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IoT Community Technologies: Leaving Users to Their Own Devices or Orchestration of Engagement?

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Abstract

Citizens are increasingly crowdfunding IoT based participatory sensing technologies that allow them to collect and share data about the environment. These initiatives are usually referred to as grassroots and are driven by a vision of widening access to tools for political action. In this paper we compare patterns of participation and user experience over 15 months in two distinct communities using 'Smart Citizen', a crowdfunded IoT participatory sensing tool. Our studies reveal that technology issues and a lack of reliability of the sensed data hindered user participation. However, in one of the communities, many of these challenges were overcome through orchestrated actions led by community champions. We discuss how crowdfunding doesn't necessarily translate into active participation and provide guidelines on how to achieve sustained engagement in crowdfunded IoT community sensing projects: enable distributed orchestration provided by local champions, encourage social interactions that embed skills and learning, and facilitate meaningful participation and reward mechanisms among community members.

Keywords: IoT community technologies, engagement, crowdfunding, social action, activism, participatory sensing.

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1. Introduction

Novel Internet of Things (IoT) devices are increasingly being created to enable citizens to engage in participatory sensing: the collection and sharing of data of common interest, making a contribution to monitoring phenomena that could not easily be measured by a single individual [17]. Initially, these initiatives tended to be part of research and citizen science projects. However, participatory sensing technologies have more recently often been funded through crowdfunding and released to communities of users who are not necessarily involved in crowdsensing projects. Crowdfunding entails the online request for resources from a distributed audience, usually in exchange for a reward [19]. Some crowdfunded collaborative technologies for social action have received wide media coverage (e.g. [10, 45]) and engaged large numbers of users who contributed data that are made public online. For example, SafeCast was used by citizens in Fukushima (Japan) to map and share radiation data after the nuclear disaster at the Daichii Power Plants [38, 24]. It was crowdfunded by 290 backers in 2011 and had reached over 20 million data entries by July 2014. Similarly, Air Quality Egg [2], an IoT kit to measure nitrogen dioxide and carbon monoxide levels indoors, raised over US$144k from 927 Kickstarter users.

Interventions such as SafeCast [38] or Air Quality Egg [2] are different to more traditional approaches such as citizen science. In research and citizen science projects the participants are typically recruited, the goals of the intervention have been set by project instigators, and user engagement strategies tend to focus on getting users to collect enough accurate contributions to meet quality and quantity standards (e.g. [40, 16]). In contrast, crowdfunded participatory sensing technologies aim to provide IoT devices that users can appropriate for their own situated

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purposes (scientific, environmental or political); technologies that may not necessarily respond to the specific needs of a community but rather inspire new tools and human practices (c.f. [36]). Moreover, they tend to be driven by an egalitarian vision of widening access to technologies for bottom-up political action [16, 9, 22] – an increasingly important topic in computer science [15] – and sometimes propose that data quality is less important than the volume of contributions produced by large crowds [38]. Finally, although there are bottom-up community-led citizen science approaches, these also differ from crowdfunded participatory sensing interventions because they are human and activity-centred and typically make "minimal use of technology" [45, p.5].

While researchers have studied many aspects of community sensing systems, including the influence of different design features on user engagement [16, 26, 18, 48], data quality and reliability [40, 43], novel forms of data visualisation [25, 48], new perspectives on materiality [27], and the need to support orchestration for data gathering campaigns [12], there is little work exploring long term user participation with crowdfunded participatory sensing initiatives. As crowdfunding becomes a more common mechanism to fund and deploy tools for collaborative social action, there is a need to better understand: 1) how communities emerge around and appropriate the technologies they crowdfund in order to attempt to effect positive change; and 2) how these bottom-up approaches compare to more conventional ones such as those adopted in citizen science. To address these gaps, we conducted the first long term study examining participation patterns and user experience with a crowdfunded IoT participatory sensing platform.

Smart Citizen (SC) (see figure 1) is an open source environmental participatory sensing platform that has been both crowdfunded by independent users and adopted in citizen science projects organised by institutions [39]. We followed a mixed methods approach to examine user participation and experience with SC over 15 months, focusing on two distinct communities of users in Barcelona and Amsterdam, which emerged following different engagement strategies. The community in Barcelona comprised 125 users who crowdfunded SC, while the community in Amsterdam consisted of 73 individuals who were recruited and lent Smart Citizen Kits (SCK) by a local cultural institution running a citizen science "experiment".

Comparing these two communities, who used the same technology but followed different engagement approaches (crowdfunded versus orchestrated deployment), revealed benefits and shortcomings of both bottom-up and top-down approaches. Contrary to previous findings on engagement with crowdfunded crowdsensing technologies (e.g. [1]), our study shows that while in Barcelona crowdfunding was an effective strategy to attract users and fund SC, it did not effectively encourage participation. Sustained engagement was hindered by issues with the usability of the devices, lack of social interactions between members, and a perception that the data were unreliable. Conversely, we identified how participatory orchestration provided by local champions, understood as the cooperative practices that make a crowdsensing campaign work (cf. [8]), fostered community building and technology uptake in Amsterdam. This orchestration helped participants to overcome technical challenges and enabled processes of sensemaking that in turn created a sense of meaningfulness among users (cf. [4, 37]).

