were trying to revive it (section 8.1). The council's goal was to directly associate WideNoise with ANASE: *"putting these two things together will be excellent"*. If each WideNoise data point could be said to represent 'community annoyance', then the data would become important evidence within the legislative framework for Heathrow. Yet if a WideNoise data point simply indicated the physical presence of an aircraft, then the data would not be as useful for the council. The whole thing seemed to depend on whether using WideNoise involved enough user effort to demonstrate intentionality and thus annoyance. The senior member argued, *"I'm sitting in my garden I have got nothing else to do, I thought I would point my camera up [sarcastic laughter]"*, the implication being that the act of making a complaint with a smartphone is too easy, *"it's got to move on beyond that, to 'this is a noise that is causing a nuisance"'*. The suggestion was that the amount of effort involved was an indication of intentionality, so if it were too easy to complain then it would become invalid. The disagreement amongst the team was thus centred around whether the physical act of using WideNoise could be interpreted as demonstrating enough intentionality to become a legitimate complaint.

Surprisingly a parallel version of this argument was discussed in a Sunday Times newspaper article (Boswell 2016), which exposed the fact that there are 5 'super-complainers' at Heathrow. Along with 5 others, they were apparently responsible for generating *"almost half the 25,000 complaints"* (para.6) that the airport had received between July and September. The thing that angered the newspaper was that these people had created a mechanism on their smartphone that quickly inserted information into the airport's official complaint system at the click of a button to make it easier to complain about a specific flight (Mcallister 2013). The newspaper quotes one of the residents as saying: *"what I ended up with was just a button on my phone which would fill in the complaint, so I just pressed the button any time one f*ed me off. It was that simple, I could be in the garden or on the toilet, and I could just press the button and it would fire off the complaint"* (Boswell 2016, para.6). The tone of the article implies that this technical hack had made complaining too easy to the point where it became an abuse of the system. The article mentions that the airport reacted by making the complaint system more difficult to fill out for residents.

The effort/legitimacy argument was thus the same as within the RBWM episode in the way it focused on the material design of these complaint systems as arbiters for legitimate ways for residents to complain. The fundamental assumption is that the laboriousness of making a complaint becomes an index for the intensity of residents' pain. Thus the material properties of the app became a site of ontological and material politics where different conceptions of legitimate behaviour were played out. RBWM wanted to use WideNoise but they had to try and find a way of legitimising it within these existing ontologies of complaints. The council team resolved this quandary by focusing on the technical qualities of the app that added time and location stamp as well as decibel value to each complaint. While human complaints, were for the senior member, *"by definition inaccurate"* the addition of these technical elements strengthened each complaint and, *"will give that accuracy"*. The RBWM cabinet briefing states that *"whilst the application is not regarded as a scientifically accurate device, [...] it 'legitimises' a resident's complaint"* (Gould 2013, p.4 emphasis in original). The quote illustrates a surreal situation, where the technical qualities of WideNoise became a way of legitimising resident complaints even though the technology was inaccurate. RBWM were strategically performing the supposed democratising and technical qualities of smartphones for their own purposes (section 2.3). RBWM were deliberately arguing for a bifurcation of nature that many of the team didn't actually believe in, because they thought this would legitimise both the app and the residents. Indeed once the app was framed in this way, it got official council approval and allowed RBWM to use the WideNoise data as the key component of their response to the critical Airports Commission that would produce the policy recommendation on runway expansion. The RBWM report and accompanying map became one of the two outputs of WideNoise (section 6.11).

6.9 Usage: WideNoise as science platform

As the WideNoise sensing campaign was taking place in Heathrow, the Red team had to report to the EveryAware consortium on the progress and motivation of the participants. This section describes the way this triggered conflict about what WideNoise was sensing.

The Red team's progress report described that the Heathrow participants framed the usage of WideNoise in terms of trying to influence the airport authorities in relation to the third runway expansion. This visibly annoyed the consortium, who suggested that this politically engaged usage was polluting the data. In their vision, the Red team should have enrolled thousands of participants without any explicit agenda so that they would generate neutral data. In my interview, a researcher from the Green team argued that the Red team had blurred the important dividing line between scientist and activist. They suggested the role of scientists should be; that *"I will tell you and it's correct and I will tell you when it is right and I will make sure that if you have something. But it is really in a scientific way"*. The issue for the Green team was not that the residents had a political agenda but a fear that this would reduce the quality of the data. For them the role of the researcher should be to enforce strict data collection protocols. One researcher suggested that the current WideNoise data was too tightly clustered and there was not enough night-time data. The consortium suggested that a rigorous protocol should involve dividing the Heathrow area into grid squares and make the participants take measurements in evenly distributed squares at regular intervals throughout the day and night. The Red team was urged to encourage the participants to get up in the middle of the night, walk to a square some distance from their house to take measurements, even though there was no noise from flights at night (night flights are prohibited). When I asked pragmatic questions such as how large the grid squares needed to be and how many measurements had to be made in each square, I was not given an answer. There appeared to be no established thresholds, yet from the scientist's perspective, having more data was simply better. This rigour expected of the 'human' participants was in stark contrast to the lack of 'technical' rigour of the sound calibration of the app. Trying to get people to wake up in the night to take measurements with an uncalibrated device, while there are no aircraft present, felt surreal. It assumed an asymmetric distribution of labour and rigour where the participants were expected to put in a vast amount of work, while the researchers were too busy to calibrate the device.

The engineers of the consortium were trying to associate the WideNoise data with the European noise directive (European Parliament 2002) that calls for noise maps to be created.

These gridded maps are based on continual traffic noise emanating from static roads. Yet gridded noise maps are not relevant for aircraft, since planes fly quickly along linear routes that ignore urban geography and create loud intermittent noise on the ground. For this reason, aviation noise maps use banded contours to represent ground exposure. Despite the fact that aircraft were clearly the only important source of noise at Heathrow, nevertheless the consortium insisted on implementing a grid protocol in Heathrow. In the end the Red team refused to enforce a spatial and temporal grid protocol onto the participants, since it seemed inappropriate for aircraft noise and would violate our relationship with the participants.

The incident identified that the consortium and residents were trying to use WideNoise to sense completely different environmental realities. The ontological clash was between enforcing scientific objectivity in order to connect to a policy directive versus a situated protocol that engaged with local pollution. The problem was that the generic policy directive was not relevant to the Heathrow context and applying it would prevent the residents from carrying out their own protocol based around noise as an issue of concern. In this case, the ontological politics of sensing created a binary opposition between whose reality of noise should be sensed.

As the EveryAware research project progressed, the consortium stopped discussing WideNoise as an app and it only featured in terms of quantity of data points. Despite not being able to enforce the grid protocol, the consortium continued to use the Heathrow data for behavioural analysis. When I asked explicitly in the final consortium meeting whether the app would be supported in the future, there was silence in the room. The participants of WideNoise were only discussed when they were described as 'lazy' for not using the tagging function enough. To increase the tagging usage, the Yellow team developed a new tagging function for WideNoise that automatically suggested tags based on geographical location or slider state. The aim was to analyse how people were using the tagging function and then experiment with different recommendation algorithms to see how tagging behaviour changed (Mueller et al. 2013). One researcher explained that the strength of WideNoise was the quantity of perception data it created, which meant it was 'better' than other noise monitoring apps that were more accurate but didn't generate enough perception data. While I had always assumed that the subjective sliders and tagging functions were merely meta-data, for most of the consortium, these 'subjective' sensors were the main data source of WideNoise. During one consortium meeting, I raised the issue that the graph about behaviour change did not have any error bars for measurement accuracy and I was told that *"people learn to guess the correct value of the device"*, the suggestion being that the participants will change in relation to the device regardless of whether the device has any relationship with environmental sound pressure.

I was told that before I joined the consortium, that there had been a proposal to present participants with random 'environmental' data, to see if they would adjust their behaviour in relation to this data. Essentially, it didn't matter that the WideNoise numbers were arbitrary. Since the consortium enacted WideNoise's sound data as an *a priori* 'objective' baseline against which human behaviour would be measured, there was no need for error bars for the microphone data. What mattered was demonstrating that people got better at guessing, as a demonstration of a behavioural shift. The Blue and Yellow teams thus shifted WideNoise's site of causation towards the feedback mechanism of the interface, rather than environmental pollution. WideNoise was thus enacted as disconnected from the external world to become a social data laboratory, where test subjects could be studied in terms of universal patterns of human behaviour. This ontological enactment created conflicts with the Heathrow actors. Near the end of the Red team's collaboration with RBWM, the council requested access to the raw WideNoise data generated by their residents in order to produce their own analysis and submit it to the official Airports Commission. Yet the consortium resisted the request for raw data, arguing *"why is the [consortium] visualisation not enough for them?"*. The consortium had multiple concerns, one of which was that the WideNoise data might be used in a court case and that the consortium might be held legally responsible. A researcher argued, *"this project is about monitoring how people's awareness increases. The measurements should be related to reality but I would never use these results in a legal framework"*. What is interesting about this quote is the way it suggests that the data should be 'related to reality' but somehow not **'be'** reality. I interpret the quote as a suggestion that the WideNoise deployment was intended to be a laboratory experiment that should not be used to directly transform the world. Academic research is thus framed as a distinct mode of reality that mirrors the world but is separated from it.

The practical impact of this ontological struggle was a protracted process that involved the council having to sign a nondisclosure agreement that prohibited them from using the data for academic purposes and required them to add disclaimers about data quality. This process made the collaboration with the council slower and more complicated. Once the Red team provided the raw data, the council found duplication errors in the WideNoise dataset that consortium had not noticed. The problem was that RBWM were relying on the data as a critical part of their report to the Airport Commission. The situation was only resolved after emergency technical fixes by the Red and Yellow teams. This incident illustrates an ontological struggle between the Blue team's conception of the data as universal insights about human awareness that clashed with RBWM's attempts to access the environmental component of the data to speak about a vibrational and political reality of noise pollution at Heathrow.

This section has highlighted an ontological politics around what WideNoise was sensing. For the Green team, WideNoise was supposed to be a scientific device with rigorous protocols to relate to EU policy. For the Blue and Yellow teams, WideNoise was a data laboratory for experimenting with user behaviour. For the Red team and Heathrow actors, WideNoise was a means to speak about the dynamics of aircraft noise.

6.10 Output: WideNoise as academic publication

There were two lasting outputs of the WideNoise device: the RBWM report and map discussed in the next section (section 6.11) and a major academic paper written by the EveryAware consortium. While WideNoise resulted in a variety of publications (Atzmueller et al. 2012, Becker, Mueller, Hotho & Stumme 2013, Mueller et al. 2013, Loreto et al. 2017), this section will focus on the 13 author collective paper called 'Awareness and Learning in Participatory Noise Sensing' (Becker et al. 2013*a*) published in PLoS ONE, a peer-reviewed journal for science and medicine. This paper included all the consortium teams and is likely to be the definitive academic output of WideNoise.

The paper's argument is that participants *"learn how to recognise different noise levels they are exposed to"* (Becker et al. 2013*a*, p.1) and that this will lead to increased awareness of environmental issues. I would like to examine how the paper builds this argument and the wider implications of the paper. The paper's introduction suggests that public health effects such as cardiovascular disease make it important to monitor environmental noise, and references the European Noise Directive that mandates the creation of noise maps to inform the public and policy-making (European Parliament 2002). The paper mentions that participatory sensing has been used to successfully target polluters such as airports and scrapyards. Yet as soon as the paper mentions the WideNoise app, it stops discussing noise as a public health issue and switches to talking about awareness and learning suggesting that *"studying changes in behaviour/perception and learning [are] very important aspects when dealing with environmental issues"* (p.4). The paper carries out an ontological somersault from sensing noise to suddenly sensing human learning without any explanation as to the value of studying people's behaviour rather than environmental pollution. The element that allows this ontological flip to happen is the WideNoise guess slider that generates the *'subjective'* data meaning 'opinions and feelings', while the smartphone's microphone is said to record *'objective'* data. The guess slider is the crucial material-semiotic component that translates the 'subjective' into numerical data for statistical analysis. The bulk of the paper then involves a series of diagrams that track the estimation error between the guess slider position and the microphone measurement baseline. These diagrams are used as evidence to claim that *"during repeated usage of the application the ability of users to guess the noise level around them increases, hence the user learns in time"* (p.7). The paper also identifies that, over time, individual users created more tags, and interprets this as *"an increase in user involvement and dedication to the task, hence in the level of awareness"* (p.8). It makes the claim that using the app creates a change in the participants that moves them from being novices to experts. Yet what is this change and expertise? The paper keeps referring to 'awareness' and 'learning' (p.11) but does not define these concepts or discuss how other research that might have used similar methodology or approaches. The end of the paper does not establish a link made between these statistical patterns and the paper's starting point of environmental noise health effects. How are they related?

Like the AirProbe paper (section 5.5), this publication neglects to analyse the material limitations of WideNoise, which is treated like an objective and transparent instrument for measuring humans and the environment. The paper's supplementary document argues that *"calibration was not deemed necessary"* (Becker et al. 2013*b*, p.5), because *"the measurements performed by the citizens involved are not required to be extremely accurate"* (ibid.). This is a surprising claim considering the paper's argument is premised on the idea that increased accuracy by the participants equates to learning and expertise. The paper omits to mention that during usage of the app, the participants were not using a consistent protocol for sound measurement or the 'subjective' features. I also question whether the paper misinterprets the increased tag usage observed by the researchers. The algorithm of the WideNoise tag function stores any tags that have been used previously. So once a tag has been used once on the app, this is always presented to the user, making it easier to add multiple tags for every entry. Thus an increase of tag usage over time likely points to the affordance of the app rather than being an isolatable 'mental' change in the participant.

