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Mapping Participatory Sensing and Community-led Environmental Monitoring Initiatives

Making Sense

H2020 CAPS Project

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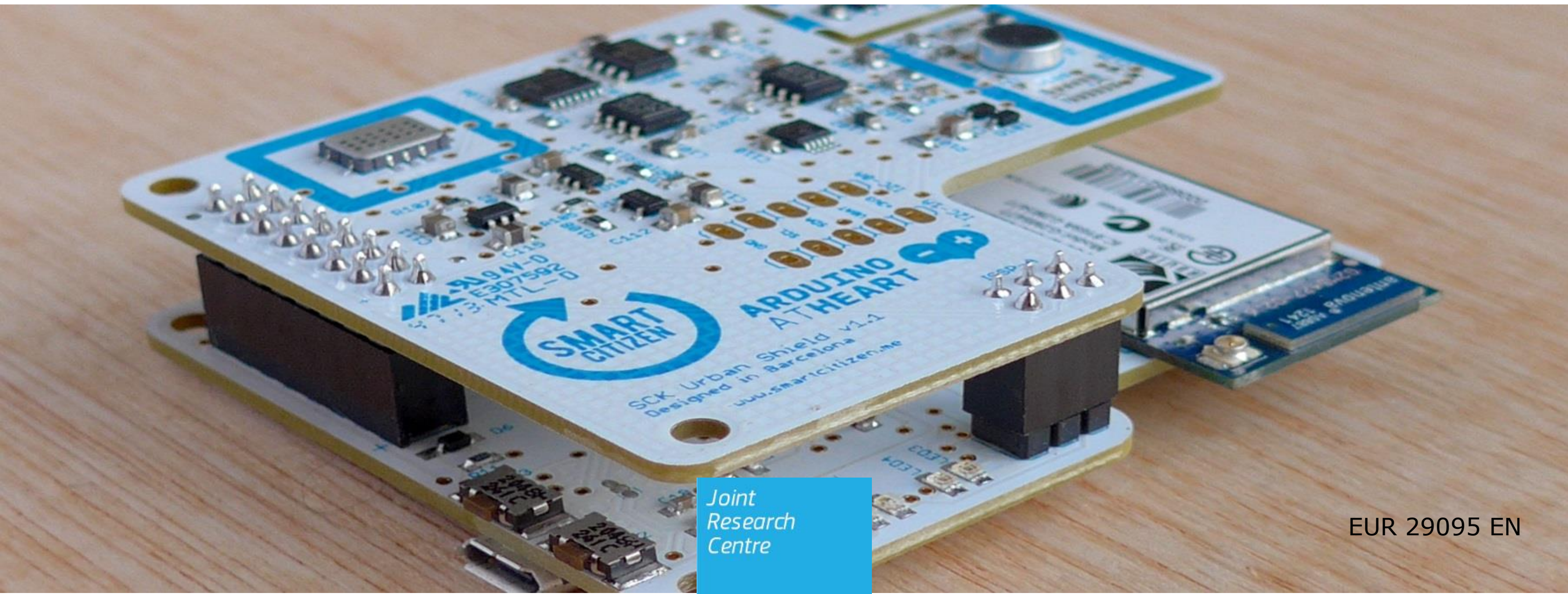

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Mapping Participatory Sensing and Community-led Environmental Monitoring Initiatives

This report presents a summary of the state of the art in urban participatory sensing and community-led environmental monitoring, the types of engagement approaches typically followed, contextual examples of current developments in this field, and current challenges and opportunities for successful interventions. The goal is to better understand the field and possible options for reflection and action around it, in order to better inform future conceptual and practical developments inside and outside the Making Sense project.

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INDEX

INTRODUCTION

High impact and sustainable examples of urban citizen and community centred sensing initiatives are still rare in 2016.

However, there have been a number of interesting case studies in places such as Amsterdam or Fukushima that shed light on a wide set of best practices at the technical and social levels that demonstrate the opportunities associated to enabling this kind of collective processes. Nowadays citizens who are interested in taking action to address issues of individual and collective concern are increasingly crossing paths with makers who develop low cost and open source artefacts and systems. This combination of bottom-up citizen action and distributed and accessible technologies can support the achievement of environmental goals in ways never envisioned before.

Nowadays, experts from both technical and social disciplines are increasingly accepting the potential of lay perspectives and innovations in science and technology, and gradually incorporating them into their traditionally established knowledge fields. Moreover, policy makers and political actors are paying more attention to what is happening in non conventional innovation contexts, while looking for newer paths to generate planning and action frameworks towards more suitable solutions to current problems. The combination of these trends provides a unique opportunity to move forward in changing the way community driven environmental monitoring is still perceived and put in practice.

We can harness the power of these changing times and tap into previous experiences in the context of participatory sensing to deliver the change we envision to the largest amount of individual and collective beneficiaries.

> We can learn from the valuable processes developed to date, from their successful strategies but also from their major shortcomings, to inform the design of more participatory, robust and sustainable sensing tools and methodologies for bottom-up environmental monitoring.

Recent developments like The Array of Things (AoT), a network of interactive, modular sensor boxes deployed in Chicago, which supports both research and public use, have demonstrated for instance that future urban sensing initiatives may blend bottom-up and top-down approaches and provide models that can be appropriated in diverse contexts. By supporting and developing more initiatives of the kind, we can advance the field of urban citizen sensing from valuable but piecemeal examples to a sustainable and robust community of thinkers and practitioners that can offer more immediate and tested solutions for the widest possible pool of stakeholders.

This document is a combined effort of IAAC (Institute for Advanced Architecture of Catalonia) and JRC (Joint Research Center, European Commission), based on the integration of D6.2 and D4.1 deliverables. The Making Sense collaborative and interdisciplinary approach have allowed us to develop shared viewpoints and common work methods, leading to the creation of enriched and balanced outputs. As a result we were able to dialogically intertwine previously separated technical and social elements into the same mapping venture. This ultimately allows access to an **augmented report that we hope will act not only as an internal tool to reinforce mutual learning practices between all partners of Making Sense, but also as a snapshot on the current initiatives in this field for present and future reference.**

We thus present a summary of the state of the art in urban participatory sensing, the types of engagement approaches typically followed in participatory sensing, contextual examples of current developments in this fields, and current challenges and opportunities for successful interventions. The goal of this document is to better understand the field and possible options for reflection and action around it, in order to better inform future conceptual and practical developments inside and outside Making Sense. Its structure is the following:

SECTION 1 defines urban participatory citizen sensing and the range of past and on-going interventions to open up new modes for sensing and production of knowledge. It goes on to address the shifting boundaries between top-down and bottom-up approaches for participatory sensing, from research or institutionally-led initiatives to more citizen or community-led projects. An in-depth debate over what is assumed and expected from involved actors, or who decides about the initial questions and goals, who collects the data, interprets it and uses it for collective action, is offered.

SECTION 2 delivers the state of the art of environmental sensing projects and initiatives in terms of their main technical and social aspects. It is divided between research and citizen science technologies, which are more institutionally led or research oriented, and more DIY and bottom-up technologies (e.g. Air Quality Egg, Safecast or Smart Citizen) with their origin in communities of users and/or supporters.

SECTION 3 summarises previous experiences within urban participatory sensing, in Making Sense pilot development contexts (Barcelona, Amsterdam and Prishtina), and other cities with relevant examples in participatory snesing (Manchester, Madrid, Fukushima and Beijing). Together with a brief report of the activities conducted in these contexts, special attention is given to their best practices, but also to some of their problems, and to their future internal development plans at both technical and social levels.

SECTION 4 identifies challenges and recommendations to enable new forms of citizen and community engagement through participatory sensing. It considers not only access to technology or scientific or technical quality of data, but broader questions around social interaction, diversity, or governance models. The report finalises with an annex section that includes an overview of other Internet of Things (IoT) low-cost sensing technologies for bottom-up environmental action.

1

URBAN PARTICIPATORY CITIZEN SENSING

Urban participatory sensing can be understood as a socio-technical process in which citizens use lightweight and accessible sensor-technologies to collectively monitor the environment by performing a number of tasks that typically entail collecting, sharing and/or interpreting data.

A plethora of light-weight and low-cost urban sensing technologies that have been designed to be used by citizens have been around for over a decade. These tools range from specific sensing devices or mobile applications [Stevens & D'Hondt, 2010; Honicky et al., 2008; Mun et al., 2009] to Internet of things (IoT) smart and connected devices such as Air Quality Egg[1] or Smart Citizen [Diez & Posada, 2012] (see more in annex). The broader field of DIY environmental monitoring has a long history of initiatives. For example more recently a number of projects are monitoring water and air pollution around fracking sites, such as the Citizen Sense[2] kit in northeasthern Pennsylvania; the CATTFish[3] developed by Create Lab, or ALLARM Shale Gas Monitoring Toolkit[4] at Dickinson College; or the Elk County Water Monitoring Project[5].

Futhermore, participatory sensing covers a wide range of user involvement [Lane et al. 2008; Ganti et al., 2011]. On the one hand, participatory sensing requires the active involvement of individuals to contribute data related to a phenomenon that is too large to be addressed by a single person (e.g. air quality in a city). Examples of these kinds of collective practices tend to rely on applications thatmake use of the sensors available in handheld devices in order to allow users to measure anything from noise levels [Maisonneuve et al., 2009] to chemicals in the air (e.g. the Cell-all initiative[6]). On the other hand, *opportunistic sensing* is more autonomous as, for example, devices are programmed to produce continuous location sampling (e.g. Air Quality Egg).

1 http://airqualityegg.com/

2 http://www.citizensense.net/sensors/citizen-sense-monitoring-kit-pennsylvania/

3 https://www.cattfish.com/

4 http://www.dickinson.edu/info/20173/alliance_for_aquatic_resource_monitoring_allarm/2911/volunteer_monitoring /3

5 http://www.waterworld.com/articles/print/volume-28/issue-10/departments/case-studies/fracking-concerns-quality-monitoring-program.html

6 http://www.dhs.gov/science-and-technology/cell-all-super-smartphones-sniff-out- suspicious-substances

A large number of urban participatory sensing interventions have been organised as part of research or citizen science projects. In such experiences the focus was on perfecting the technologies to produce systems that were user-friendly and relatively lightweight but also capable of producing and delivering accurate data. For example, 5 Citizens' Observatories projects (Citi-Sense, WeSenseIt, Cobweb, Citclops and Omniscientis[7]) were funded in the first round by the EU as part of the topic ENV.2012.6.5-1 "Developing community based environmental monitoring and information systems using innovative and novel earth observation applications".

They ranged from air quality outdoor (cycling/walking) and indoor (schools), odor nuisance, to monitoring of natural waters (lakes, rivers, coasts, oceans) and flood risks. Their focus is onharvesting and quality control of crowdsourced environmental data through sensor devices, mobile apps and data management systems developed within the projects. The Citizen Observatories aim to enablecitizen co-participation and co-operative planning but still facilitated by environmental monitoring, data collection, interpretation and information delivery systems designed and run by experts from academia and companies.