Most crowdfunded IoT platforms have tended to be presented as enablers of successful bottom-up grassroots movements due to the large number of people who contributed to them financially [1, 2, 24, 38]. Nevertheless, this assumption hinders more detailed understanding of how to design and deploy these technologies to achieve long-term appropriation and community empowerment. We argue that crowdfunded IoT technologies, if left to their own devices, are unlikely to become successful community tools. We provide a set of guidelines to support researchers and practitioners who are planning to design and deploy IoT based participatory sensing technologies: enable distributed orchestration provided by local champions, embed skills, foster peer-learning, and enable meaningful participation and reward mechanisms.

2. Related Work

Citizen science and participatory sensing have a varied history [7] and it is not uncommon to see either terms used interchangeably, or the latter to be considered a type of the former [20, 46]. Citizen science typically refers to a collaborative process of data collection, curation, and analysis in which individuals contribute towards a scientific project that is defined a priori by an authority [46]. In participatory sensing citizens contribute to data collection to tackle problems of concern to their own communities [34].

A number of taxonomic frameworks aim to reveal how citizen contributions occur in practice [20, 45, 28, 47]. They tend to distinguish between projects that are centralised and where citizens' participation is limited (collecting or curating data) and those that are more decentralised, allowing citizens to participate in decision-making and goal planning in addition to the data collection tasks. Nov et al., [33] and McQuillan [29] argue that the adoption of internet technologies enabled this shift from top-down centralised approaches to distributed and community-centred ones. Wiggins and Crowston [46] argue that citizen science projects can have different foci such as civic action, conservation, investigation, virtual action, or education according to their organisational and macrostructural properties. While civic action projects are community-centred and use scientific tools to support civic agendas, investigation projects focus on scientific research goals and have a top-down structure. Haklay's taxonomy [20] focuses on the role played by users, from basic crowdsourcing where users act as "sensors" to "extreme citizen science", a situated and bottom-up practice that takes into consideration local needs, practices and culture.

This shift has been accentuated by the recent adoption of crowdfunding by members of the maker movement, who are not necessarily primarily interested in research or science [24, 2]. That even before the technologies are developed, a community of users becomes involved with the project [1] reveals a new dimension of citizen empowerment that introduces investing in and using open-ended technologies for environmental monitoring as a type of collective and political action [24]. The creation of Pachube (now Xively), an open data sharing and visualisation platform, played an important role in the popularisation of these kinds of IoT tools. Early projects like Air Quality Egg (AQE), SafeCast and Community Sensing (CS) were closely linked to Pachube. AQE was developed in 2011 by attendees of the *Internet of Things Meetups* in NYC and Amsterdam. It comprises outdoor sensors for nitrogen dioxide and carbon monoxide that send data to an egg-shaped station, which relays it to an online platform. Although 927 backers initially supported the project, community participation was hindered by delays in the delivery of the kits, sensors perceived to be unreliable, and constant changes in the platform's design and development [2].

Two other crowdfunded projects were launched following the nuclear disaster in Fukushima (Japan) in 2011 [1, 23, 24]. SafeCast, an affordable Geiger counter to measure radiation levels, was developed by a network of stakeholders including Joichi Ito (Director of the MIT Media Lab) and the Tokyo Hackerspace. It was crowdfunded by 290 backers in 2011. By July 2014 it had reached over 20 million data entries, although the 10 most active volunteers had contributed almost 3/4 of the data [38]. In Radiation-watch the stakeholders developed open source tools including the POKEGA radiation detector, which connects to smartphones, and a bespoke device for remote sensing. The backers helped fund the project and played a role in improving its design by suggesting recommendations [23]. There are around 12,000 users.

Motivations to participate, issues around data reliability, and aims and organisational aspects are normally different in citizen science projects than in crowdfunded IoT crowdsensing interventions. While the former usually stem from research goals or specific community needs, the latter are often initially inspired by technical possibilities (c.f. [36]). It is worth understanding how these approaches differ to better frame the research contribution of the study presented in this paper.

Motivations to participate. Nov et al., [33] found that online citizen science project participants are often motivated by the opportunity to learn. This is unlike those who take part in crowdsourcing for non-scientific purposes, who are typically driven by reputation and identification with a community. Community building is also a key motivator for participation in citizen science [37], in contrast to other volunteer activities for which acknowledgement and rewards are more common motivators (e.g. open source software development). On the other hand, in crowdfunded crowdsensing initiatives the channel for engagement is the crowdfunding platform and not a particular citizen science project. Crowdfunding entails different types of investment: pure donation (users don't expect a reward), active investment (for example, users participate in the project providing feedback) and passive investment (users do not participate and wait to receive the output of the funding round as their reward) [5]. However, Gerber & Hui found that people are driven to crowdfund projects for many reasons other than a mere desire to collect rewards. They are also motivated to help others (especially creators with whom they have a personal or extended connection), support causes, and be part of a community of like-minded people or a "select group" [19, p.15].