The paper detaches the participant from the material properties of the app in order to make its assertion that it can create an *"increase in awareness toward environmental issues"* (Becker et al. 2013*a*, p.11). The paper does not explicitly articulate how a participant getting better at guessing decibel numbers might reduce environmental pollution. Yet the paper's focus on mass behaviour presents an unarticulated premise that the public is the cause of environmental pollution and that they are creating their own health problems. Thus the way to improve public health is to scale up individual behaviour changes. However, Heathrow is a situation where the residents are largely not the ones creating their own noise pollution. The Heathrow area is relatively deprived and it is people outside of this area that are gaining the main benefits of the airport. By treating the Heathrow participants as part of an aggregated mass of perpetrators whose awareness needs to be changed, the paper is blaming the victims of noise while refusing to engage with the inequalities of environmental pollution. Furthermore, the paper uses the data generated by the Heathrow residents to demonstrate changes in their behaviour without discussing their organised campaign to challenge the exclusionary socio-technical noise metrics of Heathrow. By asserting that WideNoise senses the participant's awareness, this is done at the exclusion of environmental pollution, aircraft, collective organisation and political pressure. In this way the paper is making an argument in favour of institutional mass behaviour change while neglecting community action. Upon seeing an early draft of the paper, I asked to remove my name since I disagreed with it's argument and findings.

6.11 Output: WideNoise as communicator of sensation

The second output and legacy of WideNoise is as the report and experience map submitted by RBWM council to the Airports Commission (Airports Commission 2013*a*). RBWM's aim was both to associate WideNoise data with the existing concept of community annoyance, and to suggest that the app offers a way of transcending these metrics.

The report criticises the official noise metrics arguing that *"simple noise indices such as LAeq fail to adequately predict the total effect on residential behaviour and annoyance to noise"* (Royal Borough of Windsor and Maidenhead 2013*a*, p.16) and present WideNoise as an alternative, suggesting it has *"enormous future development potential in relation to determining aircraft noise and community dose-response relationships"* (Royal Borough of Windsor and Maidenhead 2013*a*, p.19). It is striking the way the RBWM report translates WideNoise into an alternative communicator of the sensation of the Heathrow residents. The report does not highlight the decibel data from WideNoise but focuses on the 'experience sliders' to suggest that *"the residents participating can therefore be described as 'hating the man-made noise' (principally aviation) within both a solitary and social setting, resulting in the noise making them feel hectic"* (Royal Borough of Windsor and Maidenhead 2013*b*, p.70). The report includes a visualisation produced by the council of the most frequently used WideNoise tags to graphically communicate the impact of noise (Figure 6.10).

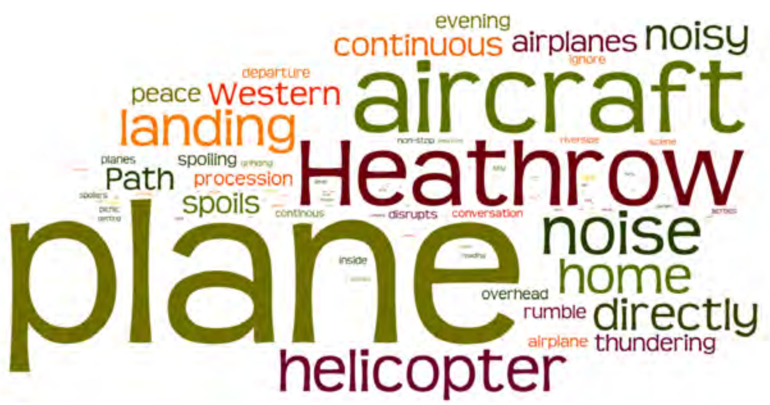

Figure 6.10: WideNoise tag visualisation created by the RBWM team for the Airports Commission report (Royal Borough of Windsor and Maidenhead 2013*a*, p.71).

The report makes the argument for *"a suite (scorecard) of descriptors relating to situations rather than a single all-encompassing averaging metric, used to derive an approximation of community 'annoyance"'* (p.16). Thus RBWM's rejection of decibel and move towards other indicators represents an ontological politicisation of the way the current metrics exclude the experiential reality of the residents. The report enthusiastically discusses a range of possible indicators as part of its suite, including the physiological sensing of the Bio Mapping art project and the noise prototypes I was in the process of building (section 8.2).

In a BBC interview, a spokesperson from RBWM talked about wanting to implement a Bio Mapping project in Heathrow, *"to take that a little bit further and find out what their body is experiencing with aircraft noise"* (BBC News Berkshire 2013). This demonstrates that RBWM saw a direct potential of these kinds of non-traditional representations for Heathrow. Based on my background as an artist and designer, the RBWM team asked me to produce an additional visualisation of the WideNoise that would highlight these experiential aspects. The result was the 'WideNoise Community Experience Map' (Figure 6.11), which combined the quantitative decibel data and geographic location of measurements with the textual WideNoise tags. The map combines measurement and sensation by making the size the of text tags dependent on the actual measured decibel data. The effect is the highlighting of incidents that were both measurably loud and disturbing enough to highlight with expressive tags such as, *'planes overhead spoil picnic'* and *'aircraft grinding across the sky'*. In this way the map reconnects the 'objective' decibel data with the 'subjective' tags to create a representation that tries to reconstitute the participants as both sensing and speaking actors. The RBWM team was closely involved in the production of the map, and requested the addition of the official 57 LAeq annoyance contour line. This was important since a number of the WideNoise measurements were located outside of the contour line, which demarcates the supposed onset of significant annoyance (section 8.1). By adding the contour, RBWM were visually demonstrating that the airport's noise problems extend well beyond the officially delineated area, thereby making an explicit socio-political point in the context of the Heathrow controversy.

The RBWM official submission to the commission combines the analysis report as well as the Experience Map. WideNoise and the map offered the council a way of destabilising

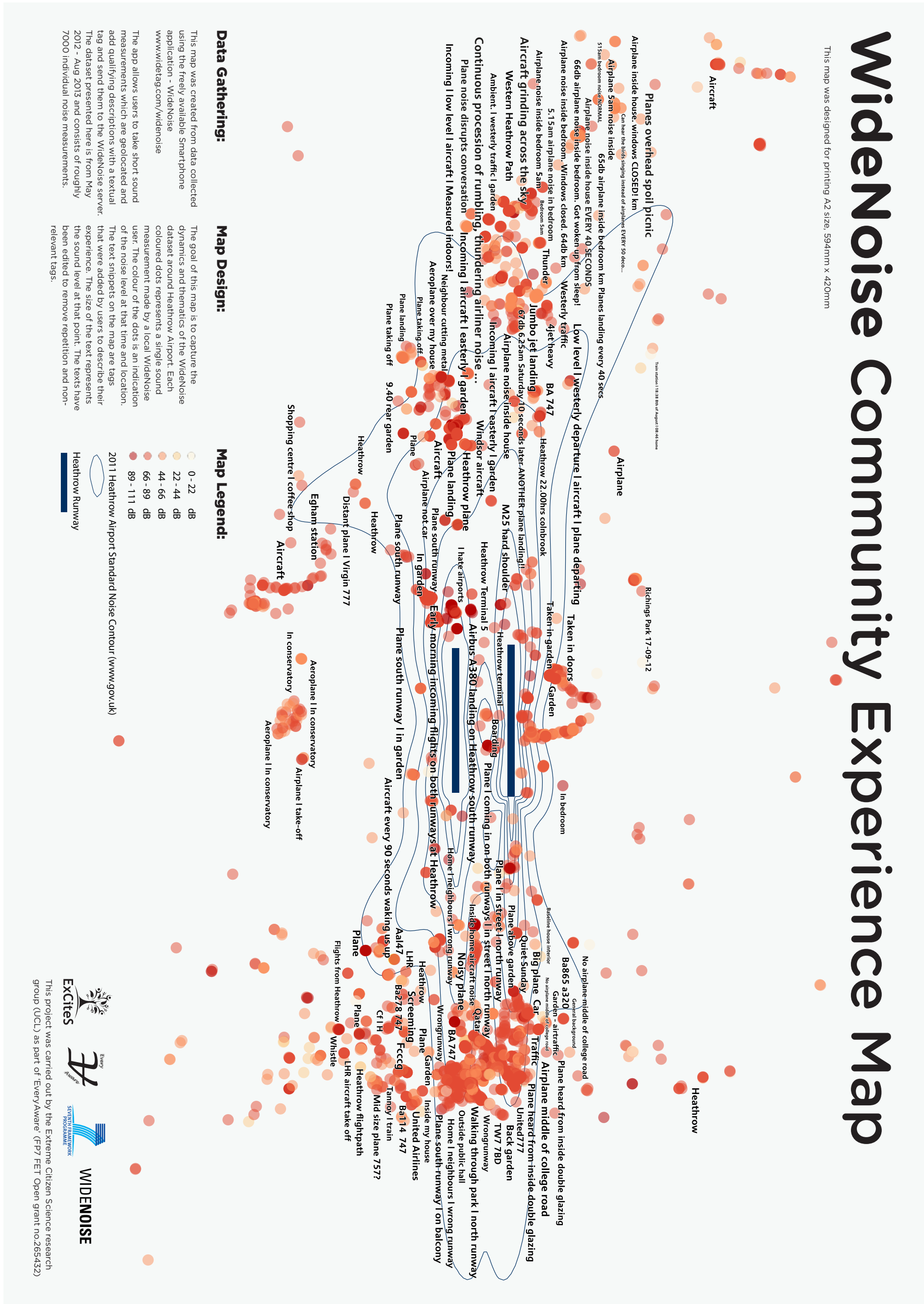

Figure 6.11: The WideNoise Community Experience Map. Each dot represents the location of a Wide-Noise measurement as well as tag text. The decibel level is indicated by colour intensity. The two rectangles in the centre indicate the two runways and the thin lines represent the official annoyance contours.

the current representations of noise and a powerfully graphic way of presenting an alternative representation of sensation. The remarkable thing is that RBWM is a Conservative party led council that includes the royal residence of Windsor Castle and Eton College. For such a traditional institution to base their critical consultation document on a experimental smartphone app and commission an artwork to make their political argument shows the way ontological politics creates surprising collaborations. The resulting Experience Map (Figure 6.11) demonstrates the potential for experimental ontological design to intervene within institutional decision-making processes and to have political agency within controversies.

6.12 Summary of the WideNoise device study

This chapter identified what was being sensed and what was doing the sensing in the design, usage and outputs of WideNoise. The device study has many similarities with the other devices in the way it strung together rhetoric and hardware to gather publicity and participants. Where it differs is that WideNoise managed to enrol an even greater variety of actors and enact a broader range of ontologies.

WideNoise	
Actor	**What is being sensed and what is doing the sensing?**
WideTag company	Greeness, spimes and data load
Green team	Scientific protocol
Blue & Yellow teams	App usage translated into behaviour change
Red team	App translated into situated issue of concern
Heathrow residents	App data translated into index of pain and political impact
HACAN	Users translated into mass demonstration
RBWM	App data translated into alternative community annoyance metric

Figure 6.12: Diagram of the different actor's ontologies of what is being sensing and what is doing the sensing with WideNoise.

My analysis is that WideNoise was designed multiple times by various actors and enacted as multiple devices that coexisted in parallel alongside each other. The app was first created to sense data load as a commercial demo while stringing together rhetorics of 'greenness' and technological singularity. Then the consortium enacted WideNoise as a professional environmental instrument as well as a sensor of user motivation, engagement and behaviour change.

The main redesign took place as it was encased within the Heathrow noise issue, which required organisational and hands on configuration. This allowed the app to be used within the ontologies of the residents, pressure group and local council. As WideNoise moved through these multiple sites of design and usage, the phenomena being sensed and what was doing the sensing shifted radically. They varied from server data load, loud aircraft, massed protest, community annoyance and behavioural change. These shifts where all sites of ontological struggle that revolved around a bifurcation of nature between an objective world and subjective human sensation. At times, the material qualities of the app were foregrounded to claim the device as a scientific instrument (EveryAware) or add legitimacy to resident complaints (RBWM). At other times, the material limitations of the app were hidden away to sense only the disembodied mind of the user (EveryAware). The most sophisticated usage was the way the residents repurposed the selective submission affordance of the app to enact the device as sensing both experiential and political pressure.

The device was the site of ontological struggles around accuracy, subjectivity and intentionality that were reflected in the two outputs of the device that enact different ontologies of noise as behaviour change and collective experiential and political pressure. In the study, none of the actors could impose a singular sensing ontology onto WideNoise, suggesting that participatory sensing has the potential to simultaneously enact multiple ontologies. The element that maintained a connective thread between the ontologies was the physical app. The device study has shown that a crude app can be used to construct new political and ontological formations within a public controversy, and that there is no clear dividing line between hardware design and the ontological reconfiguration of a device.

Chapter 7

How do power and politics take place within participatory sensing?

This chapter examines the three empirical device studies and carries out a horizontal analysis in order to identify common patterns across the field of participatory sensing. The chapter engages with the insight gap (section 2.4) and addresses the research question of how power and politics take place within participatory sensing. The chapter is divided into two parts, the first identifies two modes of power that were at work in the devices. The second part examines the ontological politics that were generated and impacts this created for the actors in the studies. The subsequent chapter (chapter 8) takes these findings as the basis for creating a series of new ontological design prototypes for Heathrow airport. Thus the ethnographic analysis of the device studies becomes an approach of creating new prototypes by 'infrastructuring' a controversy and experimenting with participatory sensing.

7.1 Modes of power: blurring and stringing together

In this section I identify two interdependent modes of power, those of 'blurring' and 'stringing together'. Elaborating these mechanisms allows me to highlight the ontological politics of participatory sensing in the following section.

Blurring

The first observation across all the studies is that there was a significant ambiguity about what the devices were sensing. What was even more surprising was that 'what was being sensed and what was doing the sensing' - essentially the subject and object of sensing - were often shifting throughout the lifetime of the devices and even inverting as the users of the device became its subject. At times, the AQE was an object that sensed gases via heated metal filaments; at other times it ceased to be hardware and became a 'care' community or a global network that measured itself. The SCK was an environmental sensor board that became a node for 3D printing cities as well as an actuator for up-grading citizens. AirProbe switched from sensing air pollutants to becoming an actuator for improving peoples' awareness and behaviour. While WideNoise started off sensing data load, it became a scientific instrument as well as a campaign tool for demonstrating emotional annoyance and finally a policy tool for making the public more environmental. These observations of instability are very different from our daily experience of physical objects like tea cups that don't change from one day to the next. All the sensing devices had a stable physical level of enclosures, circuit boards and chargers that did not change much across their lifetime. In fact, at a physical level, all the devices were totally unremarkable and used very basic hardware sensors that were extremely limited in their sensitivity to detecting differences in environmental pollutants. The innovation, flexibility and variability of these devices was due to them being much more than physical objects but material-semiotic devices (Law & Ruppert 2013) whose borders were amorphous and hard to grasp. All the devices were enveloped and swathed in layers of firmware updates, calibration models, visualisations, funding applications, campaign videos, project websites and teams of organisers and researchers that configured the devices as well as the vast range of participants and community groups and extended networks of researcher that used them as exemplars. The devices seemed remarkably unconstrained by the limitations of their poor sensing properties, which did not stop them from being funded, attracting many participants and becoming good practice exemplars (section 4.5). What was being sensed and what was doing the sensing was not being defined at the level of physical material, but was enacted across various levels of organisational and rhetorical configuration.