More recently, with the proliferation of open source technologies such as Arduino, the creation of makerspaces like Fab Labs, and the growing popularity of crowdfunding platforms, new urban sensing technologies have been designed and released to citizens without being part of specific citizen science projects or research agendas. Such novel technologies aim to empower citizens by providing Do-it-yourself (DIY) or more open systems that they can appropriate for their own purposes, enabling chains of collaboration both in geographically bounded and distributed communities.

Tools, networks and venues, such as open-source software and hardware models, peer-to-peer movements, open design, and a variety of makerspaces are promising for citizens who want to produce knowledge in creative and unexpected ways. People are doing this online and offline, in their homes, neighbourhoods, libraries, schools, but also in spaces such as makerspaces as community-oriented hands-on spaces offering tools and learning environments for wider publics to experiment and develop their own projects, objects or prototypes.

There is a unique transdisciplinary combination of knowledge from technical fields with ordinary needs, innovative DIY ideas, and local data [Nascimento & Polvora,2015]. Transdisciplinarity can be found right from the beginning,as these trends uphold open and collaborative logics mingling together fields from inside and outside traditional disciplines from sociology to computer sciences, with citizens, their communities and other relevant stakeholders.

7 http://www.citizen-obs.eu/

In such data-rich environments, the way in which participatory sensing actually manages to bring together citizens, communities, policy makers, experts, companies, NGOs and others, is crucial to establish sustainable and robust initiatives. The whole environment of tools, data of people needs further attention. Which methods are better suited for mobilizing citizens and communities? How is their engagement and the data they produce validated? Can we tailor training and educational models not only for technical literary, but also for citizen and community empowerment? How can their insights be incorporated in new governance models with other actors in urban settings? How to discuss and reconcile often disparate objectives coming from different actors? How to sustain communities over time in participatory sensing initiatives?

Urban participatory sensing approaches that privilege the empowerment of citizens and communities through DIY and bottom-up interventions, are opening up new modes for sensing and production of knowledge. People appropriating sensing tools to address their local needs and expectations give rise to normative consequences of sensing practices for individual and collective action in their urban environments, while also challenging some of the conventional conditions of the scientific and policy making sensing processes.

For instance, smart-city proposals over the years, such as the early and formative Connected Sustainable Cities (CSC) project, developed by MIT and Cisco within the Connected Urban Development initiative between 2007 and 2008, have tried out distinct material and political arrangements that potentially recast what is urban citizenship [Gabrys, 2014]. They do this by planning for new processes of distribution of governance between state actors, private companies, citizens, communities and local actors. And they point towards different ways DIY and participatory sensing can be taken up as grassroots strategies for new types of commons and democratic urban participation.

Urban participatory citizen sensing goes beyond the conditions usually set for "citizen science", and instead enters the realm of empowerment and citizenship in the city. Collection, production and use of data become practices of engagement and action through DIY sensing technologies for environmental monitoring. Data is situated and contextually bounded, that is, it comes from somewhere, it is intended for someone and it has purpose for the actors involved in these collective activities of "'making data matter" [Taylor et al, 2014]. Participatory sensing is not only about technology development but it triggers broader questions such as modes for civic participation, conditions of access to data, privacy and data protection, public controversies and divergent interpretations, choices for data use, data-related policy making, or quality of life in urban environments.

1.1 — Shifting the boundaries: From top-down to bottom-up approaches

Urban participatory sensing faces a number of tensions brewing in the boundaries between top-down and bottom-up approaches in science and technology.

It was initially tightly linked to research-led citizen science, which is a form of crowdsourcing typically instigated by scientists where users are recruited to cooperate towards scientific aims [Wiggins & Crowston, 2011]. Unlike many online communities, this type of citizen science projects is not self-organising or initiated by citizens. However, more recently there has been a growing motivation for citizens to engage in participatory sensing (also referred to as *crowdsensing*) without necessarily being recruited by scientists or contributing to top-down research agendas [Bria et al, 2015].

The debate is clearly present in the field of citizen science, which has different meanings based on what it is assumed and expected from citizen engagement. What is a "citizen scientist" has traditionally the same starting point - non-professional scientists who carry out activities within the scientific guidelines of data collection, analysis and interpretation. However, its expressions vary greatly. It can come from a top-down approach mostly allowing non-experts to assist in the scientific process run by professional scientists. Or it can be closer to a participatory push for a "form of science developed and enacted by citizens themselves" [Irwin, 1995] or "science developed and enacted by citizens themselves" [Bonney, 1996]. In what is called 'undone science' [Frickel et al., 2010] or community-based participatory research [Bidwell, 2009], members of communities, social movements and civil society organisations participate in expert-led projects seeking local input, or they can generate their own studies, as for example by using low-cost air sampling devices ('buckets') to measure toxic exposure [Ottinger, 2010].

But citizen science is moving towards more bottom-up interventions as in participatory sensing. Citizens individually and collectively are taking on active roles as direct participants or initiators themselves of processes leading to new data and knowledge. Bottom-up interventions challenge the assumption that valid knowledge is safeguarded by professional scientists in academic institutions and industry, or that the original definition of "citizen scientists" is always connected to scientific aims.

A bottom-up approach is different in that opportunities arise for citizens and communities to redesign from the start scientific and technological enterprises. Nevertheless, most of the cases they don't do it completely alone, but with expert assistance, through governmental programmes, or with the backing of civic and grassroots movements.

This shift from top-down to bottom-up participatory sensing initiatives reveals many challenges around citizen engagement, sustainability and scalability. Different types of participatory citizen sensing are based on 1) the **type of role performed by citizens and communities**, 2) the **status of the whole process** (if it's informed by scientific methods, or instead by local knowledge, values, needs, or political priorities), 3) the **origin of the issues of concern**, 4) the **overall governance** or type of relationships between involved parties (citizens, scientific community, public authorities, funding bodies, private sector, civil society), and 5) the **types of impacts expected** (scientific endeavour,communities, political agenda, etc).

While in classic research-led citizen science for urban participatory sensing, the goals, engagement and operational strategies stem from the project instigators, that is, the experts or professional scientists, in bottom-up initiatives these have to be negotiated by groups of citizens. For instance, in a traditional citizen science project such as The Missouri Stream Team Program, citizens engage in water quality monitoring in the Missouri Stream[8] (USA). The initiative is led by scientists employed by government organisations and participation focuses merely on data collection.

The project instigators set the goals and organise campaigns for people to collect the data that will help the scientists investigate issues regarding water conservation. Because such data will be used for scientific analysis, researchers pay careful attention to its scientific validity and accuracy. As a result, citizens are instructed on how to collect evidence and provide the means to do it in ways that have been established a priori by the project leaders. Additionally, the sustainability of the project depends on the capacity of the instigators to receive the required funds to run the initiative, and to keep large groups of citizens engaged using strategies ranging from gamification to a varied range of rewards.

In many classic citizen science projects [Nascimento, Pereira & Ghezzi, 2014], citizens are described as being enlisted in scientific endeavours, recruited or more typically as data collectors or observers providing experimental data, as data processors via their own resources such as computer and mobile Internet devices resources or mobile phones, amassing knowledge, or as sensors. What comes across is a limited role performed by citizens, falling into the lower levels of the typologies of citizens science. It corresponds to a contributory mode [Bonney et al, 2009] or a level 1 of crowdsourcing [Haklay, 2013], where data collection is the main task for citizens.

8 http://www.mostreamteam.org/

Eventually it can evolve to a level 2 of distributed intelligence, as in some Galaxy Zoo initiatives where citizens go through initial training, collect data and carry out simple interpretation activities. The roles of citizen participants are generally minimal because selection of focal topics, research questions, planning, structures and goals of the exercise, and overall decision-making processes are ultimately up to professional scientists or scientific institutions.

Institutional-led projects are more conservative in their understanding of citizen agency to define research questions, methods or processes through which the enquiries are done. In a more critical note, it can be argued that citizens are often seen as providers of free labour, skills, computing power, and even funding as scientists meet the growing demands from research funders for public engagement [Silvertown, 2009; Cohn, 2008]. Also citizen participation can be part of strategies to suppress anticipated public resistance [Petersen et al., 2007] or to embed and stabilize new scientific and technological interventions [Thorpe and Gregory, 2010].

Moreover, one of the obstacles faced by participatory and bottom-up approaches lies in an unconditional defense of "science" as a type of knowledge that separates itself from all others in search of facts. Many authors have criticized a public deficit model based on one-way transfer of scientific information, in favour of a two-way communication model towards more deliberative, participative, and dialogue-oriented forms of public involvement in science and technology decision-making [Devine-Wright, 2011; Gregory & Miller, 1996; Irwin & Wynne, 1996]. This "participatory turn" [Fischer, 2005; Leach, Scoones & Wynne, 2005], mostly in issues related to environment, health, food and land planning, strived for a more balanced scientific and technological governance. Such "technologies of humility" would mean an open environment for citizens to bring their knowledge and skills with the goal of solving common problems [Jasanoff, 2003].

The question remains whether these efforts have actually changed experts' willingness to accept inputs from lay or non-expert publics, and to change the status of different types of knowledge [Durant, 2008; Wynne, 2006]. The desired direction is to acknowledge that citizens' social knowledge is to play a crucial part in determining the directions and ends of any innovation process [Nascimento, 2012]. In urban participatory sensing, such type of knowledge is related to the specific circumstances and needs, and also the cultural values, personal experiences and practical judgements of local citizens and communities. Bottom-up interventions, which are citizen-led or initiated from the start, are now offering new opportunities to change such boundaries, under different assumptions and within unconventional spaces.

1.2 — Bottom-up interventions

Bottom-up interventions usually emerge when citizens share a concern or the purpose to engage in collective action.

In citizen-led environmental monitoring projects, citizens' motivation stems, for example, from their acknowledgement that environmental issues, such as increasing levels of pollution in industrialised cities have detrimental effects on their health and wellbeing. In many cases this is strengthened by the sense that data collected and shared by existing institutions and authorities cannot always be relied on or is not open and accessible. Citizens can, and should, play a leading role in conceiving, designing, building, maintaining our cities of the future, and this is heavily linked to a concept of smart citizen as core co-creator in bottom-up innovation that goes beyond a posteriori public consultations within simplistic impact assessement frameworks and similar flawed citizen engagement strategies [Hemment and Townsend, 2013].

For example, after the nuclear disaster at the Daiichi Power Plants in Fukushima (2011), Japan, a large group of citizens engaged with the Safecast project using custom built geiger counters to monitor radiation levels and sharing data via open online platforms. It has been argued that these citizens were concerned about the reliability of the radiation maps released by the government or considered that such measurements did not provide enough granularity [Kera et al., 2013]. Hundreds of citizens engaged with projects such as SafeCast or RadiationWatch that produced accessible DIY geiger counters with which they could collect their own measurements. These citizens produced vast amounts of open radiation data as well as knowledge regarding data gathering processes and hardware and software assemblage techniques. The movement has been referred to as "post apocalyptic DIY activism" [Kera el al., 2013] and "post-Fukushima DIY networks[9]".

Such citizen or community-led initiatives, taking place in a variety of makerspaces, are marking new active and critical interventions in the actual design and building of technologies. "Makers" are 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. In their thinking and practices, they are opposingthe passive andoften uncritical interventions of traditional ways of dealing with the macro and microscopic technical realms in which we all live [Nascimento & Pólvora, 2016].