Data quality. Data quality is a pressing issue in most citizen science projects [32] because experts use these contributions in scientific enquiry or make assessments that result in policy decisions. Experts often question the validity of the data provided by citizens who have varying levels of skills and knowledge [40]. Consequently, various studies have sought to address data quality and reliability issues [3, 31, 43]. While researchers have also raised concerns about the reliability of the data provided by crowdfunded tools such as AQE [41], the instigators of these novel technologies propose that data quality is less important than the volume of data produced by large crowds ("*Our goal is not to single out any individual source of data as untrustworthy (...) Multiple sources of data are always better and more accurate when aggregated."* [38]), prioritising their mission to engage the public in political action (*"Without real air quality data, people can be easily brushed aside (...). But nothing screams, "Take action!" like a link to a datastream updating in real-time showing how people are being affected at this very moment*" [2]).

Aims and engagement strategies. Researchers have argued that leveraging citizen engagement in crowdsensing requires tools for data collection and mechanisms to enable collaboration between experts and users with local knowledge [7]. Additionally, they have highlighted the need to provide features for *campaign orchestration*, understood as a predefined set of operations that are enacted in a specified order by a workflow engine [12]. Other technology-enabled collaborative systems have fostered less centralised forms of orchestration [14, 8]. While orchestration of engagement might be more easily implemented in citizen science projects where goals and organisational aspects are defined by the project instigators, this is particularly complex with crowdfunded participatory sensing platforms because the community of users has to negotiate the goals and strategies as it emerges around the technology (c.f. [21]).

Studies evaluating SafeCast and RadiationWatch have supported the vision that crowdfunded participatory sensing initiatives can empower self-organising citizen movements, but have provided little description of the mechanisms involved in such auspicious outcomes [24]. We argue that to harness the potential of crowdfunding platforms as a channel to fund and release IoT tools and empower users at the grassroots level, we need to understand how communities use and appropriate these technologies in the long term, and how this approach compares to more documented ones. In the next section, we describe the Smart Citizen project and the community participation recorded on the platform over 15 months.

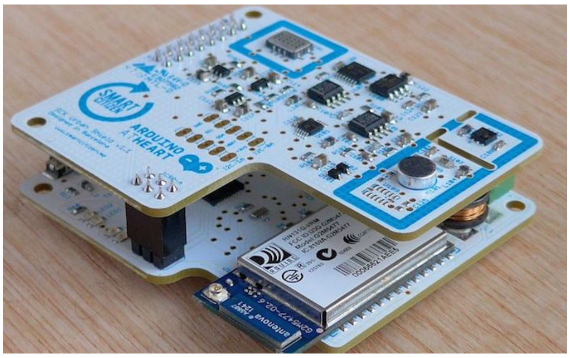

Figure 1. The SCK sensor board.

3. The Smart Citizen Project

Smart Citizen was launched by the Fab Lab Barcelona [39]. It comprises a sensor kit (SCK), an online platform, and a mobile application that enable collective sensing and sharing of environmental data (see figure 1). 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, carbon monoxide, sound, solar radiation, Wi-Fi hotspots, and battery charge level. Additionally, the kit has been developed using open source technologies to allow advanced users to add features and capabilities to meet their own purposes. In this sense, a SCK is not intended to be sold as a finished consumer product but rather an open-ended physical and digital IoT platform to be transformed and adapted by users.

The Smart Citizen online platform (smartcitizen.me) enables participants to upload data from their USKs, share them through social networks and make them available to everyone online for free [39]. Both the sensor kit and the online platform were developed with financial support from users through two crowdfunding campaigns. The first one, in 2012, raised almost €14,000 from 159 backers via Goteo, a Spanish platform that supports open source projects, and led to the production of 200 SCK units. One year later, a second campaign via Kickstarter raised US$68,000 from 517 backers and helped produce 520 USKs.

4. Methods

We followed a mixed methods approach [11] to study user experience and participation with Smart Citizen, focusing on two distinct communities located in two different cities: the community in Barcelona crowdfunded Smart Citizen while the one in Amsterdam was recruited as part of a citizen science initiative championed and orchestrated by a local cultural institution. Quantitative data about participation levels (defined minimally as keeping the sensor kit powered and connected) was collected from April 2013 when the first batch of devices was delivered to users, until July 2014. To do this we combined two data sets: (i) a database dump from SmartCitizen.me, containing metadata about registered SCK devices and time series data of all postings generated by the devices; and (ii) shipping data provided by the SC project leaders, showing when the kits were dispatched to users.

To study user experience in Barcelona and Amsterdam, we collected qualitative data over a period of seven months through online surveys, online ethnography [49], semi-structured online interviews, face-to-face open interviews in Spanish, Dutch and English, and direct observations at project meetups [42]. Data were analysed following an inductive thematic analysis approach [6] by two researchers who met weekly to discuss until agreement was reached on emergent themes. In some cases, follow up interviews were carried out to provide more data pertaining to these emergent themes. In this study, the quantitative findings complement the qualitative data by providing a baseline of participation in the two communities studied.