The mechanisms that created these enactments were very different and sometimes merely required a public discussion on a website to enact a new ontology as in the case of the AQE and SCK. Yet other ontological enactments took an enormous amount of organisational labour as in the case of WideNoise in Heathrow or the building of a game environment in the case of AirProbe. Despite the fact that some of these processes were much more intensive than others, they all served to enact a new ontological reality for a device where it would sense a new phenomena and change what was doing the sensing. In this process, they would create new kinds of associations as well as prohibit other ones. This shifting and blurring was not accidental or due to contingencies but appeared to be deliberate. In the studies, this was mainly done by the developers or organisers of the devices, but also the residents as in the case of WideNoise in Heathrow. It is possible to see this in the way the AQE organiser obfuscated what the device could or would be able to sense and in the SCK's deliberate ambiguity about its ambient sensing hardware. The SCK went even further and renamed itself to remove any reference to the hardware in order to focus solely on its rhetoric of smart citizenship. The shift of AirProbe to sensing behaviour within the game was a considered action that ended up deliberately conflating air pollution and behaviour to sense only a materialised gap in knowledge. With WideNoise symbols of 'greenness' and futurism were deliberately blended together into a mix that would gather publicity and was further extended within the consortium where it was deliberately configured into an instrument, game and behavioural sensor.

My suggestion is that the deliberate blurring had two effects. First it shifted the locus of action towards the project organisers and gave them the power to reconfigure the devices to sense whatever they wanted, whenever they wanted. It allowed them to maintain control over the devices as they entered new organisational contexts, as can be seen in the way the consortium reconfigured WideNoise from a spime into scientific instrument without any problems. Mol suggests that in her study, conflicts between ontologies were made manageable because the various medical tests take place in separate buildings and do not physically meet (Mol 2002). In these device studies, blurring seems to have played a similar role of reducing conflict by obscuring contradictions and the shifting provided no stable ground for disagreement. In this way blurring and shifting functioned as strategic tools for the organisers to maintain control over the devices and make participatory sensing 'doable' with a range of different actors.

I suggest that the blurring also had a goal of shifting environmental sensing away from being constrained to sensing only physical entities. The language being used around all the devices whether commercial or academic framed the environment as something expansive and interconnected, which included mental phenomena, behaviours as well as technologies. This chimes with Andrew Barry's study of environmental sensing where he notes *"the objects of Souhwark's study were not just motor vehicles or the behaviour of remote-sensing devices but the consciousness of the drivers themselves"* (Barry 2001, p.161). My suggestion is that blurring of what is being sensed and what is doing the sensing should be seen as a way of enacting an ambient environment that tries to bridge the gap between the external world and internal sensation. By blurring what was being sensed, the devices were trying to detach themselves from sensing material things such as pollution gases or sound vibrations to become more flexible and be associated into new formations of environment that are affective and technologically networked. In this way, the blurring represents an alternative way of perceiving the environment that is not based on cognition but what Weiser termed 'peripheral attunement' (Weiser & Brown 1996), which he illustrated via an art piece called 'Dangling String':

> *"The motor is electrically connected to a nearby Ethernet cable, so that each bit of information that goes past causes a tiny twitch of the motor. A very busy network causes a madly whirling string with a characteristic noise; a quiet network causes only a small twitch every few seconds. Placed in an unused corner of a hallway, the long string is visible and audible from many offices without being obtrusive"* (Weiser & Brown 1996, p.75).

In the artwork, data is translated into peripheral awareness without any need for cognitive interpretation. My suggestion is that the participatory sensing devices were similarly trying to translate the environmental data into ambient flows that should be felt and experienced rather than analysed. This interpretation helps to explain the surprising conflation between data load and environmental pollution that took place within the AQE and SCK and the early version of WideNoise. My suggestion is it also features in the policy proposal of AirProbe and WideNoise that offer to change behaviour via ambient awareness rather than providing information about pollutant exposure. My argument is that this slippery and blurry form of affective sensing represents a radically new model of the environment facilitated by digital participatory sensing practices. It can be seen in the vision that started this thesis of a planet covered in an electronic skin (Gross 1999) and proposed connecting *"pollution detectors, cameras, microphones, glucose sensors, EKGs, [...] endangered species, the atmosphere, our ships, highways and fleets of trucks, our conversations, our bodies–even our dreams"* (para.2). This vision has the same quality of flattening the external and internal into an all-inclusive flow of data 'sensations'. Yet as these studies have demonstrated, these data flows are largely solipsistic and do not become agents of change.

Stringing together

The second observation is a ontologically constitutive power that I call **'stringing together[1]'**. The sensing devices were conduits that connected together a wildly diverse range of hardware and rhetorics such as futuristic and policy imaginaries of radicalism, smart citizenship, spimes, awareness and behaviour change. This was evidenced in the way the devices were described by the organisers as 'beacons' (AQE), 'nodes' (SCK), 'bridges' (WideNoise) and 'vehicles' (AirProbe) towards something other than being mere pollution sensors. This expansive framing of the devices is radically different to the way sensors are normally thought to operate as stable and unremarkable objects. In the standard approach, modern electronic sensors are accompanied by manufacturer's data sheets and specifications that define their relationship towards a sensed phenomena. Sensors come with structured semantic associations that dictate how their data is meant to be translated into a system of reference. This means that sensors are supposed to operate as a series of discrete steps from the physical towards the semantic, as argued in this quote:

> *"At each of the steps—between physics, application, and insight—engineers and journalists make decisions that affect what can be measured, derived and the analysis that can be made. So, the question of 'what can be sensed' has different answers depending on which step in the process you are discussing"* (Pitt 2014, p.41).

The idea is that each step is a stable unit that builds on the previous level and has its own compartmentalised answer to the question of 'what is being sensed'. Yet in these

[1]The term 'stringing together' is taken from the AQE FAQ page (Air Quality Egg 2012*c*), where it was used to describe the unique qualities of the AQE as combining many different kinds of elements.

device studies, 'what is being sensed' did not stay confined to discrete steps but cut across scales of 'physics, application, and insight'. This meant that the physical properties of sensor filaments were radically interwoven with claims of new kinds of citizenship and scientific authority as a material-semiotic stringing together of material (things) and semiotics (ideas). This finding resonates with the observation from Gabrys (2012), that *"sensors might also be understood not as detecting essential external phenomena, but as part of generative processes for making interpretive acts of sensation possible"* (para.8). In these device studies, the result was the creation of surprising new ontological entities, where an app became a *"social environmental noise spime"* (WideTag 2009, p.1), a metal filament became a 'beacon of care' and black carbon and subjectivity were brought together as 'AirPin Difference' (Sîrbu et al. 2015*a*). What is novel about these entities is that they combined existing ontological categories of the environment and the human into new kinds of hybrids. The result of creating these new entities was to scale up the devices and make them become bigger as more entities were enrolled and became associated with in-hype discourses. The effect was that it converted sensor objects that at a physical level were crude, into something that appeared to be innovative, disruptive and show the way towards the future. For all the devices this created media publicity and allowed the devices to gather awards, participants and backers that they would not have gathered by being mere pollution sensors. This form of publicity is very different from the way Bui (2016) characterises citizen science's relationship with the media as *"a dialog between news outlets and the public when it comes to scientific enquiry and investigation"* (p.86). In contrast participatory sensing is structurally dependent on public participation to fund the hardware in the case of Kickstarter, to operate the sensing devices and finally to act as an audience. Thus publicity becomes the core of participatory sensing and goes beyond mere knowledge dissemination or mere promotion to become a form of **'publicness'** that directs public attention and gather participating entities. Stringing together thus functions as a mode of inflating the sensing devices to achieve public presence and relevance.

Implications of these modes of power

The two modes of blurring and stringing together provide a picture of participatory sensing that is radically different from the contributory science narrative, where sensing is meant to gather empirical knowledge about the environment (subsection 2.3.1). A useful way to explore this in more detail is via a comparison with Latour's model of how the scientific approach to reference operates. In the notion of 'circulating reference' (Latour 1999), Latour describes a 'chain of reference' that translates raw phenomena into published scientific knowledge:

> *"We will be able to go from her written report to the names of the plants, from these names to the dried and classified specimens. And if there is ever a dispute, we will, with the help of her notebook, be able to go back from these specimens to the marked-out site from which she started"* (Latour 1999, p.34)

Latour is arguing that science is premised on the building of chains of reference that allow research to be verified by tracing backwards from a publication all the way back to the phenomena. Building such chains requires scientific instruments and representations as intermediary objects, since *"one never travels directly from objects to words, from the referent to the sign, but always through a risky intermediary pathway"* (p.40). The question is whether the devices of participatory sensing are like these intermediary objects. While on the surface they seem to facilitate the process of moving from phenomena to text, they differ in that participatory sensing involves no linear cohesion to the way material and concepts are strung together. In the scientific process, the coherence of the chain ensures traceability: *"if the chain is interrupted at any point, it ceases to transport truth"* (p.69). Yet in participatory sensing the linkage towards phenomena is always shifting and blurred. In fact the outputs of the devices focus on their continued potential for stringing together other entities, rather than making empirical truth claims (section 5.5). While Latour suggest the scientific process is one of **reduction**, that strips away materiality to become knowledge. Participatory sensing on the contrary involves an **inflation**, as more participants and entities are gathered. This means that the participatory sensing devices are not intermediary devices for producing scientific knowledge but for creating 'publicness'. In the device studies, the effect of this was that there were remarkably few differences between devices that were designated scientific research (AirProbe, WideNoise) and those that were commercial (AQE, SCK). They converged in their focus on publicity. There is also evidence from Barry (2001) and Pritchard & Gabrys (2016), which highlight the way sensors operate as publicity devices while their epistemic status becomes less certain:

> *"Beyond the hyperbole of global media marketing, social networking, and TED-talk-style promotional campaigns, citizen sensing is in many situations not yet fully established as a legitimate practice for making evidential claims"* (Pritchard & Gabrys 2016, p.368).

Based on my observations of the device studies, I argue that while participatory sensing invokes scientific practices as its main reference and the gathering of data as knowledge, it is largely not an epistemic practice of creating knowledge about the world. Instead, participatory sensing is fundamentally an ontological practice that tries to enact new environmental realities by blurring and stringing together hardware, people and concepts.

7.2 Sites of conflict and possibility: pollution, decision-making, collectivity and issues

This section focuses on the impacts of the blurring and stringing together of participatory sensing. It uses the questions from Mol's notion of ontological politics, *"Where are the options? What is at stake? Are there really options? How should we choose?"* (Mol 1999, p.79), as a focus for identifying what is at stake in participatory sensing and how it might be done differently. Specifically it identifies four sites where participatory sensing generated conflict as well as potential for interfering in environmental decision-making.

The bottom left side of Figure 7.1 shows an idealised model of environmental monitoring as imagined within contributory science (subsection 2.3.1). It is based on the notion that there are clearly defined environmental pollutants (such as black carbon), and a calibrated reference device (μ-Aethalometer) that creates standardised data (PM2.5) which feeds into institutional decision-making. This linear chain of reference involves physical sensors, standards and organisations. The rest of the diagram shows the disruption caused by participatory sensing to this model by introducing low quality, uncalibrated devices that bring with them new actors such as participants and engaged collectives. The top half of the diagram shows a list of the main actors from the device studies and their compartmentalised interests in participatory sensing. The diagram's red and blue lines highlights four sites of conflict and possibility created by participatory sensing that I will discuss in turn.

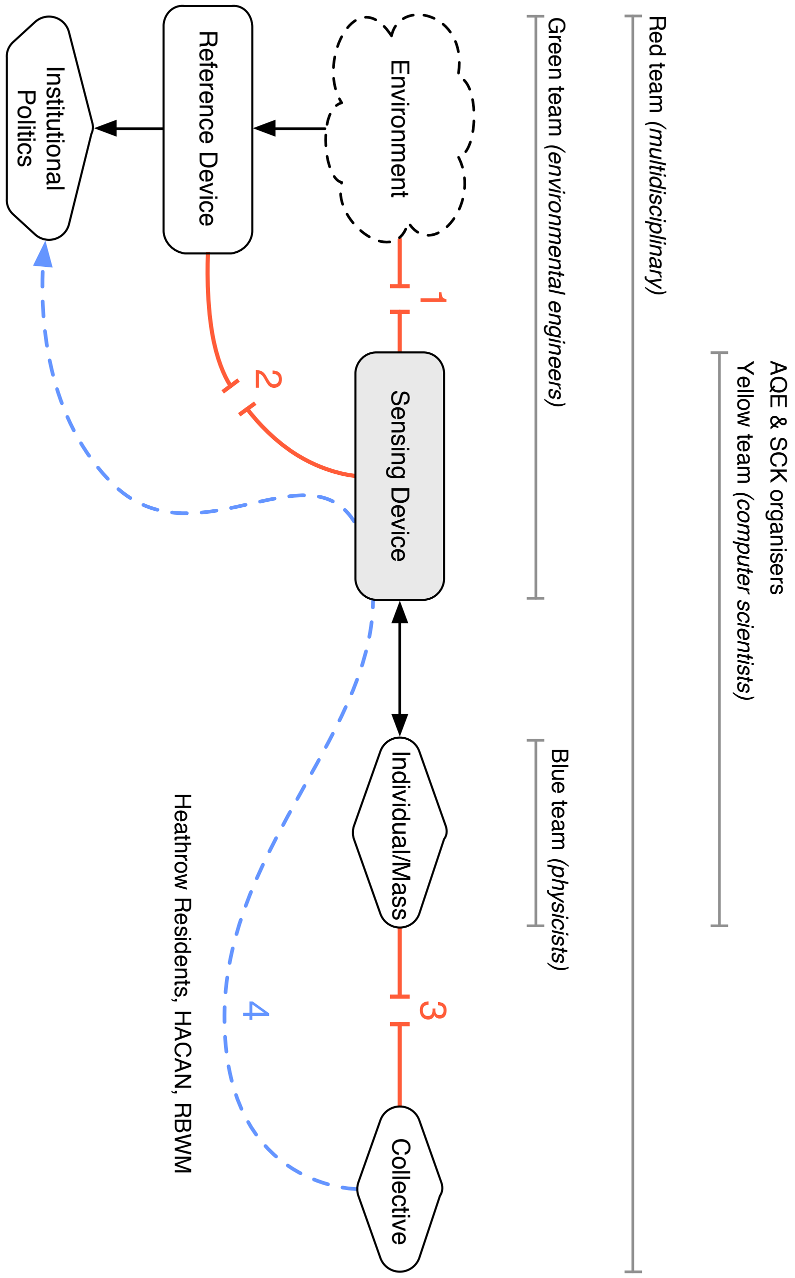

Figure 7.1: Summary diagram of the three device studies. The top half of the diagram shows the compartmentalised foci of the main actors. The bottom half shows the relationship between entities in participatory sensing. The red lines highlight the contested relationships between entities, while the blue line represents a new association created by the Heathrow actors.