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9 https://fukushimaforum.wordpress.com/workshops/sts-forum-on-the-2011- fukushima-east-japan-disaster/manuscripts/session-3-radiation-information-and- control/why-safecast-matters-a-case-study-in-collective-risk-assessment/

The combination of citizen science and Do-It-Yourself (DIY), hacker or maker practices had given rise to new forms of thinking and practice often referred to as DIY Science. DIY Science can includediverse tendencies, described as “amateur”, “garage”, “citizens”, “extreme citizen” and “activist” [Nascimento, Pereira & Ghezzi, 2014]. It’s an emerging movement that relies on projects that are initiated and developed by individuals or groups with no affiliation with the scientific establishment. Even in the cases that they have a scientific affiliation or background, their initiatives do not align with conventional or prescribed institutional rules. In this sense, “DIY scientists” are non-specialists, hobbyists and amateurs but also an increasing number of professional scientists, doing science and technology outside conventional university or lab settings, and instead in makerspaces, innovation and community-based labs, or in their homes, garages or schools.

In most DIY and bottom-up interventions, reciprocal social learning is present, and citizens and communities have responsibility on the questions asked, the framing of the research and the outcomes to be delivered. Their forms of enquiry recognise different ways of knowing and thus allow for out-of-the-box thinking and experimentation. They challenge established science and technology in their monopoly of accredited status for the provision of valid knowledge. DIY and bottom-up trends are pushing further “collaborative” and “co-creation” modes [Bonney et al, 2009], or level 3 “participatory science” and level 4 “extreme citizen science” [Haklay, 2013], where the level of collaboration between citizens and experts is raising towards co-design of problem definition, data collection, analysis, publication and dissemination. One crucial difference, however, is that such modes or levels are still most of the time bounded by scientific enterprises or methods, instead of concrete issues chosen by citizens.

Although bottom-up projects have the potential to empower citizens to take ownership over issues that affect them and collaborate towards solutions, to be successful and sustain over time they need to overcome several challenges:

> **Low-cost sensing technologies don’t always provide accurate data, citizens lack the technical skills required to set-up, calibrate and maintain sensors,** data collection efforts need to have a **clear purpose that is shared among community members, and there needs to be a trajectory from awareness to collective action and change**

(it’s not enough with proving that there’s air pollution, remedial actions should be proposed) [Balestrini et al., 2015].

Regarding the provision of accurate data, a tension between citizens’ expectations over the data and the reliability of data coming from low-cost or DIY sensing devices is often present. The loss of data quality is a highly debated issue in citizen science. But several studies have attested to the accuracy of citizen-science models in providing reliable data in different fields, such as geographical information [Haklay, 2010], bird habitat [Nagy et al, 2012], air pollution

[Tregidgo et al, 2013] or ecosystems [Gollan et al, 2012]. Quality in citizen science is more related to the actual design of the projects in terms of adequate data validation protocols or mechanisms [Bonter & Cooper, 2012]. Successful initiatives combine multiple methods to ensure data quality (Wiggins et al, 2011], while operating in different organizational settings and approaches to quality assurance [Haklay, forthcoming].

Disputes over the precision of data in bottom-up projects are shifting to other aspects also considered as important, such as improving civic commitments or opening up new forms of engagement for citizens. For example, the central aim of the project "Citizen Sense[10]" run by Jennifer Gabrys in Goldsmiths College, is to facilitate expanded citizen engagement in environmental issues. In its case studies of pollution and urban sensing, the implementation and use of sensor technologies by citizens are investigated in their impacts on new modes of environmental awareness and practice.

Nonetheless, the technical precision and calibration of data collection is still considered as a crucial element by citizens themselves to legitimize their potential claims when interacting with local authorities, business and other actors. A balance is to be struck between one hand acceptable levels of precision and calibration performed by citizens, and on the other hand an expanded practice of engagement which starts and ends with the needs and strategies defined by citizens.

Citizens' needs and strategies, at the core of bottom-up approaches in urban participatory sensing, are met with concern from experts and policy makers when they are seen as conflicts of interest between involved parties. For example, a recent editorial in Nature explicitly raised the concern over citizen scientists volunteers advancing their political objectives, as when opponents of fracking track possible pollution to gather evidence of harmful effects (Nature 2015). A debate within the citizen science community followed in social media, mailing-lists and blogs. The most relevant argument for this report is the lack of acknowledgement of motivations, value judgments and social norms coming from citizens and communities. More discussions are needed to transform rigid understandings of what constitutes relevant knowledge for science and policy.

For bottom-up interventions, the purposes and values shared among community members, together with an intention to collective action, are indeed key elements. 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. For instance, in previous alternative science and technology movements, "counterpublics" emerged as networks of individuals and organisations promoting alternative ways of conducting science and technology, more oriented to the public good, small and locally controlled [Hess, 2011]. In more recent times, crowdfunding campaigns in Kickstarter and Indiegogo are sponsoring new alternative forms of funding,but also very importantly, changing the terms of legitimacy and accountability for projects previously dismissed as unviable or trivial. The decision

10 http://www.citizensense.net/

on the existence of certain projects is partly shifted from traditional institutions to larger communities of interested or committed citizens.

Encouraging signs to address such challenges are on the rise. A new **approach for authorities** to become involved in these initiatives and collaborate with citizens to explore how such partnerships may enable new forms of civic participation in "smart cities". In Amsterdam, for example, Waag Society coordinated a participatory sensing project in which citizens were invited to take part in a "social experiment" to monitor the environment and possibly reveal environmental threats[11]. The project was supported by government institutions such as Amsterdam Smart City and Amsterdam Economic Board. Experts working at environmental agencies participated in workshops with the engaged citizens to explain how the "official" monitoring is conducted and envision ways in which citizen-generated data could be combined with "official" data sets.

There is a renewed interest in data-driven approaches for policy making. Discussions between data scientists, practitioners, policy makers and civil society representatives on new and emerging methods for data analytics, alternative data sources and visualisation, are on the rise. Within a context of increasing complexity, confusion and instability, the policy cycle is constantly being disrupted. Policy makers are pressed at the same time to respond more quickly to these disruptions and to make use of more data. In turn, the use of data in itself is also changing the policy cycle by providing more data and on real time.

When it comes to monitoring our environment, an on-going paradigm shift is happening from the pure use of official sensor networks, to low-cost sensing and data collection by citizens. More and more cases emerge in which the gathered data is used to complement traditional sources or to help optimizing existing official measurements. Still a lot if needed to transform the more traditional data-driven approaches to accept or acknowledge data coming from citizens, communities or civil society. In the end, giving a privileged role to citizens is a fundamental part of a vast debate on the relationship between science, technology and democracy, and how empowering citizens, their options and values, means the democratisation of scientific and technological design and practice [Winner, 1986; Sclove, 1995].

Taking the best practice case of Amsterdam, new governance models are to be put in place, where citizens, NGOs, the private sector, and public administration on all levels are working together towards common goals. Inclusive stakeholder networks are to be encouraged and supported, joining together citizens, environmental agencies, mapping agencies, statistical offices, NGOs, museums, libraries, research centers, academia, and media.

11 https://waag.org/en/project/smart-citizen-kit

2

STATE OF THE ART

2.1 — Research and citizen science technologies

A seminal community sensing initiative was the Air Project[12], instigated by artist and researcher Beatriz Da Costa and a group of New York based colleagues in 2006.

In this experimental project participants were invited to use a device that could measure carbon monoxide (CO), nitrogen oxides (NOx) or ozone (O3) levels in the users' immediate surrounding. In the system's display participants could simultaneously view measurements from their device and from the other devices in the network. These data could also be accessed in real time from a web platform, and was used to produce artistic visualisation works. The project was aimed to create a tool for citizens to monitor pollution and a platform for discussion around energy politics [Da Costa et al., 2006]. During the deployment participants were asked to use the device for no longer than 24 hours before passing it to a different user.

Also in 2006, Da Costa presented "PigeonBlog[13]", an intervention that investigated how animals could help humans in raising awareness to social injustice and environmental action. PigeonBlog was a collaborative endeavor between homing pigeons, artists, engineers and pigeon fanciers engaged in a grassroots data gathering process aimed at collecting and sharing information about air quality.

12 http://www.pm-air.net/

13 http://nideffer.net/shaniweb/pigeonblog.php

Pigeons were equipped with custombuilt air pollution sensing devices enabled to send the collected localized data to a server without delay. Pollution levels were visualised and plotted in real-time over Google's mapping environment

Figure 1. The Air Project in 2006 (left, photo credit: http://www.pm-air.net/). The PigeonBlog project (right, http://nideffer.net/).

Well documented research initiatives in urban participatory sensing are the N-SMARTS[14] and CommonSense Projects[15]. With CommonSense, Aoki and Willet et al. explored outdoor sensors in different contexts such as mounted on street sweepers or carried by users. The street sweeper deployment aimed at augmenting a city's existing sensor network with vehicle-mounted sensors [Aoki et al., 2009]. Overall, these studies highlighted that **although mobility provides some advantages more research and technical development are required to overcome challenges around the quality and reliability of sensor data, calibration accuracy and social acceptance of mobile sensing**. They also identified issues around privacy, authenticity of the data and security [Honicky et al., 2008].

14 http://www.eecs.berkeley.edu/Research/Projects/2008/105386.html

15 http://www.urban-atmospheres.net/CitizenScience/

Figure 2. Common Sense project (left) and NoiseTube app (right).

Similar conclusions were achieved by researchers working on PEIR[16] and NoiseTube[17] projects. The first one used location data sampled from mobile phones to estimate how the actions of users affected both their exposure and their contribution to problems such as carbon emissions [Mun et al., 2009]. NoiseTube used a mobile application and an online community memory to map noise pollution. In a two-week deployment with a small group of users researchers **identified usability issues (phones are usually in pockets or purses and therefore contribute biased measures); the need to coordinate large campaigns to promote mapping in areas that are not frequently visited by users; and the importance of data quality to foster users' trust** [Stevens & D'Hondt, 2010].

Figure 3. The Citisense mobile app (left) and a view of the inside of the CitiSense sensor (right). Photo credit: http://www.calit2.net/.

16 http://www.viewingspace.com/peir.html

17 http://noisetube.net/#&panel1-1

Building on the findings around CommonSense, researchers at University of California San Diego developed Citisense[18]. The system comprises a wearable sensor board, an Android smartphone, and a backend cyber-infrastructure that stores and analyses the collected data. The CitiSense sensors can detect ozone, nitrogen dioxide and carbon monoxide, the most common pollutants emitted by cars.

The system intends to support data sensemaking by displaying the pollution data in a user friendly way. A green cloud will appear on the screen of the device if pollutants in the air are within acceptable levels (using the government's air-quality-index AQI[19]), but as levels go up the colour of the cloud will change towards purple. The researchers concluded that **both real-time displays and permanent monitoring were key to supporting processes of data sensemaking** [Bales et al., 2012]. Nevertheless, researchers also found that **there were technical issues involved with producing reliable data using mobile low cost sensors. Additionally, data exchanges between smartphones and sensors are very power hungry, causing phones to quickly run out of battery, an issue that can lead to user disengagement.**

More recently, other crowdsensing research projects such as Citizen Sensor (CS) [CitizenSensor, 2014] or Air Casting (AC) [AirCasting, 2014] have developed Internet of Thing (IoT) devices for citizens to assembly and program following instructions manuals provided by the developers.