Smart Citizen was developed by the Fab Lab Barcelona and deployed with no previously defined research goals, in a similar way to related projects such as SafeCast or Air Quality Egg. The evaluation presented in this paper followed after the deployment decisions taken by the Fab Lab, which were aimed at testing the technology with real users in the wild to collect insights on how the system was used and what needed to be improved. There were no iterative improvements in between trials. Rather they are on-going following the outcomes of this study.

4.1 THE BARCELONA COMMUNITY

In September 2012 Smart Citizen was crowdfunded via Goteo. 159 people (117 males, 28 females and 14 anonymous or organizations) backed the project by making a financial contribution. 125 contributed enough to receive a SCK (98 males, 13 females and 14 anonymous or organizations). We consider these 125 users in Barcelona the “early cohort” as they were the first to have a SCK. We sent them an online survey via email one year after the launch of the project and received 36 anonymous responses. 72% respondents were male and 28% were female. Almost 80% were aged 32-45, 8% were aged 26-31, and the rest (12%) were aged 46-59. Three months later we selected ten of the most active users and sent them a questionnaire with open-ended questions to gather more in-depth opinions about their experiences with Smart Citizen.

4.2 THE AMSTERDAM COMMUNITY

The Amsterdam deployment ran from March to June 2014. It was organised, paid for and championed by Waag Society (a cultural institution) in collaboration with Amsterdam Smart City, Amsterdam Economic Board and Smart Citizen. The aim of the deployment was to explore how citizens might collect environmental data using affordable sensors. Waag Society hosts a Fab Lab and has been collaborating in the development of projects within the Fab Lab Network. In 2013 the Amsterdam Economic Board and the Amsterdam Smart City project delegations visited the Fab Lab Barcelona and expressed their interest in running a participatory sensing intervention, championed by Waag Society using the Smart Citizen platform.

To recruit users, Waag Society published a call in a local newspaper. To participate, users were provided with SCKs for a three-month period. At the end of the intervention, they could purchase the SCKs for €50 (a third of their price) or return them. 100 applicants were selected based on their motivations to participate, skills and the locations where they lived (or would place the sensor) in order to ensure a geographically bounded community in the city centre. The stakeholders purchased 100 SCKs but 13 became faulty, 6 people dropped out prematurely, and 8 never collected their sensors. Thus 73 users received USKs of whom 30% were female and 70% were male. However, not all sensors provided data: 8% of users dropped out over the course of the deployment and 29% of sensors never provided data (e.g., they weren't connected to the internet).

We conducted 10 hours of observations and eight interviews with users and staff from Waag Society at three Smart Citizen events. We had access to project reports compiled by the institution containing survey data and opinions from the stakeholders. Additionally, we collected data from four blog posts published by Waag Society at different stages of the deployment.

5. RESULTS

In order to assess participation levels in the Barcelona and Amsterdam communities, we measured the level of connected device utilisation. In an ideal case, once an SCK device is successfully connected to the platform, it will continuously report at its configured reporting frequency. However, packet losses due to intermittent connectivity and varying reporting frequencies make it difficult to compare utilisation levels between devices based merely on the counts of successfully received reporting records. Instead we divided a monthly period into hourly timeslots and examined in how many of these timeslots a post from a SCK device had been successfully received. A SCK that posted in every timeslot was considered to have 100% utilisation, while USKs that reported in none of the timeslots had 0% utilization. We grouped the remaining devices in four other categories between the two extremes.

Figure 2 presents the SCK utilisation levels across Barcelona and Amsterdam. We show the percentage of devices in the respective utilisation categories for each community (darker shading represents higher levels of utilisation). The Amsterdam community shows the highest levels of participation, especially from March to June 2014 (an average of 50 activated sensors of which nearly three quarters reported at least at 50%). This coincides with the orchestrated deployment organised by Waag Society. The Barcelona community is characterised by an initial phase of higher device utilisation that drops after June 2013. There are some intermediate utilisation peaks during October 2013 and July 2014, corresponding to events where the Smart Citizen Project was presented (IoT Forum and Fab10). The proportion of SCKs with a utilisation of at least of 50% is fairly small: not exceeding 20% in the Barcelona group along with a high number of SCK devices not reporting at all. In summary, although Smart Citizen is growing at a steady pace, a high percentage of users (~50%) fail to log in their USKs and therefore do not participate in contributing data to the platform. While specific local events around Smart Citizen lead to peaks in participation, the highest levels of participation were recorded in Amsterdam from March to June 2014 (figure 2). These findings provide the baseline participation trends in the two communities that we focused on in this paper.