1. Disappearing materiality of the environment

The ambiguity about what the devices sensed became a site of struggle about whether the devices could engage with environmental pollution as a material entity and issue of concern. While stringing together functioned as a creative way to generate new ontological entities such as spimes, AirPin Difference or smart citizenship, these ambient framings threatened to make the environment disappear as a material entity that could be contested. One of my key observations was that the ambient understanding of the environment did not create a meaningful hybrid coming together between the human and environment but merely a rhetorical blurring that maintained a fundamental Cartesian division between what the environment 'is' as defined by objective measurement and subjective 'feelings' about the environment on the other. In this way all the devices enacted a dualism that the philosopher Whitehead called the 'bifurcation of nature' (Whitehead 1920), which creates a hierarchy where the objective sensing of science is always the primary means of knowing the world. Within the device studies, the bifurcation of nature meant that these two realities could not be sensed together. The problem seems to have been that translating a pollutant into a health concern requires a conjoined understanding of the environment as a relationship that is materially measured **and** perceptually felt.

What the bifurcation into objective and subjective did was create cynical and clichéd enactments of the environment that did not allow hybrid forms such as health concerns to exist. Thus placing an isolated focus on the participants had the surprising effect of making pollution as a health concern disappear. This can be seen within the AQE which created a clear division between what air quality 'is', yet which it couldn't measure, and on the other hand merely 'caring' about it. This resulted in the AQE being enacted as a solipsistic network of high-frequency data throughputs or as narcissistic beacons of care. Crucially these two realities were kept apart and there was no hybrid cross-fertilisation that could create an engaged instrumented practice that would use the low quality sensors in a meaningful way to engage with health concerns. Similarly, the SCK's hyperbolic rhetoric of smart citizenship was so wildly unrelated to the material possibilities of the device that it only resulted in confusion for the participants and did not create any meaningful practices. With AirProbe and WideNoise, the consortium explicitly implemented a bifurcation of nature into objective and subjective that led to the insertion of the sliders into AirProbe and WideNoise that translated 'subjectivity' into a data category that could be operationalised to analyse human behavioural patterns. Yet the Green team, who were responsible for the ‘objective’ part of AirProbe, were not allowed to decide when the device was ready to use or how it should be deployed. The result was that AirProbe turned into a competitive game that was largely meaningless and actually provided the participants with false insights about environmental pollution. While the Red team had hoped that the use of subjective data would provide a voice for participants, in an interview a researcher mentioned being disappointed that the subjective features had actually constrained the potential of the participants. Furthermore, the division between subjective and objective was used to delegitimise practices that were deemed to be ‘not objective enough’, as was seen in the consortium’s hostility towards the engaged actors of Heathrow. The notion of scientific objectivity was used to minimise participant involvement in the design of AirProbe and to try and enforce an unrealistic data collection protocol with WideNoise. This rigour was absent when the researchers refused to calibrate the WideNoise app, yet still used the data generated by the residents as an objective baseline against which to compare people’s behaviour.

The point being that across all the studies the bifurcation into objective and subjective was not consistent or coherent, but created an exclusionary approach that delegitimised particular ways of sensing and made the environment disappear as a contestable and material entity. Most of the studies referenced the data quality and motivation literature (section 2.3) to use participatory sensing as ordering devices to police the demarcation line between objective and subjective realities were humans need to be kept in check by machines.

2. Disconnection from reference devices

The studies have shown that none of the sensing devices were successfully calibrated in relation to reference devices or official metrics[2]. Why was this the case? The actors in the device studies tell us very frankly. The AQE organisers suggested *“sensor calibration and precision is the wrong conversation”* (Air Quality Egg 2012*g*) and instead place

[2]The evolution of reference standards for environmental pollution is itself a socio-technical process that is analysed by STS historians (Karin 2008).

the focus on accessibility and autonomy, while the SCK organiser highlighted the devices' *'extra features'*. The AirProbe academic paper argues, *"the performance [of the sensors] was enough for the purposes of our project, i.e. participatory mapping of pollution with multiple devices, for enhancing environmental awareness"* (Sîrbu et al. 2015*b*, p.6). The WideNoise paper states that *"calibration was not deemed necessary [because] the measurements performed by the citizens involved are not required to be extremely accurate"* (Becker et al. 2013*b*, p.5). Across the studies, creating a link towards environmental reference standards was not a priority. Instead, the main theme was one of autonomy. The AQE and SCK organisers wanted to disconnect from existing institutions and aim at a global network of ambient connectivity. Thus they provided users with raw electrical resistance values rather than anything comparable to existing data sets. In the consortium, the Blue and Yellow teams were enacting the devices as isolated social laboratories. While these notions of autonomy were different, they coincided in wanting to disconnect from existing environmental standards. This created a conflict with other actors around the devices such as the Green and Red teams as well as the AQE and SCK users that wanted to associate the device data to reference devices in order to connect to existing institutional decision-making processes. The result was an asymmetry in the studies between actors that were often the technical developers or project organisers, who were able to string together rhetoric and define the boundaries of the device, while other actors such as project participants were not able to change the shape of the assemblage (section 4.4). Andrew Barry suggests that institutional air quality monitoring *"depends on whether a series of connections can be maintained between air and the institutions which measure it and financed this measurement"* (Barry 2001, p.172). What is at stake in deliberately cutting off the connection towards external reference devices is a wider disconnection of relations that limits the use of the devices for engaging with decision-making processes and transforming the world.

3. Hostility towards engaged collectives

Across the studies the issue of 'who' should be participating functioned as a site of conflict. Throughout all the studies the 'participant' was an essential but problematic entity that was simultaneously 'under' as well as 'over'-specified. The way participants might use the devices was largely not considered within their design and there was a basic lack of purpose to the devices. To my knowledge, there were no formal usage scenarios and the manuals focused only on the technical properties of the hardware. This meant the participants, their goals and purpose for using the devices were totally underspecified. Yet at the same time the participants were critical for funding the projects and operating the devices; without participants the projects would not exist. This meant that the project organisers over-specified the role of the participant (Figure 7.1). The AQE and SCK evoked the notion of an online community, yet focused on the individual user and an hardware device in the same way as the Yellow team, while the Blue team were focused on the behaviour dynamics of massed individuals. What they had in common was seeing the participants as solitary 'users, gamers or citizens' without any issues or political agendas and the reason why someone might participate was either for financial reward or an individualised notion of personal exposure. The result was that across all the projects, the participants were framed as agenda-less masses of individuals. This approach seemed to derive directly from disciplinary framings from computer science, HCI and maker culture and literature around crowdsourcing and smart cities (section 2.3). This bias towards individualised sensing is also highlighted in the Pritchard & Gabrys (2016) study of participatory sensing.

Yet the combination of over-and underspecification created conflicts within the consortium and with engaged participant groups. With WideNoise, the notion of the agenda-less individual led to conflicts about who could be a legitimate participant. The consortium showed distrust towards actors that wanted to actually use the data and hindered the collaboration with the local council and local collectives. While the Green and Red teams were both focused on the environmental monitoring, the Red team's focus extended towards collectives. This meant the Red team could work with HACAN and local government while the rest of the consortium tried to limit this collaboration. In the case of AirProbe, the logic of the agenda-less individual was physically embedded within the design of the competitive game, which had the result of alienating the community groups that had originally been interested in using the device. With the AQE and SCK, the organised groups that tried to use the devices were actively harmed by the fact that the devices had not been designed with engaged collectives in mind due to their limitations being obfuscated and there being no support for developing meaningful sensing processes.

In this way, this study that demonstrates what is at stake in the unstable role of the participant as empowered citizen and data drone (section 2.3). While these contradictions can be fudged over within the literature, by analysing their material practices, these studies have demonstrated the exclusionary effects and conflicts of these framings.

4. Backdoor towards the environment and institutional politics

The WideNoise deployment in Heathrow was unique amongst the device studies in the way it targeted a specific environmental problem. The dashed blue line in the diagram indicates the way the Heathrow actors managed to use WideNoise to enact new ontological connections towards the environment as well as institutional politics. For the Heathrow residents, WideNoise was sensing physical, experiential and political pressure simultaneously. HACAN enacted WideNoise as a protest against the third runway, while RBWM enacted WideNoise as an alternative metric for annoyance. These enactments involved noise realities that did not rely on a relationship with a calibrated reference sensor and yet still managed to create extensive media publicity and become part of formal decision-making processes. How was this possible? I suggest this was because Heathrow was an issue of concern where measurements of the environment and subjective human perception could be brought together in a productive way. The resident's enactment of the data as physical vibration **and** political pressure represents a refusal to bifurcate between objective noise in the world and human sensation. HACAN's use of each data point as a street protest is a refusal to accept the decibel metric as the primary way of representing the reality of noise. Similarly RBWM used WideNoise to argue against LAeq as the best metric for the experience of residents. At the same time RBWM deployed the supposed technical accuracy of a smartphone to legitimate resident complaints, without actually believing in WideNoise's ability to objectively define reality. These enactments all involved sophisticated, strategic and critical uses of the app. My suggestion is that these enactments are ontological 'hacks' that variously reconfigured the nature (objective) and culture (subjective) divide around noise to increase impacts on decision-making around the Heathrow noise issue. Rather than being at the mercy of a device that is too crude to measure 'matters of fact' (Latour 2004*c*), the Heathrow actors managed to appropriate the app to string together new inventive enactments as 'matters of concern'. By directly challenging the supposed neutrality of objective measurements and providing an alternative metric, these concern-based enactments managed to bypass reference devices as gatekeepers to decision-making. The actors validated their representations of noise by providing proof of the strength of their concern as evidenced by the number of participants, the intensity of complaints, the media coverage of the campaign and the association with the ANASE study. This strung together legitimacy was strong enough for the RBWM council to use the data as their official response to the airports commission. The success of WideNoise within the Heathrow setting suggests that within contentious issues, participatory sensing can be used to enact forms of evidence that do not need to be bifurcated.

In the other device studies, there was no success in connecting to environmental decision-making. The difference was the absence of any environmental issues of concern and the lack of a facilitating organisation like the Red team that would encase the sensing device within the issue. With AirProbe, the potential for an engaged deployment was prohibited by the implementation of the game. The AQE and SCK organisers (to my knowledge) never facilitated any situated deployments that actively targeted environmental controversies and the Louisville community group never tried to deploy the devices as anything other than 'objective' sensors. While the AQE rhetorically claimed to politicise the way institutions with expensive equipment exclude other practices of the environment, the project never managed to move beyond replicating the hierarchy between objective and subjective sensing.

The key difference between the Heathrow deployment and the other device studies is that the controversy was made part of the project. The difference between these approaches shows that there are options and choices to be made in the way participatory sensing is designed and staged. It can be used as a rhetorical vehicle for an ambient environment or it can enact the environment as a contested site and develop situated ontologies that allow creative sensing practices.

7.3 Reflections on the device studies

This analysis chapter has identified that the politics of participatory sensing reside in the way 'what is being sensed and what is doing the sensing' are resolved. It answered Mol's question of what is take in participatory sensing and where are the options for doing it differently. Overall this analysis identified four points:

- The studies demonstrate that instead of measuring clearly defined external environmental pollutants as imagined in the literature, the devices deliberately blur, shift and invert the object and subject of sensing;

- The power of these participatory sensing devices resides not in gathering epistemic knowledge but the stringing together of hardware and rhetoric into 'publicness' to create new ontological entities;

- Participatory sensing is the site of ontological conflicts about whether to sense environmental pollution as a health impact, engage with decision-making or organise collectively. The tension is based around a bifurcation of nature that establishes an exclusionary hierarchy between different ways of sensing;

- The WideNoise deployment in Heathrow has shown that it is possible to ontologically reconfigure sensing devices as matters of concern to support situated realities within public controversies and build meaningful new connections to decision-making processes.

Chapter 8

What can ontological design offer participatory sensing?

This chapter builds on the previous chapter's analysis that identified that in certain circumstances, participatory sensing can open up new ways of sensing and taking part.

The successful reconfiguration of WideNoise in Heathrow demonstrated an approach that did not divide between objective/subjective and created a backdoor to institutional politics (section 6.5). It suggested an alternative direction for participatory sensing that can focus on specific issue controversies. Rather than having to accept inadequate sensor hardware it is perhaps possible to design new devices that take an ontologically inclusive design approach towards targeting controversies. The three device studies have identified the sites of conflicts for participatory sensing as well as the potential for interference and intervention, using an issue-centred approach. This chapter explores the potential of such a approach by addressing the research question 'what can ontological design offer participatory sensing?' by revisiting the Heathrow context using an experimental prototyping approach. Marres has suggested that *"a device-centred perspective on participation brings into relief the political variability of enactments of engagement with the aid of everyday technologies"* (Marres 2012, p.79). Yet there are few examples, so the aim of this chapter is to show the potential of combining a post-ANT ethnographic approach with design to turn theoretical controversies into questions of design.

The first part of the chapter, **engaging with the sensing site as a controversy**, carries out historical analysis of the Heathrow controversy to re-articulate the noise issue as having an underlying socio-technical infrastructure. This opens up Heathrow as a site for intervention using ontological design. The second part of the chapter, **ontological design for a controversy**, describes a mini device study of designing, using and iterating prototypes using an ontological design approach.