2.2 – DIY and Crowdfunded technologies

> More recently we have observed the emergence of a new approach to the design and development of environmental monitoring technologies and interventions.

Researchers, entrepreneurs and independent makers are increasingly developing and funding

18 http://ucsdnews.ucsd.edu/pressrelease/small_portable_sensors_allow_users_to_monitor_expos ure_to_pollution_on_thei

19 airnow.gov/index.cfm?action=aqibasics.aqi

IoT technologies via crowdfunding platforms such as Kickstarter[20], Indiegogo[21] and Goteo[22] (the latter focusing on open source projects). This often means that even before technologies are developed, a community of users becomes involved with the project.

In the past five years, the broad availability of open hardware tools such as Arduino[23], the creation of online data sharing platforms like Pachube (now Xively.com[24]) or search engines such as ThingFul[25], and access to maker spaces and or Fab Labs have fostered the design of low cost and open source sensors for citizen-centred sensing. These technologies are intended to augment the granularity of the monitoring network with distributed low-cost sensors [Ganti et al., 2011] rather than replacing official monitoring stations. Moreover, they intend to foster the participation of citizens in the collection of data about urban issues, support public awareness with regards to environmental issues and possibly trigger collective action. Notable examples are Smart Citizen[26], Air Quality Egg[27] or Safecast[28].

Air Quality Egg

Air Quality Egg was developed in 2011 by a group of designers, developers, architects and other from the Internet of Things Meetups in NYC and Amsterdam. It comprises an outdoor sensor for nitrogen dioxide (NO2) and carbon monoxide (CO) that sends data to an egg-shaped station, which relays it to an online platform.

Figure 4. Air Quality Egg and data sharing platform. Photo credit: http://airqualityegg.com/

20 https://www.kickstarter.com/
21 https://www.indiegogo.com/
22 http://goteo.org/
23 http://www.arduino.cc/
24 https://xively.com/
25 https://thingful.net/
26 https://smartcitizen.me/
27 http://airqualityegg.com/
28 http://blog.safecast.org/

Although the project won widespread recognition and was was named "Best of Kickstarter 2012", AQE has faced problems the hindered community participation: there were delays in the delivery of the kits to the backers (in some cases more than a year), the sensors have been criticised for being defective and unreliable, and there have been constant changes in the platform's design and development. Users' complaints can be read on the project's Kickstarter page[29] and the initiative seems to have lost traction.

Safecast

SafeCast[30] developed an affordable Geiger counter to measure radiation levels after the Daiichi nuclear disaster in 2011 [Kera et al., 2013]. The initiative was led by a network of stakeholders including Joichi Ito (Director of the MIT Media Lab) and the Tokyo Hackerspace and was crowdfunded by 290 backers in 2011. By July 2014 it had reached over 20 million data entries, **although the 10 most active volunteers have contributed almost 3/4 of the data.**

Figure 5. The SafeCast sensors. Photo credit: http://blog.safecast.org/

Radiation-watch

In Radiation-watch.org[31], launched as a non-profit project a few months after the disaster, the stakeholders developed open source, affordable tools including the POKEGA radiation detector - that connects to smartphones, and a bespoke device for remote sensing. The

29 https://www.kickstarter.com/projects/edborden/air-quality-egg/comments

30 http://blog.safecast.org/

31 http://www.radiation-watch.org/

backers who helped fund the project also played a role in improving its design by suggesting recommendations via the project's Facebook page [Ishigaki et al., 2013]. There are currently around 12000 POKEGA users, who have uploaded more than one million data points.

Figure 6. The Pokega device by Radiation Watch. Photo credit: http://www.radiation-watch.org/

Smart Citizen

Smart Citizen is an open source participatory sensing platform that comprises a sensor kit (SCK), an online platform and a mobile application. The project was launched in 2012, instigated by the Fab Lab Barcelona, the Institute for Advanced Architecture of Catalonia (IAAC) and Hangar art production centre.

The SCK consists of an Arduino-based electronic board and shield, a battery, a Wi-Fi antenna, a MicroSD card, and a set of sensors to monitor humidity, temperature, nitrogen dioxide (NO2), carbon monoxide (CO), sound, solar radiation, Wi-Fi hotspots, and battery charge level. The kit has been developed using open source technologies to allow advanced users to add features and capabilities to meet their own purposes.

The kit can be deployed indoors or outdoors and the main board can record offline data on a MicroSD card. A key feature in the project is its online platform[32] that allows users to upload data from their SCKs, share them through social networks and make them available to everyone online for free [Diez & Posada, 2013].

32 Smartcitizen.me

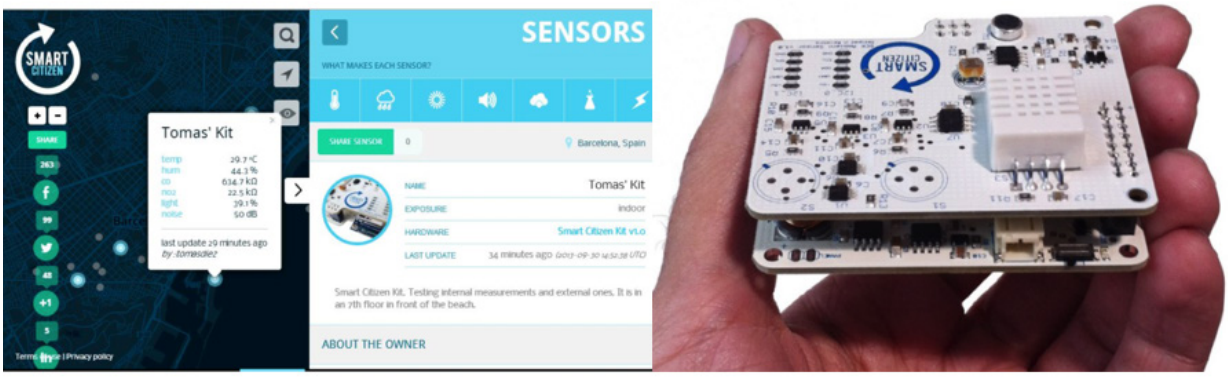

Figure 7. Smart Citizen Kit and data sharing platform. Photo credit: smartcitizen.me

The Array of things in Chicago

The Array of Things (AoT)[33] is a novel urban sensing pilot project aimed to "instrument the city" by deploying an open, flexible and modular network of sensors that will allow citizens to "speak with the city". The AoT is a semi-public network of urban sensors implemented by local institutions, private companies and universities in Chicago. The first phase of the project involved the deployment of 10-12 nodes funded by Argonne National Laboratory, installed on urban (University of Chicago, School of the Art Institute of Chicago) and suburban (Argonne National Laboratory) campuses to test the system's reliability and resilience.

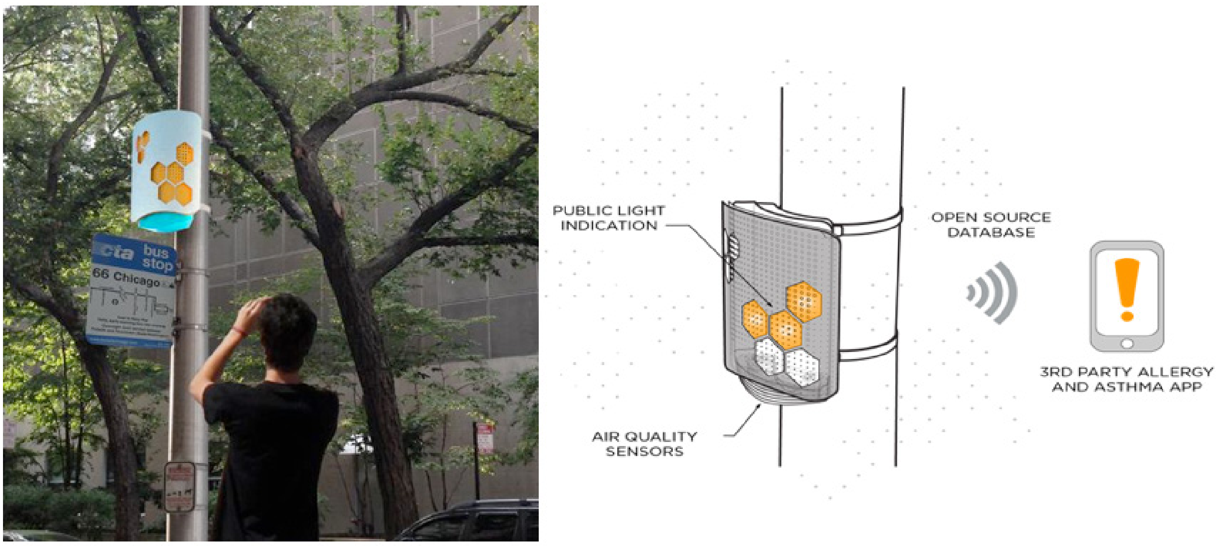

Figure 8. The array of Things in Chicago. Photo credit: https://arrayofthings.github.io/

33 https://arrayofthings.github.io/

The AoT team is in discussions with potential funding sources to deploy at least 500 additional nodes over 2015-2017, with locations driven by input from residents, scientists, and policymakers. The Array of Things project is led by Charlie Catlett and researchers from the Urban Center for Computation and Data of the Computation Institute, a joint initiative of Argonne National Laboratory and the University of Chicago.

The custom enclosure for the sensor nodes was designed at the School of the Art Institute of Chicago. The project is executed in partnership with the City of Chicago. This open and modular sensing infrastructure intends to collect and publish a wide range of urban data that could be harnessed both by public and private stakeholders to deliver novel urban services.

Other DIY technologies for bottom up approaches include (see annex):

- **AirCasting and AirBeam**, recording, mapping and sharing air quality data [http://aircasting.org/]
- **SmartNose Dust,** particulate matter [http://www.smartnosedust.com/]
- **DustDuino**, particulate matter sensor [http://publiclab.org/wiki/dustduino]
- **Shinyei**, particle matter sensor [http://aqicn.org/sensor/shinyei/]

Much of the research that has reported on urban participatory sensing projects has focused on sensor quality improvements, use-cases trials, data analytics, storage, and visualisation [Aberer et al. 2010]. Moreover, some studies have raised concerns about the reliability of the data that DIY and low-cost these sensors produce, and signposted the need to adopt verification methods and support sensemaking [Snyder et al., 2013].

More recently, artists[34] and designers have created and deployed novel sensing technologies with the aim to inspire new visions for smart cities, moving on from surveillance to engagement. Rather than hiding sensors in grey boxes a new approach is for sensing infrastructures to become visible and playful.

The Vienna Summer Scouts[35], for example, are seven sensors designed to smarten up the city by capturing and displaying data in a way that explains community sentiment and social phenomena. The sensors are designed to attract attention and communicate what it is they measure.