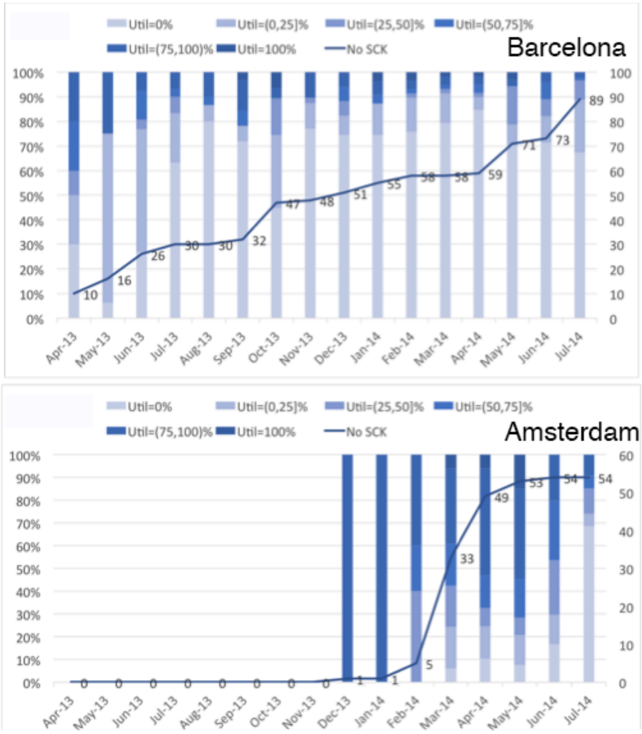

Figure 2: Breakdown of SCK population (in number of connected sensors) and level of utilisation (in percentages) across Barcelona and Amsterdam.

5.1 User experience in Smart Citizen

To compare how deployment strategies impacted user participation, we conducted a qualitative study of the Smart Citizen communities in Amsterdam and Barcelona. From our inductive thematic analysis [6] we identified five emergent themes: (i) motivations to participate, (ii) difficulties around technology set up and technology robustness, (iii) data reliability and engagement, (iv) social interactions, and (v) meaningfulness and rewards. We present these themes along with the data collected from online surveys, online content such as posts, comments and reports, semi-structured online interviews, face-to-face open interviews and direct observations at project meetups. All quotations have been transcribed and translated from Spanish and Dutch to English where necessary.

Motivations to participate

In the "early cohort" group in Barcelona all surveyed users reported having an interest in technology: 53% considered themselves "technology savvy" (with programming skills and experience hacking electronics); 28% stated they were a "technology newbie" (just starting to program); and the rest were "curious about technology". They also reported having an interest in open data (20%), open hardware (14%), smart cities (20%), and the Internet of Things (20%). Only 12% were interested in citizen science and 9% in environmentalism (5% chose "other interests"). Furthermore, a number of participants explained that they had contributed to funding the project due to sympathy for the Smart Citizen leaders; for example: "*The truth is that I contributed to the crowdfunding campaign because* [one of the project leaders] *is my friend and I wanted to help even if only symbolically*". 37% of those surveyed indicated that they knew at least one of the project instigators, and many might have not intended to actively participate by contributing data to the platform (e.g. *"I supported the project because I thought it was a cool idea coming from people I know. I like having the SCK but never had time to configure and use it*") (cf. [5, 30]).

Unlike the "early cohort" group, participants in Amsterdam had fewer technical skills, but a more focused interest in sensing the environment: Only 12% considered themselves "tech savvy", and among their motivations to take part in the project, they indicated interests such as air pollution (55%); the technology (20%); crowdsensing as a social experiment (18%); and others (7%). Apart from Waag Society staff members who personally knew the Smart Citizen developers, the participants who signed up for the trial did not know the project leaders but were motivated to participate in a crowdsensing initiative to reveal local environmental issues.

Difficulties with technology set up and robustness

72% of the Barcelona community responded to say that their sensors were not active. Despite their high stated technical skill, users highlighted difficulties when dealing with the device setup and troubleshooting advice provided in the platform: *"It's hard to set up the kit (...) I got tired of trying to configure it*". Even for those who managed to complete the setup, the process was more complicated than expected or took more time than they had available for the task: *"Honestly, I have only started using the device recently (...) the fact that I had many issues during the installation and it took me a while to solve them didn't help*". Although the Smart Citizen developers claim that a central aim of the project is that users appropriate, change and improve the devices, users would prefer to have more 'plug and play' and robust devices that required little maintenance. As indicated by this participant: "*I have it [the sensor] online, on top of my desk. It is waiting for me to put it in an adequate box and set it outdoors (...). But this is not easy because I don't have time to take care of it, and it needs to be protected from the cold, the rain, etc."* Another user suggested that Smart Citizen designers *"manage to make sensors that can connect to any type of Wi-Fi and configure without intervention from the user."*

The Amsterdam community also struggled with device setup, especially those using Windows OS. However, Waag Society carried out four activities to help them overcome these difficulties:

- they adapted the technology to be more robust and suitable for the intervention using industrial electrical boxes to protect the sensors from weather conditions;
- they helped users to acquire technical skills by organising an "install party" where community members learnt how to set up their sensors;
- they produced a user manual in Dutch because all Smart Citizen documentation is in English and *"was difficult to understand by people with little technical skills"* (Cultural Society staff member);
- they enabled a process of peer to peer technical assistance by matching tech-savvy participants who volunteered with those who faced technical difficulties (*"We took note of the contact details of those who volunteered to help, and mediated: if someone needed help, first we matched them with a volunteer via email and if they still couldn't work things out we scheduled a visit between them",* explained a staff member).