Versions of this chapter have been published as a peer reviewed paper[1] (Nold 2015) and as three different peer reviewed book chapters[2] (Nold 2016*a*,*b*, 2017).

8.1 Engaging with the sensing site as a controversy

This section carries out an in-depth historical analysis of the issue of noise at Heathrow to identify how it can stimulate the design of new sensing prototypes that can engage with the complexities of this controversy.

During the WideNoise device study the residents, researchers, airport authorities and local councils had requested static noise monitors that could be widely deployed across the area to track changes in flight patterns and produce data that could be comparable with the official dataset. This request had not been considered to be part of the EU project's goals so was not followed up. However, it gave me a concrete starting point for my own research as well as raising a number of questions: who should I be designing for? What exactly should the device do, and what position should it take in relation to Heathrow?

In order to find a way of engaging with the Heathrow controversy using a new sensing device required a new way of understanding it as a site for design. Heathrow airport is normally seen as a political controversy especially in relation to the planned third runway. While the Airports Commission has recommended the expansion of Heathrow in 2015, the government has repeatedly postponed their final decision, since it is seen as

[1] Nold, C. (2015) Micro/macro prototyping.

[2] Nold, C. (2016) How designers can reshape public controversies. Nold, C. (2016) Metrics of Unrest: Building Social and Technical Networks for Heathrow Noise. Nold, C. (2017) Turning controversies into questions of design: Prototyping alternative metrics for Heathrow airport.

a 'toxic dilemma' (Kuenssberg 2015) that is likely to alienate large parts of the national electorate. If one starts to look at Heathrow using a 'political' lens, one sees politicians, industries and residents caught in a political battle around tradeoffs about whether economic benefits should outweigh the residents' annoyance. If one looks at the Heathrow controversy through a 'material' lens one sees only aircraft and noise measurement devices. Yet by applying the concept of relational infrastructure (Star & Ruhleder 1996), one sees new connections across the material and political registers, such as techniques and metrics that mediate between the aircraft, local residents and the legislative authorities by measuring and governing the impact of the airport. I had learnt some of these aspects via the WideNoise device study but felt in order to create a custom participatory sensing device for Heathrow, I had to understand the historical relational infrastructure of the controversy.

Aircraft noise emerged as an issue at Heathrow with the introduction of turbo-jet aircraft in 1958, which quickly led to the 1961 study into the impact of aircraft sound on humans. This was the first of three significant UK-based studies where standardised interviews of residents were carried out in relation to measurements of acoustic energy. Residents were asked how much the noise bothered them: 'very much, moderately, a little, not at all'. The study found that, while there was little correlation between acoustic energy measurements and stated annoyance at an individual level, once aggregated, a weak dose-response relationship emerged. The study resulted in the creation of the Noise and Number Index (NNI) metric, which had three threshold points that were said to denote high, moderate and low community annoyance (Civil Aviation Authority 1981). Using modelled sound dispersion, these threshold levels could then be plotted as spatial contour bands radiating out from the runways to define people living there as experiencing a set level of annoyance. In this way, a new policy instrument based on a metric and contours was created to allow for *"estimating the disturbance resulting from a change in the scale or pattern of airport operations, or from a new airport"* (Brooker et al. 1985, p.1). This diagram describes the infrastructure of the metric and the way it functions:

Survey + measurements = annoyance contours > define people affected > governance

For the last 50 years, this metric and its successor, LAeq, have been used as a calculative infrastructure to define how many people are said to be affected by the noise of the airport. People living within a contour band are said to be affected for the purposes of compensation and subsidised sound insulation, while those outside of it are not. The 2015 Airports Commission report (Airports Commission 2015) used the number of affected people as the key indicator of local impact when comparing the different airport options and for making their key recommendation for the building of the third runway at Heathrow.

One way to understand the construction and function of community annoyance is through the metaphor of the Leviathan as analysed by Callon & Latour (1981). The authors use this metaphor to describe the way collective power comes to be consolidated within a single entity. The Leviathan represents the power of a king and is visually represented as a crowned giant that is physically assembled from the bodies of all his subjects. Callon and Latour argue that this visual image can be interpreted as an allegory for the constitutive power of macro-actors. In their words: *"the construction of this artificial body is calculated in such a way that the absolute sovereign is nothing other than the sum of the multitude's wishes"* (Callon & Latour 1981, p.278). I argue that community annoyance can be conceived of as a Leviathan figure that has been constructed to act as 'spokesman, mask-bearer and amplifier' for the collective of humans living under the flight path. Yet the local residents are highly frustrated with the way community annoyance is made to speak on their behalf. Here is one resident's response to the airports commission:

> *"Heathrow are also exploiting the 57dB noise threshold to make it look like there is a reduction in noise with an expanded airport. The reality of course is that noise continues to be hugely disturbing to many people considerably below that threshold, me included. Where I currently live whilst better than Kew (hence I moved here) and just outside the 57dB contour is still disturbing enough to wake my children regularly"* (Airports Commission 2013*b*).

I suggest that the annoyance metric acts as the socio-technical infrastructure of the Heathrow controversy that connects aircraft, residents and politicians and dictates decision-making. Yet this connection is asymmetrical, since this calculative spokesperson is used to dismiss individual residents' claims of affectedness and exclude them from having to be personally consulted. While the metric is largely invisible within the media coverage of the issue, the 57dB(a) threshold appears as a stable and self-contained actor within the narratives of the opponents to Heathrow expansion. Yet there was only one brief period when the metric became a visible actor as a result of a controversy around a noise impact

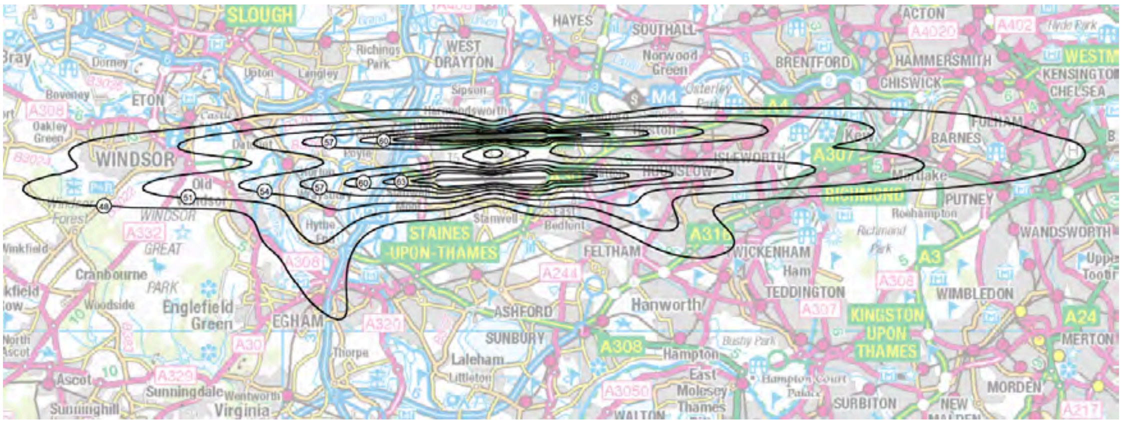

Figure 8.1: Official Heathrow Airport 2014 LAeq Contours (Department for Transport 2014)

study. In 2007, the ANASE study (Le Masurier et al. 2007) identified a new threshold of around 50dB(a) as the 'onset of significant community annoyance', which was much lower than the one identified in the 1982 study (Brooker et al. 1985). The ANASE study found that people were affected at much lower noise levels, which would extend the annoyance contour much further and envelop a much larger number of people. This was seized on by the media and opponents of the airport who argued that the *"true number affected by Heathrow operations is around 1m[illion] – four times the figure implied by the 57dB contour"* (Airportwatch 2013). The outcry increased when the ANASE study was officially dismissed for methodological discrepancies. Despite the fact that many high profile politicians, local councils and pressure groups argued strongly against this dismissal and pointed to the problems of the 57dB contour, the official legislative standard remained at the level of the older 1982 study.

How is it possible that despite the political pressure and loss of public confidence, the metric has remained in place? The technical acoustics literature, where these metrics originate, is actually ambivalence about them, arguing that all the different noise metrics are *"more a matter of convenience than any reflection on the strength of any assumed underlying dose-effect relationships"* (Flindell 2003). This quote suggests that these metrics are not empirical facts of the world, but political tools that enable convenient management of the controversy. Large amounts of data have been accumulated using a single metric, making comparisons between different operational proposals simple and convenient. I suggest that the airport opponents' lack of success in challenging the metric may be due to the fact that they have been trying to politicise the level of the threshold, rather than challenging the composition and function of community annoyance. The metric is simply too convenient for the authorities to abandon and too technically complex to turn into a sustained political controversy. In the media framing of the issue, the metric is largely invisible with the focus being placed squarely on political choices that are presented as ideological or pragmatic trade-offs between economic benefits and alienating certain voters. While the controversy around the ANASE study allowed the 57dB(a) annoyance contour to briefly emerge as a public topic, it does not feature in the current media discussions.

Yet there are some interesting aspects to the dismissal of the ANASE study that point to an alternative method for intervening in the controversy. The official reason given for the rejection of the study cited specific procedures conducted during the interviews. The reviewers of the study discussed a number of methodological issues but focused on the interview process that took place in people's homes and included portable audio speakers. They argued that, *"the act of setting up and calibrating equipment would almost certainly have enabled respondents to deduce that the study was about attitudes to noise. Furthermore, the fact that the social survey sites selected were located away from other sources of noise may have enabled some respondents to conclude that the study pertained to aircraft noise"* (Civil Aviation Authority & Bureau Vertias 2007, p.16). The reviewers thus concluded that, *"there is a risk that the social survey results may have been contaminated by respondent bias. That is, respondents may have used the opportunity to voice their opinion on the Government's aviation policy and may have either deliberately or sub-consciously exaggerated their reaction to aircraft noise in the way they answered the question"* (ibid.). To summarise, the reviewers' argument is that the physical presence of the speakers made the residents think about aircraft noise as political and they thus exaggerated their annoyance.

In response, the ANASE authors published a report rebutting these points. They suggest the loudspeakers *"were not in fact used until after the key annoyance questions had been dealt with"* (Ian Flindell & Associates & MVA Consultancy 2013, p.12). Yet more broadly, they argue that the issue of the speakers, is part of a broader disagreement with the reviewers about the reality of annoyance and how it should be staged. They argue that the *"review group's comments suggest a fundamental misunderstanding of the nature of noise annoyance, that it is somehow some kind of underlying and fixed physiological or neurological response to noise which is always the same regardless of any changes* *in attitudes and opinions in the people concerned"* (ibid.). The authors suggest that it is impossible to isolate annoyance from the politics of aviation policy and that it would be *"impossible to ever find a 'good' time to be able to carry out a supposedly unbiased aircraft noise questionnaire survey"* (Ian Flindell & Associates & MVA Consultancy 2013, p.11). What is at stake is an ontological disagreement about different ways of staging community annoyance, as neurological and disembodied on the one hand, or as pragmatically embodied with sound equipment and situated within political arguments on the other. The controversy around the ANASE study reminds us that there are many practical choices to be taken in curating situations in which people can provide evidence of their experience. The context in which residents are asked questions, the physical props that are present during the interview as well as the manner in which the questions are asked. If we go along with the idea that the respondents were strongly affected by the mere presence of the speakers, then this suggests the articulation of annoyance may be approached as a creative occasion for public experimentation, one in which a multiplicity of different elements might be introduced to generate new articulations of annoyance. The end effect would be that rather than having a single way of defining and measuring annoyance, there would be multiple competing compositions.

This episode illuminates that there is not one but several controversies around noise at Heathrow: a media controversy focused on economic trade-offs, a failed political controversy about the number of people affected by noise, as well as an ontological controversy of how to articulate annoyance as a matter of concern. Targeting the ontological controversy opens up a question of how a more suitable annoyance metric could be created, what elements it should consist of and how such a design process could be publicly legitimated. Interestingly, a number of acousticians who worked with social survey methods for decades are now proposing a shift towards spontaneous self-reporting of complaints by residents as a way of bringing back transparency and legitimacy into noise governance. Fidell argues that noise complaints had been abandoned in the 1970s because they *"were difficult to process and systematically compare, largely inaccessible to researchers, and generally awkward to interpret"* (Fidell 2003, p.3012). He argues that the growth in distributed, networked computing devices is making it possible for geographically tagged noise complaints to function as a new metric. Adopting such a system would shift annoyance from a given neurological concept-measure into an active process of resident participation. The key aspect of this shift in register is that it turns annoyance into a questions of design, which invariably opens up a multitude of practical questions of how to stage annoyance.

This analysis of the Heathrow noise problem had revealed it as a site where participatory sensing devices could directly intervene within the ontological politics of the issue. Instead of seeing it merely as a site for deployment to gather lots of data as had been the case within EveryAware, these insights identified a way fundamentally transforming the way the issue functioned. This analysis also identified whom to design for. Instead of setting out to create a sensing device for a particular group of residents or an institution handling the issue, my aim was to design participatory sensing for the infrastructure of the controversy itself. Rather than being accountable to a human client, my role was one of trying to be responsive to the issue of noise at Heathrow. The research had provided me with a design target in the form of the annoyance metric, as well as an approach of infrastructuring using 'micro/macro prototyping' (Nold 2015). My goal was to build an alternative Leviathan - one that differed in crucial respects from how the annoyance metric composed the public. My alternative 'body politic' would be composed of new entities and should ideally be able to compete with the existing metric in a kind of robot battle over who gets to wield the authority of collective experience.

Suddenly I understood the reason RBWM had enacted WideNoise as an alternative annoyance metric (section 6.8). Despite the shortcomings of the app, it had allowed RBWM to challenge the ontology of the existing annoyance metrics and suggest an alternative. My aim was thus to build on the way WideNoise had been enacted within Heathrow and extended on this process with new prototypes.

8.2 Ontological design for a controversy

This mini device study describes the process of creating and testing a new participatory sensing device consisting of custom hardware and software to test with interested parties. The prototypes were designed as material-semiotic devices that setup new propositions about the relationship between aircraft, residents and governance. Each prototype was a device in the sense of Law and Ruppert's notion of a 'patterned teleological arrangement' (Law & Ruppert 2013, p.230), but they were also infrastructural compositions (Star & Ruhleder 1996) that propose structurally different ways in which noise governance might be handled by inserting or removing symbolic or computational elements.