34 http://xdesign.ucsd.edu/feralrobots/

35 http://www.psfk.com/2015/06/whimsically-designed-big-data-sensors-vienna.html

A “pool scout” has been placed in the community swimming pool to report if sunscreen levels have reached the pre-determined “summer threshold”, while the “movement scout” sits at an ice-cream parlor to measure if scooping movements are up to summer-time levels.

Figure 9: Vienna Summer Scouts. The “movement scout” tracks ice-cream scoops (left). The “pool scout” measures quantities of sunscreen (right).

3

SUMMARISING PREVIOUS EXPERIENCES

This section summarises previous experiences within urban participatory sensing and community driven environmental monitoring, in Making Sense pilot development contexts (Barcelona, Amsterdam and Prishtina), and other cities with relevant examples in this field (Manchester, Madrid, Fukushima and Beijing).

Together with a brief report of the activities in these contexts, special attention is given to their best practices, but also to some of their problems, and to their future internal development plans at both technical and social levels.

In many cases, these interventions extend the limits of geographically-bounded communities and demonstrate the potential of emergent distributed communities who contribute data on common issues within a shared technology platform. For example, Smart Citizen Kits developed in Barcelona are widely used in other cities such as Prishtina, Amsterdam or Manchester.

The activities conducted in different cities tend to inform each other as community champions share knowledge on best practice. Moreover, these linked pilot initiatives have added to a shared database of distributed environmental data.

3.1 Making Sense Pilot Contexts

3.1.1 Barcelona, Spain

Barcelona emerges as the context where the Smart Citizen platform was originally developed in 2012, at Fab Lab Barcelona and IAAC in collaboration with Hangar, and included as part of other local smart city projects, such as iCity[36] or larger public and private led initiatives, as those aimed at launching Barcelona as a Fab City[37].

No other significant crowdsensing project has managed to materialize in the Barcelona context until now, and Smart Citizen has since been regarded as a benchmark case study in citizen environmental monitoring with extended scientific and media attention.

Initial external funding for Smart Citizen came in September of its starting year with a crowdfunding campaign via the Spanish platform Goteo (€13.748 was the final value of this campaign, with 125 participants contributing enough to receive a SCK, among which 98 males, 13 females and 14 anonymous or organizations). In 2013 a new crowdfunding campaign was established in Kickstarter, aiming towards further developments of the SCK and platforms ($68.000 was the value achieved with 517 backers).

At this time, the project largely surpassed its original Barcelona context by promoting a general collective construction of smarter cities by their own inhabitants. It also benefited from media attention by key technology media organisations such as Wired, Techcrunch or Makezine, which was later extended to general outlets as The Guardian or BBC.

Smart Citizen has been successfully deployed from the city of Barcelona since 2013, with good practices registered on documentation and community support, as well as on the incentives given by the project instigators towards its adoption in multiple other cities and non-urban contexts for community-driven monitoring, such as in the Open Source Beehives initiative[38].

36 http://icityproject.eu/
37 http://fab.city/
38 http://docs.opensourcebeehives.net/docs/alpha-sensor-kit

Moreover, this is a project characterized by their intensive effort on open source and open data frameworks, with widespread public availability of both software and hardware documentation in multiple platforms. But apart from project led networking and public showcase events, there is current lack of evidence regarding the social establishment of stable communities of practice or interest linked to crowdsensing activities in the city of Barcelona itself. The activities developed in this context seem to be profoundly characterized by their technical focus up to this date.

Excluding engagement peaks connected to specific project events or new technical developments, less than 20% of the Barcelona based sensors are currently online. 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, or yet on the lack of community targeted status updates[39].

Even if the original backers of 2012 are regarded as an early cohort, being the first wave of citizens to be in contact with Smart Citizen for urban participatory sensing and self-assembling into the first Smart Citizen community, 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.

According to internal assessment based on quantitative and qualitative data, often 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., 2015].

The Barcelona experience with Smart Citizen seems to expose therefore that although a project may have all the best technical features and support, and even be successful on crowdfunding campaigns this does not ensure active citizen participation in data collection or sustained community development [Balestrini et al., 2015]..

Recent studies on crowdfunding have shed light on the reasons why people crowdfund projects. For example, a big source of motivation to support a project can simply be sympathy with those who instigate the initiative [Belleflammea et al., 2014; Kuppuswamy & Bayus, 2015]. The desire to "do good" can also act as a strong source of motivation. Furthermore, those who have crowdfunded tools for environmental monitor have also shared the expectation to be part of active communities that gather frequently and contribute towards common goals. Having the opportunity to participate in the design and technical development of the projects can fuel the engagement of the more tech savvy contributors.

39 https://forum.smartcitizen.me/

Future steps

Current partners of Smart Citizen include Ajuntament de Barcelona and Barcelona Cultura, but also Amsterdam Smart City and Waag Society, Future Everything, Cisco, Intel, Array Of Things or Organicity. It is within this enlarged context that specific changes are now being planned on both technical and social dimensions. These are grounded on structured assessments of not only the early cohort experiences in Barcelona, but also previous deployments of Smart Citizen Kits in Manchester and Amsterdam, conducted respectively by Future Everything and Waag Society.

Considering the technical dimension, a renewed Smart Citizen Kit is expected for the Summer of 2016, with the air quality sensors being replaced with others capable of providing higher accuracy levels, the design of new enclosure models and their online availability for 3D printing at local maker spaces, and also the redesign of the online interface to support data comparison and sensemaking from external sources.

On the social dimension, Fab Lab Barcelona will collaborate with the recent Fab Labs city project "Xarxa de Ateneus de Fabricació", which is expected to build a distributed network of makerspaces in different neighbourhood of Barcelona. The project's vision is to facilitate access to digital fabrication technologies and the skills for citizens to harness their potential and bootstrap social innovation at the grassroots level. This is expected to harness more sustained community engagement and building practices for the Smart Citizen project while also enlarging its civic campaigning spectrum.

3.1.2 Amsterdam, Netherlands

The largest and most significant urban community sensing initiative held in this city was organised between February and July 2014 by Waag Society with Amsterdam Smart City[40], Amsterdam Economic Board and Smart Citizen. Its development has since been framed as a flagship endeavour of Waag's "Amsterdam Smart Citizen Lab".

The initiative itself was preceded by debates and workshops conducted by Waag in in 2013 about alternative means and models to enhance environmental monitoring in the city of Amsterdam, considering the limits and costs of the existent official air quality measurement

40 http://www.boomingcities.be/media/docs/2013/01_Vermast.pdf

stations at the time. Its coordinators ended up focusing on a mix of citizen science with open source and low cost sensor kits as a way to simultaneously expand the city monitoring areas and data production capabilities, create collective awareness towards change around urban environmental issues such as air pollution, and help citizens grow their own technical skills. But as additional outcome they also pointed at the added value of a participatory action research framework capable of boosting a community driven creation of better public policies through continuous dialogues and strong partnerships between citizens, experts and policy makers.

During 2014 participants worked with Smart Citizen Kits in a series of hands on workshops and practical field work deployments. The project instigators purchased 100 kits and published a call in a local newspaper to broaden the possible participation spectrum. 100 applicants were then selected based on their home address or other location where they chose to place the sensor. Only 73 users received SCKs of (30% female and 70% male) and nearly over 50 continuously uploaded data. At the end of this initiative all participants were offered the possibility of returning their kit to Waag Society, or acquire it instead for a third of the price (150 euro) and keep up with their own monitoring through the Smart Citizen platform[41].

To enable active citizen participation in the project other key activities also took place during this period to help overcome technical hitches and encourage engagement in fields that have typically hindered other urban participatory sensing initiatives. Examples of such activities entail: adapting the existent technology or adding new components for it to become more robust and suitable to the monitoring contexts; enabling community assistance schemes by matching tech-savvy participants with others who lack technical skills; using already existing events or creating new ones such as meetups and install parties to engage new users and help them acquire the needed technological skills for this sensing initiative; and creating user documentation in the local language to avoid possible linguistic gaps that could jeopardize results.

Future steps

Waag Society and their partners agreed on pursuing and extending their citizen science framework with follow up projects and through what was referred to as"Smart Citizen Approach" [Herriquez et al, 2016][42]. This is based on a sequential plan of "*Meet, Match, Map, Make, Measure, Master and Mobilize*" along with a seven step research methodology:

1) What do you want to measure?

2) What are you trying to learn from measuring it?

41 http://waag.org/en/project/smart-citizen-kit

42 https://waag.org/sites/waag/files/public/media/publicaties/amsterdam-smart-citizen-lab-publicatie.pdf

3) How much data must be gathered to generate valuable conclusions?

4) What type of analysis will be done?

5) What kind of data is needed to complete the analysis?

6) How much money, time and resources are available?

7) When will you consider your efforts a success?

This approach has led to the creation of "Amsterdam Smart Citizens Lab[43]" (ASCL) by Waag Society and a consortium of partners including the CTO Office of Amsterdam, Amsterdam Institute of Advanced Metropolitan Solutions (AMS), Rijksinstituut voor Volksgezondheid en Milieu (RIVM), HvA, Wageningen University and Amsterdam Sensemakers, which decided to continue with the citizen-led exploration of bottom-up participatory sensing aimed at empowering lay people and their communities.

In the context of ASCL, Waag will concentrate most of the community driven environmental monitoring activities planned for the city of Amsterdam in the near future. By keeping on with best practices of integrating bottom-up data with data from official networks, they expect to address not only data accuracy issues and build trust on civic science projects, but also showcase the potential of open source and DIY/DIT technologies for the advance of public policies. Moreover they also expect to continue on exemplifying how crowdsourcing and sharing environmental data can help citizens themselves to understand the workings of their city and enhance the quality of their lives.

ASCL seems to be heavily linked to the ambition of developing sensors and sensing strategies from the ground up, by working with citizen participants without any special hardware or software experiences. Several initiatives were already conducted in this context between May and October 2015, and while drawing from iterations to the first pilot period, new participatory sensing teams were established on the topics of Air Quality and Noise pollution for instance.

Together with the work of more technically oriented groups, as the Sense Makers, a meetup community in the intersection of sensors and sensor networks with Internet of Things (IoT) and Free Libre Open Source Software and Hardware (FLOSSH), the contributions of these new teams are now base for future experiments within the ASCL paradigm, so that it will become more pervasive and relevant in the transformation of Amsterdam's urban context[44].

43 https://waag.org/en/project/smart-citizens-lab

44 https://waag.org/sites/waag/files/public/media/publicaties/amsterdam-smart-citizen-lab-publicatie.pdf

Amongst the activities organised withinthe ASCL we find some that are also meaningful as best practices for its future plans in the field of community driven environmental monitoring:

1) Online community building, with open membership and an interactive platform to announce events and exchange experiences between internal and external participants;

2) Stakeholder mix and match events, by joining communities of interest and practice towards practical and conceptual debates;

3) Technology development, via the establishment of new community assistance means and testing with new hardware and software tools, such as the 'Urban Knowledge Collider' [Bozzon et al. 2016];

4) Public outreach, with FabLab and WetLab open days, together with the creation of other intertwined public engagement events that could strengthen common identities in the project.