By April 2014, most users had their kits installed and contributing data to SmartCitizen.me. At the end of the deployment around 13 users purchased the SCKs and kept them online. Having their sensors active for a period of time, users in the Amsterdam community began to identify more complex technology issues: the carbon monoxide and nitrogen dioxide sensors were found not to be as suitable for measuring outdoor air quality as had been expected, the enclosure provided by Waag Society influenced the reliability of the measurements, and the Wi-Fi module did not always operate properly. As explained by one of the users during the debriefing session: *"The air pollution sensor was the biggest problem because it only measures extremes (....) it measures high concentrations and that is not always present or interesting in cities.*"

Data Reliability and Engagement

Users in the Barcelona community supported Smart Citizen because they believed that having access to tools to produce free and open environmental data is empowering: *"Sharing these data and having access to it in an open and free way is a totally different concept that didn't exist until now.*" However, the lack of quality of these data hindered engagement: *"I participated because I think that having access to information helps us take action regarding issues* (….) [But] *I've checked several times my sensor data compared to that in the surrounding area to see if there were patterns but it is complicated because of the lack of consistency of some metrics.*" Most low-cost sensors for environmental monitoring lack the robustness required to produce reliable data (cf. [41]). In addition, keeping the sensors calibrated and placed in appropriate contexts is crucial to obtaining reliable measures, but the vast majority of users ignored the guidance for calibration and placement provided on the Smart Citizen forum. This led to random readings that negatively impacted the quality of the data. If users distrusted the data they tended to disengage with the project, for example: *"I think that we are storing a lot of data, but this data has a lot of inaccuracies. For the moment, I would not use the kit in projects that need some functionality"*. None of the interviewees declared having used the data collected by SCKs for their own purposes because they felt that they were unreliable. This meant that once users passed the novelty period associated with having the device itself, they paid little attention to the overall project: *"In the beginning, during the setup and configuration I experimented more with the device (...) but now that it is fully operational I just monitor the readings sometimes."*

Users in the Amsterdam group also highlighted that data provided by SCKs was "unreliable" both due to the characteristics of the sensors and their lack of knowledge about calibration and environmental monitoring. However, this only led to disengagement by a small number of users (8%) probably because Waag Society took actions to alleviate the situation: "*We decided to organise a lecture and invited an air quality specialist working for the government. He explained how they measure air quality, what data means and how different sensors work. After this meetup it became more apparent that SCKs were not a reliable technology*" (Waag Society staff member). Having learnt about the complexities involved with sensing technologies and practices, the community thought of ways they could overcome data reliability issues in the future: "*It's essential to measure under more controlled circumstances"*, and *"Maybe we could cooperate with environmental organisations who have more experience with measuring*" (Amsterdam participants).

Social interactions

When we asked users in the Barcelona group how frequently they interacted with other members of the Smart Citizen Community through the project's website, 85% answered that they hardly ever or never did; 10% said they did it once a week; and the remaining 5% did it once a month. Nevertheless, many of them recognised that there is value in socialising with members of the community, especially to share and compare the data, to learn how to set up and maintain the devices, or to plan joint activities. One user indicated that he would like it if there were *"workshops in key cities to learn more about how to set up and maintain the device and see what others are doing with it*", while another highlighted: "*...more interaction among participants would enrich and improve this project in all of its aspects"*. The Fab Lab organised a meetup for those who had backed the project via Goteo to meet and receive their SCKs. Around 20 participants attended. A second event was organised a year later to connect the two communities of users in Barcelona and Amsterdam, using Google Hangouts. Around 38 users (8 from Barcelona and ~30 from Amsterdam) participated. No other events have been held, which is highlighted as a negative aspect of the project by many users: *"The experience with the community (...) is poor. The online platform helps us stay connected but it would be better if we had more contact, for example, as we did during the Google Hangout with Amsterdam (...).*"

Conversely, social interactions among participants in the Amsterdam community fostered engagement (*"I am enthusiastic about the drive and expertise of other participants and I think that it is essential to create this dialogue between citizens and institutions."*). Within a three-month period there were four occasions where community members met: the "install party", the Smart Citizen café, an air quality workshop, and a final debriefing session. Despite the difficulties that disengaged some users, Waag Society managed to create a sense of community that fostered participation and dialogue: *"This all led to discussions and we didn't position ourselves as if we knew everything but rather as 'we are in this together and we are also learning.'"* Additionally, the peer-to-peer assistance system enabled by Waag Society (matching tech-savvy users with others facing technical issues) fostered social connectedness and commitment among the community. As an example, one of the tech-savvy users became a champion by not only providing technical assistance to others with fewer skills, but also organising a meetup (the 'Smart Citizen café') to further discuss technical aspects of the project and the collected data.

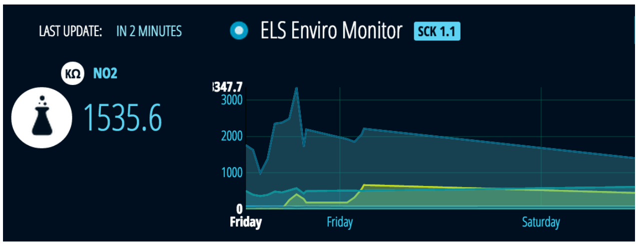

Figure 3: Air quality data displayed on the Smart Citizen online platform.