I gave each of the prototypes names to identify the specific ontological proposition they present and reinforce the notion that each of the prototypes is a unique actor with its own distinct voice. This design approach was based on the kinds of projective design methods I outlined in the design review (subsubsection 2.2.1.2). The aim of the prototypes was not to seek approval for the designs but to allow the participants to experience and articulate new infrastructural compositions and to build alternative networks of human and nonhuman actors that might challenge the existing annoyance metric. I took the four initial prototypes to potential partners who might want to join the process such as the airport administration, local councils and residents. During the meetings and workshops, the prototypes were used as props and demonstration devices. The following vignettes describe one of these workshops at a community centre located under the Heathrow flight path, with nine residents who did not know each other beforehand. This is followed by a description of the results of a year-long deployment of three prototypes with residents.

Prototype 1: I speak your feelings

The first prototype (Figure 8.2) samples the voltage sensed by a microphone and translates this into a phrase displayed on a LCD screen. Instead of decibel numbers, the screen displays sound level using a scale of emotive words: *"quiet, audible, loud, very loud, extremely loud and painful"*. The words on the screen change continuously in response to sudden sounds. The prototype uses the dose-response logic implied by the community annoyance metric and turns it into a tangible object that can be placed on a coffee table. The machine experiences sound pressure on behalf of humans, which is transformed into an emotive language without people being involved. The prototype is designed to performatively highlight the simplistic relationship between measured acoustic pressure and annoyance level that the current official metric relies on. The following diagram represents the composition and function of the prototype:

Figure 8.2: Photo of the ‘I speak your feelings’ prototype

Sound sensor > translation into annoyance words > LCD display

When the device was presented to the workshop group, it acted as a catalyst for the participants to talk about the way noise affected them in their daily lives such as, *“I don’t want to cut myself off, which is really what noise is about, it is cutting you off”*. They identified elements that the current LAeq metric does not capture, such as the interval between flights and the harmonics of noise with someone arguing that *“it’s not just decibels, there is something else in there as well”*. The participants suggested the need for *“a more complex device which will analyse the sound and tell you about the interesting element of the sound harmonics and different pitches”*. In addition, some proposed alternative ways of providing evidence of their experience, such as measuring their physiological responses to noise. Yet two of the participants seemed frustrated: *“I think it would be completely chaotic if you just had people’s feelings about it. What would you do with that data? You have got to have an objective reference”*. Their argument was that *“for the purposes of any kind of campaign it’s got to be objective. So it’s amounts of particles per million, it’s got to be measurable rather than [respondent pauses] smelling”*. At this point, another participant interjected that social policy uses anecdotal stories as evidence in conjunction with statistical data.

During the workshop, the reductive emotive words the prototype was displaying seemed to spur the participants into describing the limitations of the current noise metrics when it comes to their ability to encompass their experience of noise. This triggered a process of reflection on different ways of evidencing the impacts of noise. While it was widely agreed that evidence was needed, there was disagreement as to which method or technology would provide the greatest political legitimacy for campaigning. Yet the participant who was most vocal about the need for an objective reference asked, *"is it really worth debating this? I mean people have different opinions, why don't people contribute what they contribute from their perspectives"* and followed this with an enthusiastic exclamation of *"take it all"*. The main observation I took from this prototype interaction was the pragmatic suggestion to combine different evidential methods in order to build a cohesive collective around the issue.

Prototype 2: I display noise publicly

Figure 8.3: Image mockup of the 'I display noise publicly' prototype

The second prototype (Figure 8.3) consists of a mock-up of a large noise meter display mounted on the exterior walls of a building. The device illuminates when a specified noise level has been exceeded. The prototype investigates where the issue of noise should be located and whom it should address. It was based on the observation that the geographical area around Heathrow looks like many other suburban areas in Britain without the built environment providing any visual reference to the noise overhead. Many of the residents I had been in contact with talked about aircraft noise in the context of their private home and described its effects in a solitary and personal way. As a provocation, this prototype locates the issue of noise outdoors within public space. In the workshop, I introduced the prototype as something that could be mounted on the participants' houses as a way to engage their neighbours, and described a scenario in which a plane coming in to land at night would see the ground light up as it flew overhead. The composition and logic of the device is as follows:

Sound sensor > **outdoor warning display** > **addressing a nearby public**

During the workshop it quickly emerged that the participants were excited by the device, yet no-one wanted to fix it onto their own home. Instead, they suggested that it should become a 'norm' to have it installed on public buildings such as offices and schools. One of the participants suggested that mounting it on one's own house could have negative consequences:

> *"I don't want to be a downer on this, but we do have to bear in mind that people think that campaigning and emphasising the noise problem is giving them a problem. Because it affects the value of their house and they might want to sell their house and they don't want to be labelled as a problem area. And we have found that schools have quite remarkably low levels of interest because they get money out of the airport for various activities and they don't want to be seen as the wrong school to send your child to. [Others nodded and voiced agreement]"*.

This interaction clearly identified an aspect of the prototype that I had not considered. Placing the device on one's own home would characterise the immediate area as affected by noise and would make oneself personally identifiable as a campaigner, which would have direct negative effects for that person. The prototype identified a tendency to 'make private' the issue of noise pollution, namely to locate noise within individual people's homes and to not define it as a collective problem. This atomisation of the issue is re-inforced by the remedial measures that the airport offers, which focus on noise insulation for individual homes rather than public spaces. This effect can also be seen in the telephone hotline infrastructure the airport has set up to allow individuals to make complaints. What is absent are public platforms that allow local residents to engage with the noise controversy collectively. Taking into account the participants' responses highlighting the dangers of public campaigning, this prototype interaction suggested to me a need for a sound-monitoring network that could discreetly connect individual's homes and institutions.

Prototype 3: I make someone responsible

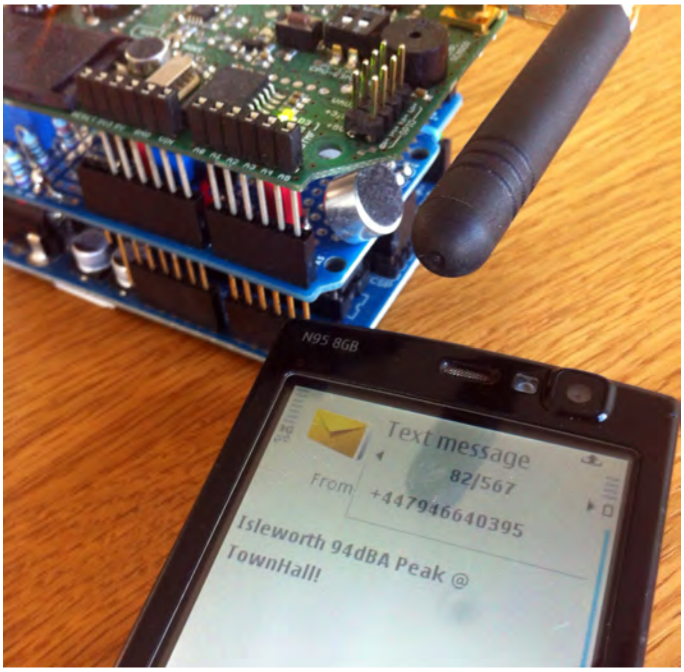

Figure 8.4: Photo of the 'I make someone responsible' prototype

The third prototype (Figure 8.4) is programmed to send an SMS text showing the measured decibel level to a mobile phone whenever a peak decibel level of 90dB is exceeded. The prototype is based on conversations with residents in which I felt there was a lack of clarity as to who or what was responsible for noise pollution. Whole ranges of entities were identified from local and national politics, government agencies, the airport, individual airlines as well as capitalism itself. The provocation of the prototype is to choose a single entity that might be held directly responsible. The logic of the device is as follows:

Sound sensor > **SMS alert** > **targeting individual entity**

When I introduced the prototype, I showed the workshop participants the source code of the micro-controller and mentioned that the mobile number could be changed to anybody's phone number. Suddenly a dramatic change of atmosphere occurred, with all the participants laughing loudly, as they understood the implication of inserting somebody else's number into the source-code. The participants excitedly discussed a range of potential entities that could have their number inserted, from airport complaint lines, institutional bodies, politicians in favour of airport expansion, as well as the prime minister. Whilst a range of entities was discussed, there was no consensus about who should be held accountable. During the workshop, whenever voices were raised or a plane flew overhead, the prototype would send an SMS message that would be received with loud bleeps and the group would respond with laughter. It was interesting to observe the way the prototype held the participants' visual attention and tightly focused the discussion on technical interventions. Some participants were highly engaged by the confrontational approach of the prototype and extended its logic by talking about an event when loudspeakers had been setup outside a politician's house to wake them up with the noise of the early morning flights. Others in the group felt that the targeting logic of the prototype was too personal and wanted to make the SMS messages more 'public' by redirecting them to a Twitter stream or automated hotlines, *"I think tweeting may well be a more acceptable way of doing that and it's in the public domain so you can see there have been 80 tweets at that time in the morning and it's not going to a direct person"*.

From my perspective, the prototype allowed the group to experience a new relational infrastructure that created a direct connection between a noise event and an actor that is made responsible. This bypassed the technical mediators who currently deal with noise data. Instead of the sanctioned infrastructure of the annoyance metric that traces long-term patterns, the prototype is a technical hack that used the decibel data to act like a shouted complaint at a politician in the street. The prototype triggered a group discussion about the strategies and tactics that a noise-monitoring network should adopt. Should it force new political connections by holding individuals accountable, or should it focus on building a data repository that is more acceptable to the current logic of the airport's data practices? What was at stake were different ways of staging annoyance. Yet the diversity of reactions amongst the workshop participants made it clear that any infrastructure designed for this collective could not adopt a single way of staging annoyance but would have to support a multiplicity of approaches.

Prototype 4: I turn noise into numbers

This prototype uploads sound pressure measurements at regular intervals to an online repository, where it is presented as a time series. The noise of an aircraft can be identified as visual spikes on the online graph. The prototype directly addresses the requests by residents for a static monitoring device that can be placed in their own home to provide evidence of their noise exposure. The composition and function of the device is as follows:

Sound sensor > **decibel data** > **online data archive**

During the workshop, this prototype triggered the least discussion and provoked no disagreement amongst the group. The residents asked practical questions about where it could be located in their home and whether future versions could me more accurate. Compared with the previous prototypes, this one is the most similar in function to the existing official noise meters, which produce decibel numbers as their output. The innovation of the device is that its low-cost would allow the participants to carry out their own data gathering by choosing where and how they monitored noise, whilst still allowing a connection to the existing data infrastructure of the airport. Yet at a conceptual level, the prototype was not challenging and seemed to be largely familiar to the participants. Despite the fact that it was not clear what exactly would happen to the collected data, the prototype was treated as a tool that could be used, rather than a provocation that needed to be discussed. At the end of the workshop I asked the participants if they wanted to borrow any of the prototypes and half of the group excitedly asked to take this prototype home with them.

Infrastructuring a noise monitoring collective

The result from the workshop was that a number of people were now enthusiastic to be part of a noise-monitoring network. For me this research had uncovered the way the noise and the metrics function in the local area to enact and prohibit particular realities for the residents. I had identified a prototype that people wanted to use and gathered insights for future prototypes. I installed the 'I turn noise into numbers' prototype in one of the participant's homes, where it was in operation for three months. During this time, one of the other workshop participants informed me when the device temporarily stopped sending data, so I knew that at least some people were paying attention to the data feed. This encouraged me to continue the process and build a new device that would incorporate the insights from the workshop. I tried to enrol additional actors to put together a loose team to develop and test the prototypes as well as gather financial support for the hardware. Over a period of a year, I assembled a network that continued the collaboration with RBWM, who had agreed to co-locate a prototype alongside their noise monitors as well as with HACAN who provided strategic advice and a charitable foundation that funded the hardware as well as individual local residents, sound artists and academics working on noise and bio diversity. The hardware and software were created as a loose collaboration with the sound artists, an academic and a Heathrow resident who is a programmer. It was not only the issue of Heathrow noise that encouraged people to join the network, but also the practical development of the device, which became a tangible focal point for the gathering of this network. During a follow-up workshop at which the group met to work on the programming, one of the members spoke about their surprise at the mix of collaborators involved with the prototype, which included personal friends, family members, local residents, a charity, a local council and a pressure group.

Prototype 5: `I quantify AND broadcast'

Figure 8.5: Photo of the 'I quantify AND broadcast' prototype

This was the final prototype (Figure 8.5) in this development process and used a Raspberry Pi computer and a calibrated measurement microphone, which were chosen for their measurement accuracy, low unit cost and availability for the foreseeable future. The key feature of the device is that it sets up two parallel infrastructures and ways of dealing with sound. The first treats voltage changes at the microphone as acoustic pressure, which are converted into the LAeq official noise metrics of the airport. The decibel data was adjusted against a class 2 industrial sound level calibrator (Reed 2014) and the calibration was checked 6 months after outdoor deployment and the accuracy was still ±4dB(a) which is much better than WideNoise (section 6.3). A script on the Raspberry Pi samples, filters and uploads the data to an online repository where it is viewable as a time-series graph and historical data. The second approach treats the voltage changes at the microphone as a soundscape and creates a sound stream that is available as a real-time Internet radio station. A computer program continuously encodes the microphone data and posts it to a public server where listeners can experience the soundscape. These two infrastructures are intended to materialise the diversity of actors involved in the assembly of the monitoring prototype and opinions articulated during the workshops. The device relies on an ontology of noise as decibel measurement in order to enrol existing institutional actors such as the airport but also adds an ontology of sound as audio broadcast which is alien within the context of Heathrow noise pollution monitoring. While at a conceptual level this doubling up seems contradictory, at a material and technical level it is perfectly normal to run multiple software scripts simultaneously. In fact, virtually all computer systems run hundreds of scripts as part of their operating system. Using a design approach to dealing with the ontological controversy about how to stage annoyance allows an additive methodology: devices can stack multiple ontologies on top of each other rather than having to replace one logic with another. The aim of the two infrastructures is not just to represent diversity but also to enable a multiplicity of sound practices that support each other. During the EveryAware research, the WideNoise app (section 6.5) had received the criticism that residents might be using it to measure spikes caused by other noise sources and not just aircraft. By synchronising the sound and data feeds, this prototype can verify the source of a spike, as well as allowing people to visually identify and listen to particularly loud or quiet parts of the soundscape. In this way, the two ontologies of the prototype start to overlap and mutually support each other.