3.1.3 Prishtina, Kosovo

The Prishtina context is characterised by the citizen science activities of Science for Change Kosovo[45].

This project was publicly launched in June 2014 under the motto "Get data, drive change" and is a joint initiative of local NGO Peer Educators Network (PEN) with Unicef Innovations Lab Kosovo, Czech Ministry of Foreign Affairs and Czech NGO Transitions (TOL), plus UK practitioners InternetArtizans.

On top of being currently based in Prishtina, this is a movement that equally supports participation from other Kosovo contexts dealing with environmental challenges and the need for alternative ways of producing and using data, including individuals and groups from Plementina, Drenas, Mitrovica, or Hani Elezit[46]. Extra efforts were made throughout all phases of the project to involve specific social groups, such as the Roma community living in the area

45 https://www.facebook.com/CitSciKS

46 http://www.internetartizans.co.uk/kosovo_science_for_change_launch

of Kosovo's lignite power plants outside Prishtina, or younger strata of the general population, here engaged for example by linking up existing environmental, civic or political motivations with individual or collective curiosity and interests in digital and mobile technologies[47].

The Science for Change community-driven environmental monitoring practices were established from the beginning as a means of promoting civic data collection and use for advocacy purposes, and of inciting wider reflections on the values of established scientific or technological inquiries. Their events have been marked by this approach, through the engagement of citizens to acquire not only new skills in non-traditional science and technology practices, but also to get an understanding on what it means to decide their own scientific and technological focus, and use the acquired data to support their claims at institutional levels.

Their goals are specially attached to civic science and advocacy processes alongside what they can bring in terms of societal changes, not outputs that assume particular agency properties in the data per se. Moreover, monitoring activities conducted by Science for Change adopt and recognize the significance of extended peer review frameworks, translating them for instance in the development of key operational plans through participatory consultation, as the reframing or adaptation of particular topics, or more specifically, the choice of data collection points by the communities.

The primary focus of Science for Change sensing activities has been on air quality through measurements of nitrogen dioxide (NO2) and sulphur dioxide (SO2), even if water and soil pollution or waste management fields were also envisioned as possible monitoring targets. Main tools used in this context have been Smart Citizen Kits along with non digital methods such as diffusion tubes and ghost wipes, as method to calibrate live digital readings using laboratory results. Additionally, project instigators have put a strong emphasis in the creation of logging and mapping outputs, as well as in open dissemination of data and project outcomes via community events or social media. Technical support was mainly provided by volunteer participants coming from FLOSSK (Free Libre Open Source Software Kosova) and Prishtina Hackerspace.

Apart from political and social hitches largely tied to national or local circumstances, problems in Science for Change community sensing were mainly reported on technical levels. Complications were registered for instance on the use of some data obtained through the Smart Citizen Kits, due to mismatches between sensor datasheets and non digital complementary readings. And this kind of issues may have had impact not only on quantitative levels, but also on the effectiveness of open data dissemination strategies tied to live campaigning via social media. Nonetheless, the project was able to demonstrate for instance that levels of NO2 at hotspots in Prishtina exceeded EU limits by large margins, through the combined use of Smart Citizen Kits data and participatory assessment methods employed in field work by volunteer participants. And data generated from Drenas made it

47 http://www.mobilisationlab.org/kosovo-youth-set-agenda-and-gather-data-for-change/

not only into a Parliamentary Commission, but also into a court case against the heavy metal plant “Ferronikeli” by the Ministry of Environment of Kosovo[48].

Future steps

Science for Change Kosovo is currently planning several expansions on their sensing activities, particularly concerning heavy metal contaminations from elements such as lead, but also from PM2.5 and PM10 dust particles categorized as particulates, a form of pollution undeniably linked to multiple health and environmental hazards.

They have acquired a TSI SidePak[49] compact and portable environmental monitor that will allow them to expand their current real time sensing spectrum, regarding both the new air pollution elements that they are able to detect and measure, and the amount of contexts where they can grow into given the added mobility of this tool. The design of new civic actions is already in motion by having in mind several possibilities offered by this portable monitor, as for instance the mapping and creation of new walking and cycling routes able to reduce human exposure to specific air pollution elements.

In addition, the Science for Change movement will also continue their activities with Smart Citizen Kits and other low cost sensors, namely via junior citizen science hands on workshops in schools and other educational spaces. This will allow them to keep exploring citizen science in different contexts, while also continuing to experiment with open technologies and data for environmental participatory action research via one of their key community engagement strategies, targeting and mobilising Kosovo’s younger populations[50].

48 http://danmcquillan.doc.gold.ac.uk/scienceforchangekosovo-year1.html

49 http://www.tsi.com/sidepak-personal-aerosol-monitor-am510/

50 http://danmcquillan.doc.gold.ac.uk/scienceforchangekosovo-year1.html

3.2 Other Contexts

3.2.1 Manchester, United Kingdom

The Manchester participatory sensing pilot was led by Future Everything (FE), a Community Interest enterprise, and supported by Intel[51].

It was launched in March 2014 to investigate how citizens could use Smart Citizen Kits to acquire, analyze, store, and use data collected using low cost and open source environmental sensors.

To enable participation in the pilot, an open call was launched through the FutureEverything Festival and Fab Lab Barcelona websites to identify potential users. The selection criteria were based on the level of technical skills and the topics of interests stated by the applicants.

The stakeholders agreed to deploy 15 sensors only in an initial phase with selected participants who were asked to keep the sensors online for a 6 month period. Three workshops were organised for users to learn how to setup and maintain the sensors and discuss data sensemaking processes and activities. This initial pilot demonstrated the difficulties associated with sustained community engagement with environmental monitoring. Because there was no shared cause that united all participants beyond their desire to use novel technologies to collect and share data, users struggled to keep their sensors active and providing readings.

In 2015 the initiative has focused on schools. The new project "Smart Schools"[52] conducted by Future Everything, Smart Citizen and RM Education aims to develop a programme of workshops to introduce schoolchildren to concepts around sensors, data and computational thinking. Five local schools from around Salford are involved in the project, with 30 students aged 8 to 15.

51 http://futureeverything.org/projects/smart-citizen/

52 http://futureeverything.org/news/smartschools-workshop-ten-centre/

3.2.2 Madrid, Spain

With the aim to understand how data could empower communities and catalyse social change, the data-citizen driven city project[53] (DCD City) was developed in Madrid in 2011 by a multidisciplinary team consisting of IT experts, designers, an artist and an architect.

The project was hosted at the Medialab-Prado (MP) and focused on building a network for citizens to collect air quality data.

The project leaders organised weekly gatherings known as "Friday Open Lab in MP" to deliver workshops for the community to become familiar with open technologies, air quality sensors, data storage platforms and devices. The results from the workshops were shared periodically and made public on the Medialab-Prado's wiki. In 2012 the project joined the community developing the Air Quality Egg, which led to the installation of several AQEs around Madrid. DCD City also created the Device library[54] to enable citizens to have access to knowledge and resources to assemble their own air quality sensing tools.

DCD City revealed the challenges associated with enabling the appropriation of open source sensing technologies in hands of users. Their approach focused on delivering workshops to foster learning as it was clear that citizens often lack the skills to assemble and operate sensing technologies. Moreover, once data has been collected further skills are required for users to make sense of them. The community who instigated DCD City has now funded the Maker Space Madrid[55], aimed at continuing their efforts to produce and enable shared knowledge with regards to open technologies for citizen empowerment.

53 http://thedatacitizendrivencity.com/

54 ttp://thedatacitizendrivencity.com/?page_id=26

55 http://makespacemadrid.org/

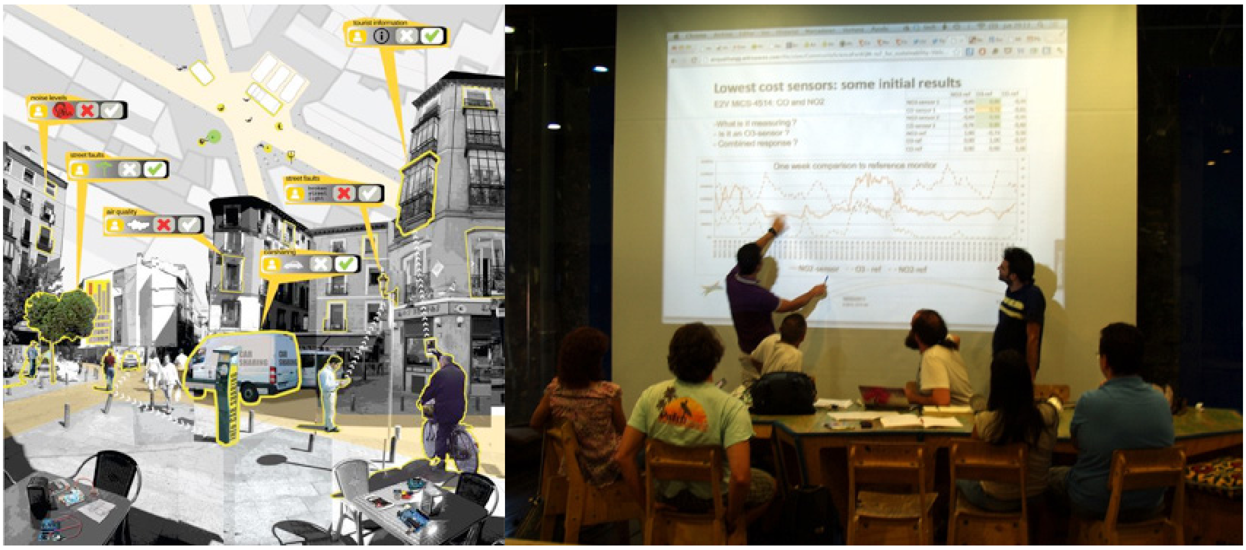

Figure 10. The DCD City project in Madrid. Photo credit: http://thedatacitizendrivencity.com/

3.2.3 Fukushima, Japan

Safecast is a volunteer organization focused on collecting environmental data through a sensor network and data submissions from the public.

Currently focused on radiation levels in Japan, Safecast[56] is committed to open data, open hardware and empowering people with information about their surroundings. Immediately after the nuclear accident, the project instigators (Sean Bonner, Joichi Ito, and Pieter Franken) created the initial Geiger counters with the Tokyo Hacker Space in the hope to give citizens the opportunity to monitor radiation levels by themselves instead of relying on local authorities. build). The project was crowdfunded and has been appropriated by bottom-up movements facing environmental concerns. Since then, Safecast has become one of the well-known post-Fukushima DIY networks by getting different groups of people involved such as engineers at Tokyo Hacker Space, journalists, and scholars, among others[57]. In collaboration with its network of stakeholders Safecast has developed Geiger counters as a technology to collect radiation measurement data effectively, such as a portable and low-cost device “the bGeigie Nano Kit.”

In Fukushima the project has deployed a Fixed Sensor Network including 100 radiation sensors inside and outside the exclusion zone to detect any significant variation in radiation level. While it started as an independent project aimed at responding to citizens’ need to have access to densely distributed and updated open data regarding radioactivity, which was not

56 http://blog.safecast.org/

57 http://opinionator.blogs.nytimes.com/2011/03/28/crowdsourcing-a-better-world/?_r=1

being provided by local authorities, Safecast is now collaborating with Japanese authorities in different cities to map radioactivity[58].