Meaningfulness and rewards

As in other related IoT sensing systems, the Smart Citizen online platform displays real time streams of numerical and graphical data (figure 3). Participants in the Amsterdam community struggled to make sense of the data they produced due to the lack of features for data comparison and annotation, and the lack of visualisations to support sensemaking. One of the tech-savvy users indicated that he was initially "charmed" with the looks of the Smart Citizen website but the lack of tools for annotating data was a burden *"... when I needed to make notes next to measurements to make sense of them... I realised that I didn't find the site to be useful"*.

If users fail to make sense of data then they might become disengaged because they can't see the purpose in their efforts. However, when data makes sense then it has the potential to produce actionable insights. This is empowering for the community as it reveals a way towards positive change: *"Sound measures are good. People in my* *neighbourhood rely on my sensor kit to monitor that. We could do visualisations of these data because finding silence is important for people and might define where they want to live".* She also suggested that these data *"could help citizens put pressure on the government to better control how bars and cafes impact the quality of life in certain areas"* (Amsterdam user).

Nevertheless, meaningfulness doesn't only come from making sense of data. A sense of meaningful participation may foster engagement (cf. [4]) when the community feels like their efforts contributes to a novel venture that produces learning and can have a positive impact: *"Despite the difficulties, the deployment was a positive experience"* (Waag Society staff member). Firstly, the community learnt about technology and environmental monitoring: *"We now know more about hardware, sensors, sensing and housing…."* (Amsterdam participant). Secondly, they engaged in fruitful discussions about how citizens might harness the potential of technology to participate in civic life. In her own words: *"Official institutions now have more interest in working with citizens to measure data…* [This deployment showed that] *there are a lot of citizens who are concerned about the city and have motivation to participate in citizen science. But official institutions also notice that the data citizens are collecting is not correct…the technology is cheap and affordable but the data is not good. We need to continue working on this."* And participants suggested getting more citizens with different skillsets involved: *"We should give these sensors to art students so they can produce data visualisation projects."* This level of meaningful participation, which seems to be influenced by social interactions among community members, was absent in the early cohort in Barcelona.

Participants also raised issues about the fact that IoT based participatory sensing systems lack the means to reward users who contribute to the collection of open data. As one participant in the Barcelona community suggested "*To incentivise users to keep their sensors uploading data Smart Citizen should enable more applications with practical uses and features (…) and find a way to reward those who contribute the most*". Another user suggested that the platform "*rewarded users with tokens or points because we are producing open data which could be valuable to third parties as well*".

6. Discussion

Our studies analysing the early cohort group in Barcelona highlighted a number of issues that prevented sustained and meaningful engagement with Smart Citizen. While these users crowdfunded the project their participation has been limited. This occurred because, on the one hand, a third knew the developers of Smart Citizen and wanted to support them and be part of a like-minded community of people but possibly didn't intend to actively use their devices (c.f. [22]). About 70% of the Barcelona cohort did not set up their SCKs and would have liked more help in doing so (e.g. better troubleshooting advice and documentation). In addition, a few of those who had used their devices did not trust the data they produced. Finally, the users agreed that poor community building actions hindered engagement (c.f. [33]); the lack of social interactions among users (both online and offline) prevented them from helping each other with technical difficulties, discussing and making sense of the data, and even planning joint activities to further develop the project. They expected the Smart Citizen team to organise events to foster community connectedness and to improve the device's robustness. They also suggested that users' participation should be rewarded either by offering more practical applications and features, or tokens and points to those who contribute by producing data.

In contrast, the study around the Amsterdam community indicated that a more orchestrated deployment led by local champions could significantly foster community participation. Waag Society orchestrated the Smart Citizen pilot by engaging a group of users with diverse interests and skillsets, adapting the technology and providing skills, and facilitating social interactions and peer to peer assistance, that in turn fostered community engagement throughout the intervention. These actions helped the community overcome challenges associated with the technology and the lack of experience with crowdsensing, enabled discussion around data quality and sensing practices, and embedded resources and skills in the community. Their participation revealed issues with Smart Citizen, such as the quality and suitability of the sensors, the perceived unreliability of the data, and the lack of tools to support data sensemaking. Furthermore, the deployment highlighted the potential of orchestrated participatory sensing interventions to trigger processes of dialogue between citizens and official institutions than can potentially lead to political change.

We argue that while crowdfunding may be a satisfactory way to attract users and enable the development of technologies for collaborative social action, collaborating with local champions to orchestrate crowdsensing campaigns is key to their uptake. We draw on our findings to propose three guidelines to foster sustained and meaningful engagement with crowdfunded participatory sensing interventions.

Orchestrated championing

While many related community projects are publicised as grassroots and self-organising, our study suggests that participatory orchestration matters. Projects that evolve around concrete championing provided by groups or institutions may have higher chances of achieving sustained participation, where a key part of this involves establishing the goals of the project. Champions can foster social interactions by organising frequent meetups and workshops that will keep participants engaged. They may also identify different skillsets among users and enable processes by which each can perform roles that might enrich the community. They can also intervene in crisis situations by contacting experts and helping to channel discussions as well as enabling collaboration with stakeholders to assist with data validation. In addition, champions who are knowledgeable about local issues can help focus community efforts to make sense of the data collectively and make it actionable (cf. [7]).