At the time of writing in 2017, three prototypes have been installed, with the oldest in Windsor having collected more than a year of data. The Windsor device is 6.5 km west of the Heathrow runways; another is in Hanwell, 9.5 km east of the runways; and the last is in Camberwell, 24 km from the runways. Based on these installations, it has been possible to make some observations about the sound practices they have enabled. The Windsor device is hosted in the garden of a member of the development team who is skilled in data analysis. The data has been used to identify particularly disruptive flights by correlating the measured noise peaks with third party aircraft data, in order to generate detailed evidence for making official complaints to the airport.

> *"On Fri 4th Nov at 13:20, BAW17 directly overflew my house at 73.8db LAeq2s. It was off track and should have been 1km further north. The usual noise level of outbound flights going north is around 60–65db. Please discipline the pilot. Please contact me to confirm this complaint. I attach screen clips of noise level and track"* (Figure 8.6).

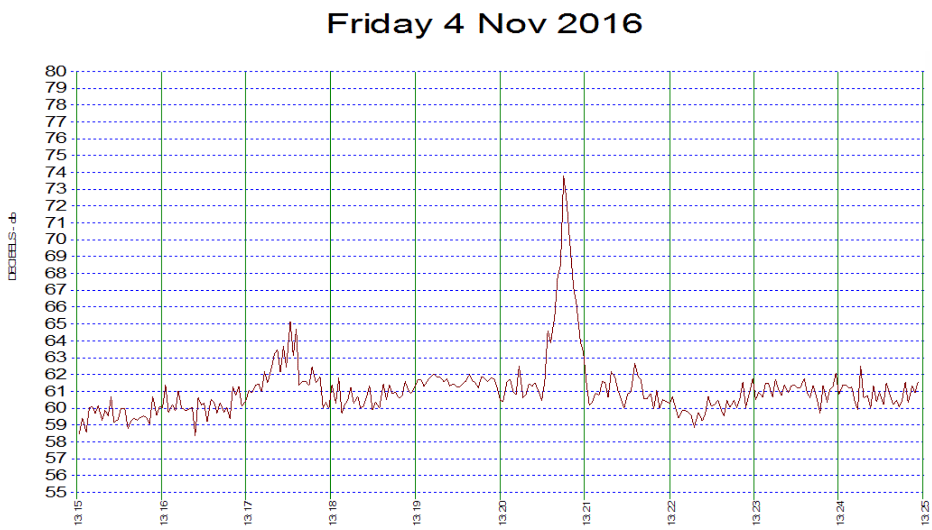

Figure 8.6: Graph generated by the Windsor resident and used to make a complaint about an off-track aircraft.

In this usage the prototype functioned like this:

sound sensor > **decibel data** > **annotated sound event** > **complaint to authorities**

Furthermore, the host of the Windsor device used the prototype to determine whether *"Heathrow [is] getting better or worse and how fast"*, by building custom software to identify long-term trends in the noise exposure and the airport operation. What is interesting about this approach is that it steps beyond the logic of individual complaints to focus on the creation of longitudinal data models that until now had been the reserve of the airport. In their public literature, the airport continually make the claim that *"Heathrow is getting quieter"* (Heathrow Airport Limited 2013, p.14) based on graphs showing shrinkage in the annoyance contour. However, based on a visualisation of one year of data from the Windsor prototype (Figure 8.7), it has been possible to demonstrate that at this site the noise has remained fairly constant but certainly not decreased. This visualisation thus presents situated evidence that can interrogate the claims of the airport. The dataset has been shared with the Aviation Forum, HACAN and the environmental officers of RBWM. It presents a new way for residents to collaborate with local organisations to hold the airport to account. What is key about this long-term visualisation is that it starts to rescale the prototype into a spokesperson that can stand alongside the official noise metrics and begin to challenge the airport's Leviathan. I suggest that this approach points the way towards a model for staging annoyance based on situated empirical data collected by residents rather than aggregated social surveys. The prototype thus enacts the following infrastructure:

sound sensor > **decibel data archive** > **long-term metric - impact not clear yet**

The Internet radio station part of the prototype has enabled two public art installations that were attended by over 1200 people (Figure 8.8). These installations allowed visitors to see the data feeds, read an account by one of the prototype hosts and listen to the live soundscapes at Windsor and Camberwell in order to compare them. While the visitors at the exhibitions expected aircraft noise in Windsor, the frequent and loud aircraft in Camberwell, which was 24 km from the runways and outside the annoyance contours, shocked them. This was the first time that many visitors had paid active attention to aircraft noise and noted the different sonic qualities of the aircraft and their effect on wildlife. When I was present I would draw people's attention to the way birds seemed to screech in shock from the aircraft. Even after a jet passed, it was possible to hear the lingering impact on the birds as they continued to squawk. Despite the fact that the visitors were listening remotely, the sound installation created a tangible experiential connection to Heathrow. The hosts of the prototypes were present to talk to members of the public about their own experience with noise as well as the wider issue of Heathrow. In this deployment, the prototype had the following infrastructure:

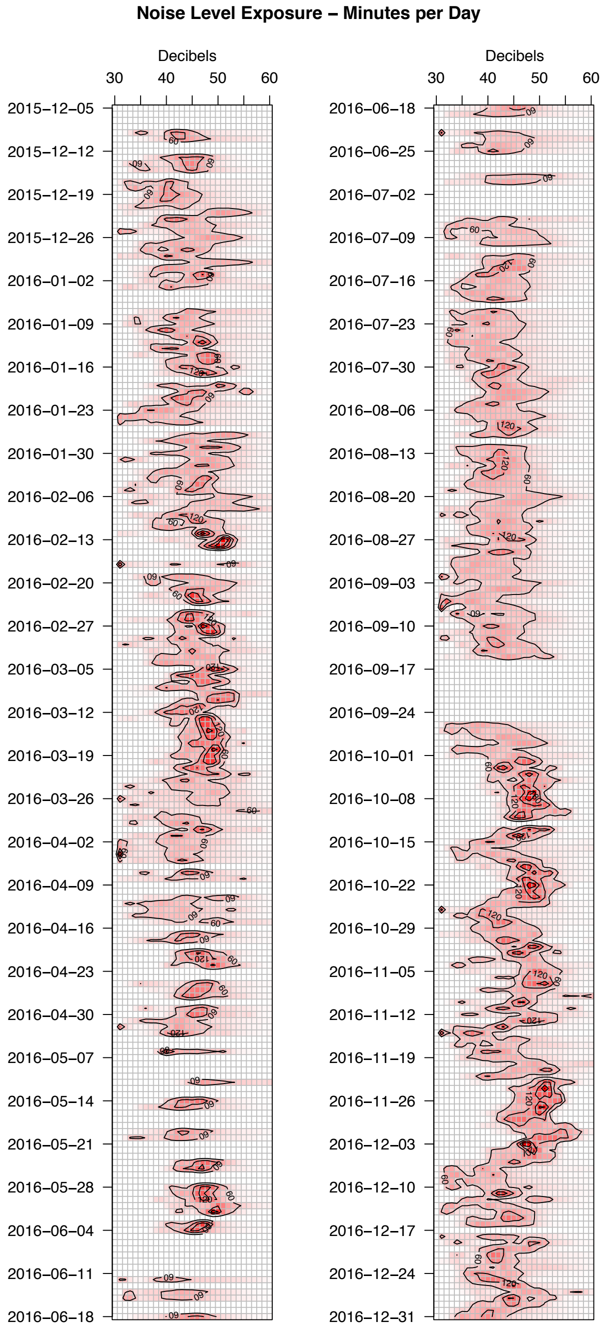

Figure 8.7: Visualisation of one year of noise data December 2015–2016 from the Windsor prototype. The date chronology runs from top left to bottom left and then from top right to bottom right. The coloured areas indicate intense clusters of exposure minutes at different decibel levels. Gaps in the visualisation are due to connectivity issues and a lightning strike in October 2016.

Figure 8.8: Photo of the 'Prototyping a new Heathrow Airport' sound installation where people could listen and watch the data streams from the Windsor and Camberwell prototypes in realtime.

sound sensor > **online radio station** > **sound installation** > **public experience noise**

The multiple functions of the prototype as noise complaint, monitoring device and sound installation have demonstrated the versatility of the sensing device. The prototype has enabled a variety of different ontological infrastructures that engage existing participants in the controversy, such as the local councils and airport authorities, but also made a connection to a broader audience of people who did not previously have any specific personal relation to the issue of Heathrow. This project is continuing beyond the scope of this thesis and growing as there are other Heathrow residents waiting to install prototypes at their home. The plan for this loose prototype collective is to support the deployment of a dozen devices and continue developing functionality that could enable programmatic sound identification of birds in order to demonstrate the broad impact of aircraft noise on living entities at Heathrow.

8.3 Summary: what does ontological design offer participatory sensing?

This chapter showed a novel approach for participatory sensing that does not frame sensing as contributory science, democratising science or autonomous networks. Instead, it demonstrated a way of using participatory sensing to engage with a situated controversy. This mini device study of prototypes has extended the WideNoise study in Heathrow to show that such an approach can analyse, support and transform public controversies. This approach has identified the ontological composition of community annoyance as the key infrastructure at the heart of this controversy and showed how ontological design might lead to more equitable solutions to the problem of noise management. The design of the final prototype has shown that it is possible to stage annoyance in a multiplicity of ways and feasible to do this in a publicly collaborative format that allows analysis, discussion and iteration towards better enactments of annoyance. At a practical level the final prototype was deployed as a sound monitoring network at three sites and allowed the participants to create targeted complaints that were not possible before, as well as developing a novel long-term exposure metric that could challenge the airports claims that it was getting quieter. In this way this mini device study has demonstrated that participatory sensing can become an alternative political ‘spokesperson’ that can act on behalf of an affected community group.

Chapter 9

How does participatory sensing construct sensation and the environment?

This is the latter of the two analysis chapters. It assesses the potential of participatory sensing in the light of the Heathrow prototypes while focused on the methodological and insights gaps in the literature (chapter 2) and referring to the three main device studies.

9.1 Methodological gap

The post-ANT literature highlights that researchers should move beyond mere description towards 'interfering' (Law 2004*b*), yet offers few practical examples of how to 'do' ontological politics (subsubsection 2.1.4.2). The methodological gap in the design literature is the question of how to scale projective design methods to have more impact (Ratto et al. 2014). While ontological design seems to offer a solution, there are few practical examples (subsubsection 2.2.2.2).

It is possible to turn controversies into issues of design

A key contribution from the mini device study in Heathrow is that it showed that a post-ANT focus on ontological politics can be combined with design to interfere in public controversies. The study used historical research to identify the composition of community annoyance, developed a range of prototypes and built a final device that has been productive for engaging with decision-making processes. I suggest this experiment passed the criteria for 'interference' (Woolgar & Lezaun 2013, 2015), since it demonstrated a way of changing the constitution of a controversy instead of just suggesting that things *"could be otherwise"* (p.465). In regards to the Heathrow noise controversy, the study provided concrete answers to Mol's questions of ontological politics: *"Where are the options? What is at stake? Are there really options? How should we choose?"* (Mol 1999, p.79). The prototypes identified **where** the options are by presenting a range of possible relationships between residents, noise and the airport. The process allowed residents to analyse, experiment and experience the possibilities of these prototypes, and the year-long deployment showed that these are 'real' options. The study identified **what** is at stake in the noise issue by highlighting the complex, social and cultural impacts on entities such as schools in the area (subsection 8.2.2). The study also answered Mol's other questions: *"which version might be better to live with? Which worse? How, and for whom?"* (Mol 2013, p.381). The process encouraged the participants to take positions and articulate the normative differences between the proposals and define which mode of engagement suited the group. The study also indicated **how** this collaborative process could continue beyond my devices, by setting up a large-scale public prototyping operation as an alternative to dialogue-based consultative processes. In addition, the prototypes have defined **who** should be a stakeholder in such a process, since they showed that it must include a much wider range of entities than those labeled as affected by the 57dB(a) noise contour.

Rather than treating Heathrow as an epistemic knowledge controversy, where an STS researcher, might try to legitimate the expertise of the residents as stakeholders, this study has demonstrated an ontological approach of changing the composition of annoyance. In this way, the study has provided a practical and reproducible example of how post-ANT and ontological design can be combined to intervene in public controversies.

It is possible to combine ethnography and making

While ethnographic observation and building electronic prototypes appear to be very different activities, when engaged with devices, these differences melt away. Throughout the overall study, my roles as ethnographer, project researcher and designer, all involved soldering circuit boards, uploading firmware and calibrating sensors. This was practical work that provided insights into the way sensing objects function, but also into the limits of agency and choice for the different actors. Without this specific knowledge it would have been difficult to judge, where and when, rhetoric strays from material constraints. These material insights and frustrations also encouraged me to get personally involved and build my own sensing objects to intervene in the Heathrow controversy. My suggestion is that the proximity and personal involvement with devices creates a smooth transition from device ethnography to building prototypes. Thus an ethnographic focus on ontological politics and ontological design are complimentary methods, which ought to be transferable towards other sites and controversies.

It is useful to combine the 'device' and 'infrastructure'

The combination of the 'device' (Law & Ruppert 2013) and 'relational infrastructure' (Star & Ruhleder 1996) proved to be methodologically productive for integrating ontological politics and design. While the concept of the device offers fluidity and agendas, infrastructure added a focus on the structural aspects of composition. The concept of infrastructure made it easier to imagine changing modules within the controversy: such as inserting someone to be held responsible (subsection 8.2.3), or removing humans (subsection 8.2.1). The direct mapping between the composition of the prototypes and the controversy turned ontological politics into a tactile process, where different realities could be prototyped with participants. In this study, the notion of the device as concentration of intentions integrated well with the concept of infrastructure as relational connector and prohibitor. The ontological approach to devices and infrastructure created a scaling effect that continually oscillated between the micro of electronic devices and the macro of socio-political governance. In this way, the combination of these two concepts supported a design approach that can scale to engage with real world controversies and address the methodological gap in the design literature.