To enable and sustain participation within Fukushima and across different geographies, the Safecast team conducted a great number of public events ranging from workshops to hackathons, seminars, funding drive, etc. Moreover, Safecast has made efforts to take readings globally to help with education and understanding of just what these measurements mean to residents of affected areas, and those nearby. These events aimed to provide skills to citizens with no technical expertise for them to assemble and maintain their own sensors, as well as to enable data sensemaking and awareness processes[59].

3.2.4 Beijing, China

Air pollution is a burning issue across the most important cities in China.

There is an increasing number of mobile apps that provide data with regards to the official air quality readings. Nevertheless, students and entrepreneurs are starting to assemble their own low-costsensing technologies to collect their own air quality data. For example, Air. Air[60] is a portable air quality monitor that connects to a smartphone and has been crowdfunded via Kickstarter.

In Beijing, in 2012, a group of design students from Carnegie Mellon University and Harvard University developed FLOAT 'smart' kites[61] to map air pollution over the city and raise awareness. Such glow-in-the-dark kites can detect carbon monoxide and particulate matter. Pollution levels are then reflected by color changes in the LED lights. The project was crowdfunded via Kickstarter[62] and included the delivery of a number of workshops to teach people how to assemble and use their own smart kites.

58 http://blog.safecast.org/wp-content/uploads/2011/11/Learning-from-Fukushima_report.pdf
59 https://medium.com/safecast-report/part-1-the-safecast-project-update-march-2015-ae304903b275
60 https://www.kickstarter.com/projects/1886143677/airair-portable-air-quality-detector
61 http://f-l-o-a-t.com/
62 https://www.kickstarter.com/projects/replaymy/smart-air-kites-float-beijing

4

CHALLENGES AND OPPORTUNITIES

Although there have been a number of inspiring urban participatory sensing interventions across the globe, there are still no examples of large scale and sustainable citizen-centred networks.

Our research has indicated that interest in participatory sensing is still niche and it most commonly engages male technology enthusiasts. Nevertheless, the case studies described in this report show that this kind of initiatives have the potential to enable new forms of citizens engagement, foster awareness with regards to environmental and urban lifestyle issues, and facilitate social interactions that in turn can increase social connectedness and capital.

Moreover, the repeated success of environmental monitoring tools in crowdfunding campaigns, the community empowerment enabled in a post-apocalyptic Fukushima by initiatives like Safecast, and the experiences in cities such as Amsterdam and Barcelona provide evidence to suggest that citizens are increasingly driven to harness the potential of open and accessible technological tools to effect positive change. However, enabling such processes requires a lot more than just providing access to technology. Following, we identify the challenges and opportunities derived from the case studies analysed in this report.

4.1 Technology issues

Although low-cost environmental monitoring tools such as Air Quality Egg or Smart Citizen are designed to be easy to set up, users typically lack the skills to operate and maintain them.

If citizens are expected to get these technologies successfully running and reporting data then they need to have access to material, technical and methodological resources and assistance (e.g troubleshooting and documentation) that they can check online while setting up their devices at home or at their workplace.

While off-the-shelf sensors typically provide documentation for the technology setup and troubleshooting, these files tend to be written in a way that is often too hard to understand by non experts. Providing such advice in the form of online video tutorials might be more useful than creating technical reports. Another best practice comes from Arduino and Genuino Starter Kits, which offers not only a selection of electronic components but also a well-designed Project Book with step-by-step tutorials of a first batch of projects with a growing level of difficulty.

4.2 Calibration and accuracy

Despite current research and development efforts, many low-cost sensors for environmental monitoring still lack the robustness required to produce reliable data [Snyder et al., 2013][63].

In addition, users either receive uncalibrated sensors or struggle to keep them calibrated throughout time, which is crucial to obtaining reliable measures. If sensors are not well calibrated they can report random readings. Nevertheless, new assessment methods for data reliability and quality are being studied [Wiggins et al, 2011], as well as alternative organizational settings and approaches for quality assurance [Haklay, forthcoming].
Other aspects of participatory sensing are also increasingly considered as important, such as improving and opening up new forms of engagement for citizens. Nevertheless, certain levels of technical efficiency and reliability are still needed, and even expected from citizens and communities. Support for calibration can be provided both through an online platform and face to face technical meetups that, in turn, can foster social interactions and discussions

63 Snyder, E. G., Watkins, T. H., Solomon, P. A., Thoma, E. D., Williams, R. W., Hagler, G. S., ... & Preuss, P. W. (2013). The changing paradigm of air pollution monitoring. Environmental science & technology, 47(20), 11369-11377.

leading to collective awareness, as demonstrated both in the Safecast and Amsterdam case studies.

4.3 Ownership and trust

Having a sense of ownsership over a technology intervention has been associated to sustained community engagement [Hayes et al., 2011; Balestrini et al., 2014].

To have a sense of ownership, citizens should have opportunities to contribute to the technical and design appropriation of the tools that they intend to use. In this direction, citizens should be able to adapt tools so these become instrumental to tackling local needs and are perceived as useful.

For example, while cyclists might want to augment their bikes with air quality sensors and make better choices regarding the routes they ride on, families living in the city centre may prefer to monitor noise pollution. Technical appropriation requires that the users acquire certain skills that in turn strenghten their sense of autonomy: skilled citizens can use, alter and repair their own tools [Balestrini et al., 2014].

Furthermore, although public sensing infrastructures have tended to be designed and placed in ways that prevent citizens from noticing them (e.g. gray boxes on lampposts), a new approach (cf. Array of Things) is for urban sensing technologies to not be hidden but rather comprise enclosures that are visually attractive and even intriguing. Local artists and designers can participate in the design of such enclosures via open innovation initiatives, workshops and hackathons.

4.4 Social interactions

Citizen engagement with technology interventions can be emergent but is more likely to sustain and scale up if community championing is provided.

Such was the case in Amsterdam, where Waag Society instrumented a programme by collaborating with local institutions, community groups and government officials [Balestrini et al., 2014]. Furthermore, facilitating social interactions among community members, both face to face and distal, has been associated to the sustainability of citizen interventions.

Community building is an integral part of any participatory sensing focusing on alternative practices, devices and platforms for harvesting, aggregating and visualising data. More types of data can be put into place to foster social interaction, as for example walking events, sensing workshops, notebooks and guides, maps and historical diagrams to create a sense of local context [Citizen Sense project], or artistic and public installations, record of participants' everyday life such as daily movements, remembered local stories, etc. [Taylor, 2014].

4.5 Diversity

Asymmetries in social, cultural, economic and political capitals are crucial factors in any discussion about citizens' appropriation of technological tools for participatory sensing.

Previous "deficit models" for public engagement are still visible in some discourses, stating that the main reason for citizens are not motivated or involved in science and technology is a matter of lack of scientific or technical literacy. Participation and empowerment, however, are to be assessed within societalimbalances which influence the actual access and use ofknowledge, tools and technologies, arising from gender, education, ethnicity, income or geographical origin.

Recent research have made explicit for instance in parts of the maker community a biased group of users, predominantly students, young, male and with an academicbackground [Carstensen, 2014]. However, there are some encouraging signs, for instance in a part ofthe open knowledge and open source hardware movement,towards the inclusion of women-in-tech or in'geek' communities, under-represented groups and economically-marginalized communities. Accounting for and planning for diversity is crucial for participatory sensing initiatives: broadening the places to meet up with citizens and communities, avoiding institutional or conventional settings and instead privileging others where communities already meet (cultural associations, neighboorhood gatherings, etc.); lower as much as possible potential barriers for social interaction, for instance meeting hours or associated costs/fees which may exclude people with low income, childcare responsibilities or with special working hours.

4.6 Governance models

Urban participatory sensing requires new governance models, where citizens, communities, NGOs, public administrations, companies and others, can work together towards common goals in an urban setting.

Open and inclusive type of relationships between involved parties are to be encouraged and supported, under which all parties can engage in meaningful interactions and generate collaborative know-how. Many challenges still need to be overcome. An open and public debate between all claims in a given situation – eithercoming from public authorities, think tanks, scientific organizations, communities and citizens– has to be fostered, with mutual acknowledgement of competing and/or divergent ideas of common good.

Political willingness from public bodies to support institutional, political and cultural conditions, at the basis of such open and collaborative frameworks, is a primary condition for any inclusive initiative. It also entails an environment of mutual respect between citizens, experts and decision-makers, together with availability to exchange views and to change the issues at stake. It concerns a certain sense of mutual control between stakeholders, that is, when they can agree on the exerted influence between them and thus accept degrees of control over each other. The need remains for a 'sharing of power' where experts and policy-makers allow the outcomes of participatory sensing to truly be unpredictable and to have substantial consequences.

4.7 Data issues

Citizen-driven data practices are becoming more and more common.

But most initiatives are building their own communities and their own specific information systems, which poses issues of interoperability, re-usability, and sustainability in terms of storage and curation. From the point of view of citizen science, the Joint Research Centre (JRC) is looking into such issues and experimenting with a data archive for curating the outcomes of EU-funded Citizen Science projects (including data, methods, software, apps, services, publications, etc[64].). From a broader point of view around data, there is recent work around the politics of data visualization[65] and the development of new networks such as the Responsible Data Forum[66] bringing together practitioners, activists and academics to tackle such issues.

64 https://ec.europa.eu/jrc/en/news/citizen-science-survey

65 https://civic.mit.edu/feminist-data-visualization

66 https://responsibledata.io/

The production and availability of large quantities of data also raises the issues of adequate practices of accountability and data protection, especially sensitive or personal information. The limits of anonymisation are now well proven, as for example recent research showed only that 4 points/pieces of information from mobile phones were needed to identify 95% of people in his sample of 1.5M people[67]. It is essential for initiatives to develop an ethical framework with clear guidelines for data management (e.g. access, use, audit, reuse, IP) under common principles of transparency, secondary uses, consent, liability, and privacy [Kuan Lun, Salil & Wen, 2010; De Cristofaro & Soriente, 2013]. Alsosocial practices of sharing and controlling information are at the center of such framework, dealing with the relevance and quality of information, information overload, the immediacy of transfer, digital divides and more.

Furthermore, previous studies have demonstrated that data sensemaking can deter user engagement in citizen science projects.If users fail to make sense of data they can quickly disengage with the process of sensing because they can't find purpose in their efforts. On the one hand, a sense of meaningfulness can be supported by adopting inclusive methodologies such as co-design, allowing citizens to meet at makerspaces to collaboratively build tools and develop sensemaking techniques (e.g data annotation and comparison) [Balestrini et al., 2015]. On the other hand, storytelling can truly support sensemaking by contextualising data and illustrating scenarios with visible outcomes. Collaborating with data journalist who can tell stories using citizen-generated data can both assist in sensemaking and strengthen engagement by fostering community pride.

4.8 Transdisciplinarity

A number of existing tools, networks and venues,such as open-source software and hardware, peer-to-peer movements, and a variety of makerspaces, are gathering a diverse crowd of people.