If users cannot get their sensors to start producing data they will progressively disengage with the project. Additionally, once users manage to start gathering data they can disengage if they cannot make sense of it or trust it. However, while system developers typically focus their efforts on increasing the robustness of the technology, champions can follow participatory approaches to help manage users' expectations by properly communicating the weaknesses of these novel technologies and making them feel part of an on-going development process. The suitability of applying participatory methods to help manage expectations has been repeatedly highlighted in the literature on community technologies [44, 9, 4].

Embed external skills and enable learning

Technology designers and champions could embed skills in the community by providing troubleshooting advice and documentation, possibly in the form of video tutorials. They could also incentivise users to post questions in the platform's forum and motivate others to provide answers. Furthermore, our experience with Smart Citizen has shown that processes of learning can take place within the community, when members with more technical skills help others overcome issues. Enabling peer-to-peer assistance and group workshops could strengthen social interactions among participants and the overall sense of community, possibly fostering the sustainability of the participation. This type of orchestration resembles that proposed by Crabtree and Benford [8], where the community creates a conductive environment for cooperation among members, augmenting the shared resources of the community to collectively tackle difficulties.

Enable meaningful participation

Insights from the early cohort in Barcelona revealed that funding and owning the technology does not necessarily translate into active participation, a fundamental issue that has been largely overlooked in previous reports that equate the success of a crowdfunding campaign with the active use of the participatory sensing technologies [24, 1, 2, 38]. Those in the Amsterdam community were lent devices in exchange for participation and proved to be more engaged than those in Barcelona. They felt responsible for the data they produced and could envision how it might translate into collective action (mapping noise levels in an area to revise legislation for bars and cafes, for example) suggesting that meaningful participation can nurture a feeling of ownership. To support meaningful participation, participatory sensing platforms could help users make sense of the data by providing features for data comparison and annotation. Moreover, local champions can catalyse community dialogues to produce actionable insights that create a sense of empowerment in the community.

Additionally, designers of crowdsensing platforms and organisers of deployments could devise different roles for different skillsets. While most of the Smart Citizen users had an interest in technology, their skills varied widely. From the moment the crowdfunding campaign is launched and throughout the deployment, the instigators of participatory sensing platforms could provide opportunities for users to contribute their skills, communicating that their participation matters and is valued by the rest of the users. Profiting from open source tools and providing users with an open-ended device means that the most advanced community members can collaborate with the project developers to extend or improve the system's features.

Finally, IoT participatory sensing initiatives should carefully consider how they reward users' contributions. As users become more aware of the value of data they expect to be rewarded for their efforts as data contributors. Designing features that can effectively quantify data provision and translate it to "points" or "tokens" that represent a form of value may support sustained engagement and a sense of meaningfulness.

There are some limitations to this study: in particular, it is difficult to assess to what extent the experience in Barcelona influenced the deployment in Amsterdam and the latter only lasted for three months. However, the participation numbers and reported user responses to Smart Citizen that emerged in this study are representative of those reported in the blogs and forums of other crowdfunded participatory sensing technologies [2, 38].

7. Conclusion

The research contribution of this paper is to present a scientific evaluation of 15 months of user experience with Smart Citizen, a crowdfunded IoT crowdsensing platform. Our results demonstrate that difficulties around data reliability and sensemaking, lack of technical skills and incentives can hinder sustained engagement with crowdsensing interventions. Moreover, by comparing two communities, which engaged with the project following different strategies (crowdfunding versus orchestrated deployment), we observed that while crowdfunding might be an effective way to fund these tools and attract users, participatory orchestration provided by local champions is key to encourage active and meaningful participation.

The findings presented in this paper shed some light on the challenges associated to the design and deployment of socio-technical systems for participatory sensing. Those who instigate crowdfunded IoT crowdsensing platforms often refer to these initiatives as being bottom-up, community-led efforts for social and political action (cf. [13, 24]). Additionally, the assumptions that data quality is less important than quantity (cf. [38]) and that these tools are successful because they are funded by large numbers of people, hinder more detailed understanding of how to design and deploy open-ended technologies for social and political action.

Our study contributes to a research agenda referred to as the "Rhetoric of engagement" that promotes empowerment through technology and involves "*…demonstrating, and eventually handing over to people our toolkits, know how, and technologies so they can decide what to do with them in* *their own contexts*" [35, p.49]. We propose that community participation in crowdfunded IoT participatory sensing projects can be supported by enabling orchestration provided by local champions, embedding external skills and fostering internal learning, and enabling meaningful participation by supporting data sensemaking and reward mechanisms. We hope that these recommendations will be useful to researchers and practitioners planning to develop and release IoT collaborative technologies for social action via crowdfunding.

8. Future work

The findings in this study have motivated changes in the Smart Citizen sensor board, such as the adoption of new higher quality modular carbon monoxide/nitrogen dioxide sensor shields. They have also informed Smart Citizen's engagement strategy and a new deployment has been set up in a third city following the participatory orchestration guidelines provided in the paper. We look forward to analysing how these changes affect user participation among the new participant community.

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