Stacking allows a rethink of ontologies

The final Heathrow prototype showed an unusual way in which different ontologies of noise as measurable evidence and as sound sensation functioned simultaneously within a single object. I argue that this involved the 'stacking' of ontologies on top of each other. While this idea links to Mol's notion of ontologies as multiple, where different diagnostic techniques and medical instruments enact different ontologies, these enactments avoid conflict because they are distributed and have little contact with each other (Mol 2002). However, the final Heathrow prototype showed a way in which computational objects can pragmatically accommodate multiple ontologies within a single object. I suggest that one of the theoretical contributions of this study is that it allows a rethinking of the notion of ontological politics as focused around the contested configurations of devices. If we accept the metaphor of ontologies as ‘stackable’, then perhaps this can be used to transform a range of other ontological conflicts. If an ontological design approach had been followed in creating the AirProbe device, could this have allowed the three different consortium ontologies to co-exist (section 5.2)? Perhaps this approach opens up the potential for post-ANT and ontological design to collaborate further in designing new kinds of device-centred interventions.

9.2 Insight gap

I now turn to focus on the insight gap in the participatory sensing literature, which provides little detail about the participant, the material practices of sensing and the kinds of politics taking place (section 2.3). This gap has already been addressed in the horizontal analysis of the three device studies (chapter 7), so this section revisits the gap to identify which insights the Heathrow prototypes have added.

Participatory sensing becomes meaningful when engaging controversies

The AQE/SCK and EveryAware devices enacted the environment as bifurcated into objective measurement and subjective perception. In these enactments, the environment disappeared into blurred rhetorics of data flows, citizenship and behaviour change that could not be used or acted upon (subsection 7.2.1). In contrast, the WideNoise deployment in Heathrow, and the subsequent prototyping process, present a model of doing participatory sensing where environmental pollutants are not divided into measurement and perception, but are conjoined within public controversies. In this approach, participatory sensing has to engage with the assemblage of entities involved in a controversy: such as the history of technical metrics, pressure groups as well as the sensations and practices of residents. The mini device study showed a qualitative difference in the specificity of the environment enacted through a controversy-focused approach where the environment became meaningful and transformable for the people who were in contact with the devices. I suggest this study has demonstrated that participatory sensing can construct a range of different sensations and environments. It can enact bifurcations of nature that exclude entities from participating, or it can engage with controversies to intervene within the contestation between different realities of sensation and the environment. However, issue-focused approaches are largely absent from the participatory sensing literature, which instead frames sensing as a scientific/institutional object (subsection 2.3.1), an inclusion issue (subsection 2.3.2) or autonomous networks (subsection 2.3.3). This raises fundamental questions about how the environment should be reframed within participatory sensing in order to support meaningful sensing practices.

Participatory sensing can generate a multiplicity of ways of referencing the world

The dominant narrative within the participatory sensing literature is the contributory science model (subsection 2.3.1) where sensing is meant to gather empirical knowledge about the environment, and the focus is on data quality. While in the narrative of democratising science (subsection 2.3.2) sensing is framed as making empowered scientific citizens, and the focus is on participation.

However, the Heathrow prototypes showed that participatory sensing can support a much wider range of references. While the prototypes were technically simple, they were complex in the way they fluidly experimented with different ontologies of sound. The final prototype was calibrated to use the official LAeq metric and conform with reference devices since this seemed important for building relationships with local institutions and residents. However, the innovation of the prototype is that it managed to combine multiple ontologies of an objectively measurable environment with human affectedness. By measuring sound pressure, significant quantities of calibrated data could be collected for engaging with institutional decision-making, while the live audio stream allowed new publics to experience the impact of Heathrow by listening remotely and allowed new discussions on the impact of noise. In this way the ontologically open approach of *"take it all"* (subsection 8.2.1) allowed the inclusion of ontologies that are currently being excluded from participating in community annoyance. It also enabled the noise monitoring network to grow beyond predefined constituencies. The resulting impact and publicity of the prototypes was not based on scientific chains of reference (Latour 1999) or democratic inclusion, but the way they created new arrangements of the controversy. Like the other devices, the Heathrow prototypes were also involved in 'stringing together', yet they did so in a way that multiplied ontological reference rather than excluding it. WideNoise in Heathrow and these prototypes show that scientific reference via calibrated devices is merely one way of relating to the world, and that participatory sensing can move beyond this to adopt ontological experimentation and a plurality of ways of referencing the world.

Issues re-articulate the participant

Both the literature review (subsubsection 2.3.1.4) and the empirical device studies identified that there are significant problems with the way the participant is both over-and underspecified in participatory sensing (subsection 7.2.3). However, the Heathrow prototypes demonstrated a radically different approach for re-articulating the precarious position of the participant. Rather than adopting the literature's framing of people as MULEs (Figure 2.3), democratically empowered citizens (subsubsection 2.3.2.1) or subjects of behaviour change (subsubsection 2.3.2.2), the prototypes demonstrate that it is possible to build a collective by focusing on the infrastructure of a controversy. This led to the emergence of a previously non-existent group around the prototypes, made up of a surprising mix of friends, family members, Heathrow residents, a charity, local council and pressure group (subsection 8.2.5). This is what Marres (2005*a*) and Marres & Lezaun (2011) describe as an issue or material public that forms to engage with an issue that is institutionally not cared for and uses devices as collectivising scaffolds (Le Dantec & DiSalvo 2013). This makes it possible to organise participatory sensing projects without *a priori* specifying participants, communities or institutions. While this issue-focused approach has overlaps with the autonomous networks narrative (subsection 2.3.3), it differs in the way it sets the controversy as its focus and is prepared to collaborate with institutions for its own strategic purpose. Instead of over or underspecifying the participant, people are treated as part of the controversy rather than something to be added as an afterthought onto a device.

The final Heathrow prototype demonstrates the success of an issue-focused approach via the resilience and continuity of the noise monitoring collective that has been in place for more than a year and gathered over 20 million data points. It stands in contrast to the short-term nature and problems with the other device deployments (section 4.4). This demonstrates that an ontological design approach is a practical model for participatory sensing to adopt more widely, and suggests the need to rethink the assumptions of participatory sensing in particular 'what is being sensed and what is doing the sensing'.

9.3 Future research

The Heathrow prototype study is continuing with additional devices being deployed with residents who have requested devices to be installed at their home. Thus it would be useful to carry out a follow-up study in 2018 to gauge the impact of the sensing network in relation to the third runway expansion process that is entering the next consultation phase.

As a follow-up study it would be productive to engage with the literature that has used the devices featured in this study as good practice exemplars. The aim would be to develop evaluation criteria that better capture the ontological politics of participatory sensing.

The focus of this study was on participatory sensing as a technological device phenomena. This meant the study didn't examine traditional environmental data gathering tools such as diffusion tubes (subsubsection 2.3.1.1). It also didn't venture deeply into artistic sensing practices and the way they enact the environment. The epistemic and ontological patterns in these practices are likely to differ from the participatory sensing examined in this study, so they would be a productive comparison for future research.

The methodology of long-term ethnographic accounts of the design and usage provided in-depth understanding of the material practices of the devices. Yet a continuation study would be useful for following the sensing devices upstream, by tracing the tendrils of these 'minimal exemplars' into policy and funding agendas (section 4.5).

It would be productive to explore the methodological notion of 'stacking ontologies' further to see the potential and limitations of this approach. In particular, it should explore whether 'stacking' is a unique feature of computational objects or whether it can be applied more broadly.

Chapter 10

Conclusion

This conclusion summarises the findings and contributions of the study. The **introduction chapter** (chapter 1) outlined that participatory sensing consists of new ubiquitous sensing technologies that are being used to engage publics in environmental monitoring with the literature claiming that this is contributing to science, improving the environment and creating new forms of democratic citizenship. The **literature review** (chapter 2) revealed two gaps: an insight gap, suggesting that little is known about the material practices of participatory sensing, the participant or the kinds of politics taking place within these practices (section 2.3); and a methodological gap which showed there were few examples of how to 'do' ontological politics by interfering in research (subsubsection 2.1.4.2), while in the design literature there were few practical examples of how to scale up projective design methods to have more impact (subsubsection 2.2.2.2).

The **methodology chapter** (chapter 3) outlined the research design adopted an approach from post actor-network theory and ontological design to theorise and intervene in the relationship between, people, technology and environment. The study used four research questions:

'What is being sensed and what is doing the sensing?'
'How do power and politics take place within participatory sensing?'
'What can ontological design offer participatory sensing?'
'How does participatory sensing construct sensation and the environment?'

These research questions were addressed via three empirical device studies and a series of Heathrow prototypes that were built in response to the findings from the device studies. The core of this study are the three long-duration ethnographic device studies that are divided into three parts design, usage and outputs. The three device studies address the central research question of 'what is being sensed and what is doing the sensing'.

The **Air Quality Egg and Smart Citizen Kit study** (chapter 4) identified that both devices were successful in recruiting backers and organisations by stringing together rhetoric and hardware of heated filaments, concerns about air pollution, revolutionary change, smart citizenship and anti-governmental ideas. However, due to dividing between objective sensing and subjective 'human care', neither device managed to create new practices of citizenship or ontologies of sensing that could convincingly make 'sense' of the low quality sensors. The usage of the devices was confined to electronic tinkering while people who wanted engage with health issues or political concerns could not use the devices or were marginalised. Yet despite these major flaws, both devices became good practice exemplars of smart citizenship, citizen science and IOT.

The **AirProbe study** (chapter 5) identified that this device gathered academic funding by stringing together gas sensors with rhetorics of motivation, awareness and behaviour change. However, the design of AirProbe involved a struggle between competing realities of air quality - as a public health policy instrument, an indicator of behaviour change or a situated community concern. The deployment as a competitive game only enabled an ontology of air pollution as a baseline for behaviour change of participants while public health policy and community concerns were ignored. The participants acquired false insights about air pollution from the poorly calibrated sensing device. The online game proved to be surprisingly addictive, yet futile in the way it encouraged the participants to compete in a self-referential system that had no meaningful connection to the external world. Finally, the academic output from the device ignored the pollution data and focused on the participant to claim their environmental awareness was increased. Thus a device that started off sensing pollution as a public health and personal exposure issue was transformed into a rhetorical actuator for changing human behaviour as an institutional policy instrument.

The **WideNoise study** (chapter 6) highlighted that WideNoise was designed multiple times by various actors and enacted as multiple parallel devices. The app was first created by stringing together rhetorics of 'greenness' and technological singularity and sense data load; later, it became a professional environmental instrument as well as a sensor of user motivation, engagement and behaviour change; finally, it measured loud aircraft and community annoyance. These shifts in what was being sensed and doing the sensing revolved around ontological struggles about how to sense the environment. At times the material qualities of the app were foregrounded to claim the device as a scientific instrument and add legitimacy to resident complaints, while other times the material limitations of the app were hidden to sense only the mind of the user. None of the actors could impose a singular sensing ontology onto WideNoise and the app was reconfigured by residents, activists and a local council to sense noise as both experiential and political pressure.

The **'How do power and politics take place within participatory sensing?' chapter** (chapter 7) carried out a horizontal analysis across the three device studies and suggested that instead of measuring defined external environmental pollutants as imagined in the literature, the devices were blurring, shifting and inverting the subject and object of sensing. The power of these devices resides not in creating epistemic knowledge but the stringing together of hardware and rhetoric into publicity to create new ontological entities. In addition participatory sensing is the site of ontological conflicts about whether to sense environmental pollution as a health impact, engage with decision-making or organise collectively. These tensions are based around bifurcations of nature that establishes an exclusionary hierarchy between different ways of sensing. Yet the WideNoise deployment in Heathrow showed that alternative kinds of participatory sensing are possible by ontologically reconfiguring sensing devices within controversies to establish connections to decision-making processes.

The **'What can ontological design offer participatory sensing?' chapter** (chapter 8) experimented with these findings by returning to the site of Heathrow airport with a mini device study of sensing prototypes that analyse, support and begin to transform the public controversy of noise. This approach managed to identify the ontological composition of community annoyance as a key infrastructure at the heart of the noise controversy and turn this into a question of design. The prototyping process demonstrated that it is possible to publicly and collaboratively prototype sensing devices to stage a multiplicity of annoyance. The final prototype enabled targeted complaints and the development of a novel long-term exposure metric that could be used to challenge the airports claims that it was getting quieter. In this way, the Heathrow study demonstrated that participatory sensing can become a political 'spokesperson' that can act on behalf of an affected community group.

The **'How does participatory sensing construct sensation and the environment?' chapter** (chapter 9) analysed participatory sensing in the light of the Heathrow study to draw conclusions about the methodological and insight gaps as well as the wider potential of participatory sensing.

Methodologically, the Heathrow study provided a demonstration of how a post-ANT focus on ontological politics could be combined with design to provide detailed analytic answers about the nature of public controversies and how to intervene in them. The study demonstrated that an ethnographic focus on material devices creates proximity and personal involvement that allow a smooth transition to designing devices to intervene within a research site. The methodological concepts of devices and infrastructure are combinable to suggest fluidity as well as material connectors and prohibitors of relations. Finally the notion of stacking ontologies is both politically and theoretically interesting for rethinking the potential of ontologies for directly transforming the world.

The Heathrow prototypes demonstrate that participatory sensing becomes meaningful when engaging controversies. The prototyping process enacted the environment as a tangible, meaningful and transformable entity for people who came in contact with the devices. This demonstrates a qualitative difference in the specificity and actionability of the environment as enacted through a controversy-focused approach and raises questions about the way the environment is framed within participatory sensing. The study demonstrated that participatory sensing can involve multiple modes of referencing the world that combine scientific measurement with affective modes to allow new publics to experience environmental impacts. Scientific reference via calibrated devices is merely one mode of connecting to the world and participatory sensing must move beyond this to adopt ontological experimentation and multiple modes of engagement. The prototypes demonstrated that it is possible to gather collectives around sensing devices when targeting a controversy. The resilience and continuity of this collective stands in contrast to the problems with the other device deployments and demonstrates that an ontological design approach is a viable model for participatory sensing to adopt.

The contribution of this study has been to carry out long-term ethnographic devices studies that identified the material practices and ontological politics of participatory sensing. It also demonstrated that ethnography can be combined with an ontological design method for intervening and transforming public controversies.

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