Transdisciplinarity can be found in such open and collaborative logics minglingtogether fields from inside and outside traditional disciplines with citizens and other stakeholders [Nascimento & Polvora,2015]. In its original sense, transdisciplinarity generates comprehensive knowledge for solving concrete issues through collaborative platforms, which operate both horizontally, to involve and mix different areas of expertise such as design, computer science, IT development, social sciences, environmental sciences, etc. and vertically, to include stakeholders from civil society, private and public sectors.

67 http://www.demontjoye.com/

A transdisciplinary pool of tools, knowledge, ideas and data is thus emerging in urban participatory sensing. Bringing together everyone interested and keeping their involvement is a challenge to be tackled from the beginning of any project. A clear assessment of the needs and expectations of involved citizens, communities, public authorities, civil society associations and other stakeholders, needs further emphasis with appropriate time and resource allocation. An example of public funding for such multidisciplinary initiatives comes from Horizon2020 CAPS Programme on “Collective Awareness Platforms for Sustainability and Social Innovation”, under the goal of supporting digital social platforms at larger scales towards the development of innovative solutions to societalchallenges.

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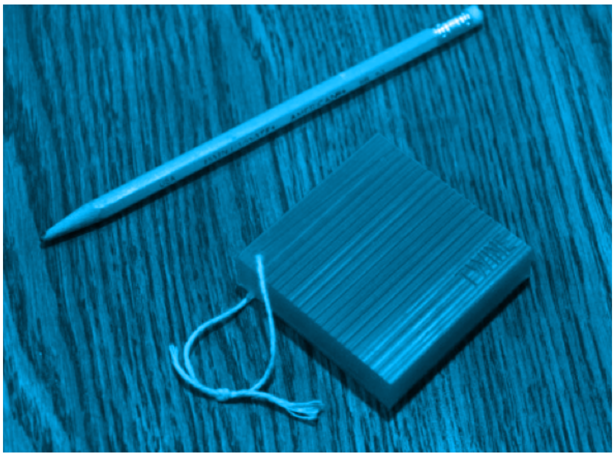
ANNEX

An overview of IoT low-cost sensing technologies



Supermechanical: Twine

supermechanical.com/

Description:
Twine is a wireless sensor block tightly integrated with a cloud-based service. The durable, rubbery block has Wi-Fi, on-board temperature and orientation sensors, and an expansion connector for other sensors. Power is supplied by micro USB or two AAA batteries that will run for up to 3 months (and Twine will email you when you need to change the batteries).

Dedicated platform: Twine

Web app: Yes

Mobile app: Yes

Portable: Yes

Hardware license: Proprietary?

Sensoring capacities:

Temperature – Humidity – Accelerometer

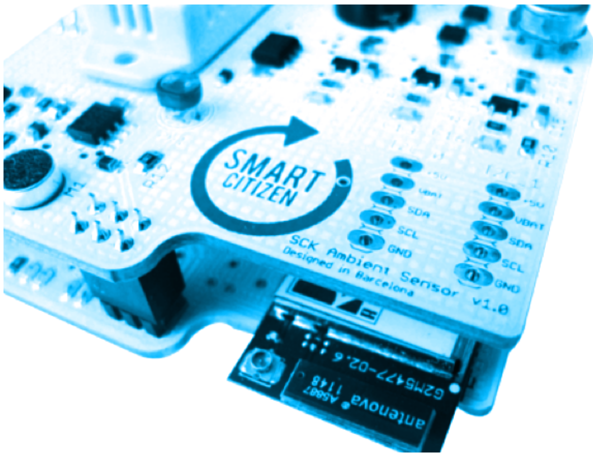
Easy to add external sensors: Yes

Battery: Yes (Two AAA Batteries)

Wifi: No

Bluetooth: No

GPS: Yes



Smart Citizen

smartcitizen.me/en/

Description:
Smart Citizen is a platform to generate participatory processes of people in the cities. Connecting data, people and knowledge, the objective of the platform is to serve as a node for building productive and open indicators, and distributed tools, and thereafter the collective construction of the city for its own inhabitants.

Dedicated platform: Smart Citizen

Web app: Yes

Mobile app: Yes

Portable: No

Hardware license: Open

Sensoring capacities:

Temperature – Luminosity – Humidity – Smoke – Gas - Noise

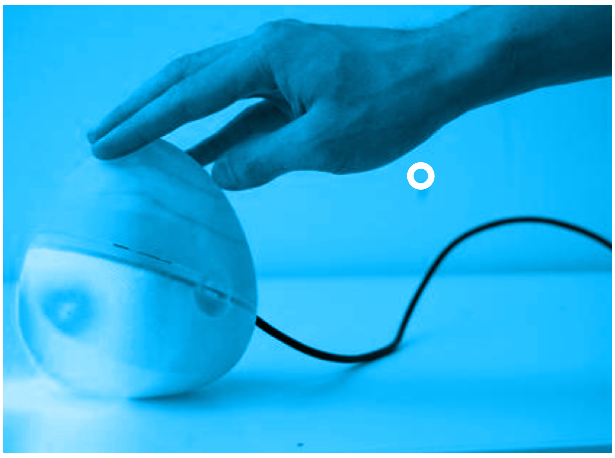
Easy to add external sensors: Yes

Battery: Yes (Lithium-Polymer)

Wifi: No

Bluetooth: No

GPS: No



Air Quality Egg

airqualityegg.com/

Description:
A project aiming to give citizens a way to participate in the conversation about air quality. It is composed of a sensing device that measures the air quality in the immediate environment and an on-line community that is sharing this information in real-time. It is a community-developed, open source project that is driven by people who care about the air they breathe.

Dedicated platform: Cosm

Web app: Yes

Mobile app: No

Portable: No

Hardware license: Open Source

Sensoring capacities:

Smoke - Gas

Easy to add external sensors: N/A

Battery: No

Wifi: No

Bluetooth: No

GPS: Yes

Ninja Sphere Blocks

https://ninjablocks.com/ninjasphere

Description:
Ninja Sphere is both a hardware and software platform designed to seamlessly bridge your Smart devices together. By connecting to products from various brands, you home can start using them in new and exciting ways. While you're away from home the sphere app can notify you if it sees a problem and will help you to fix it.

Dedicated platform: Ninja Blocks

Web app: Yes

Mobile app: Yes

Portable: Yes

Hardware license: Open Source

Sensoring capacities:

Temperature – Luminosity – Humidity -

Accelometer

Easy to add external sensors: Yes

Battery: Yes (AAA Battery Pack)

Wifi: No

Bluetooth: No

GPS: Yes

Sensorcor

http://sensorcon.com/

Description:
Sensorcon is dedicated to creating durable, high quality environmental sensor products to meet the most demanding of domestic, professional and industrial needs.

Dedicated platform: No

Web app: Yes

Mobile app: Yes

Portable: Yes

Hardware license: Proprietary

Sensoring capacities:

Temperature – Luminosoty – Humidity – Gas - Pressure

Easy to add external sensors: Yes

Battery: Yes (Lithium-Polymer)

Wifi: Yes

Bluetooth: No

GPS: Yes

Safecast

http://blog.safecast.org/

Description:
Safecast is a global volunter-centered citizen science project working to empower people with data about their environments. We believe that having more freely available open data is better for everyone. Everything we do is aimed at putting data and data collection know-how in the hands of people worldwide.

Dedicated platform: Safecast

Web app: Yes

Mobile app: Yes

Portable: Yes

Hardware license: Open Source

Sensoring capacities:

Accelerometer

Easy to add external sensors: N/A

Battery: No (Lithium-Polymer)

Wifi: No

Bluetooth: No

GPS: No

Variable

http://www.variableinc.com/

Description:
The NODE+ system can take measurements on the go, and then transmit data wirelessly to your mobile device. Add one of our modules to customize it to your specific industry and begin collecting and transmitting data for temperature, light, color, gas, motion and so much more.

Dedicated platform: Node Kore

Web app: No

Mobile app: Yes

Portable: Yes

Hardware license: Proprietary

Sensoring capacities:

Temperature – Luminosity - Humidity

Easy to add external sensors: Yes

Battery: Yes (700 mAh lithium ion)

Wifi: Yes

Bluetooth: No

GPS: Yes

Amperic / Knut water

amperic.com

Description:
Smart Water Detector

Dedicated platform: Knut

Web app: Yes

Mobile app: Yes

Portable: Yes

Hardware license: N/A

Sensoring capacities:

Temperature – Humidity - Accelerometer

Easy to add external sensors: Yes

Battery: Yes (two AAA batteries)

Wifi: No

Bluetooth: No

GPS: Yes

Libelium

http://www.libelium.com/

Dedicated platform: Meshlium

Web app: No

Mobile app: No

Portable: Yes

Hardware license: Open Source

Sensoring capacities:

Temperature – Luminosity – Acceleromenter (ozone)

Easy to add external sensors: No

Battery: N/A

Wifi: Yes

Bluetooth: Yes

GPS: No

Community Sensing

http://communitysensing.org/

Description:
Mobile sensing technologies that help communities gather and analyze environmental data.

Dedicated platform: Common Sense

Web app: Yes

Mobile app: Yes

Portable: Yes

Hardware license: Propietary

Sensoring capacities:

Temperature – Humidity – Gas (CO) – Noise (NOx) – Accelerometer (ozone)

Easy to add external sensors: No

Battery: N/A

Wifi: N/A

Bluetooth: No

GPS: Yes

Sensaris

http://www.sensaris.com/

Description:
Sensaris is using Bluetooth wireless sensors, used in combination with mobile phones, that allow citizens to monitor and report air and sound quality data.

Dedicated platform: Sensaris

Web app: Yes

Mobile app: Yes

Portable: Yes

Hardware license: Proprietary

Sensoring capacities:

Temperature – Humidity – Gas (CO) – Noise (NOx) – Accelerometer

Easy to add external sensors: No

Battery: No

Wifi: No

Bluetooth: Yes

GPS: Yes

Bitponics

http://www.bitponics.com/

Description:
Bitponics is developing a sensor device that measures a garden's vital signs, sending information back to a central computer. This then remotely controls water pumps and lights, and Bitponics sends alerts to members suggesting "reservoir" refills and other maintenance. The advice is based on pre-agreed "growing plans" that Bitponics generates based on what plants people want to grow.

Dedicated platform: Cosm

Web app: Yes

Mobile app: No

Portable: Yes

Hardware license: Open Source

Sensors:

Temperature – Luminosoty – Humidity -

Easy to add external sensors:

Battery: No (Power Socket)

Wifi: No

Bluetooth: No

GPS: Yes

Citizen Sensor

citizensensor.cc/

Description:
Citizen Sensor is a DIY and open-source hardware and software initiative to encourage personal and community pollution monitoring.
Development has been done in both mobile and stationary forms and has been used in educational, research and artistic applications around the world.

Dedicated platform: Cosm

Web app: Yes

Mobile app: No

Portable: Yes

Hardware license: Open Source

Sensoring capacities:

Luminosity – Gas – Noise

Easy to add external sensors: Yes

Battery: N/A

Wifi: Yes

Bluetooth: No

GPS: Yes

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