A City in Common: A Framework to Orchestrate Large-scale Citizen Engagement around Urban Issues

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ABSTRACT
Citizen sensing is an approach that develops and uses lightweight technologies with local communities to collect, share and act upon data. In doing so it enables them to become more aware of how they can tackle local issues. We report here on the development and uptake of the 'City-Commons Framework for Citizen Sensing', a conceptual model that builds on Participatory Action Research with the aim of playing an integrating role: outlining the processes and mechanisms for ensuring sensing technologies are co-designed by citizens to address their concerns. At the heart of the framework is the idea of a *city commons*: a pool of community-managed resources. We discuss how the framework was used by communities in Bristol to measure and monitor the problem of damp housing.

Author Keywords
Smart cities; commons; citizen engagement; publics; citizen sensing; open data; framework; methods

ACM Classification Keywords
H.5.m. Human Factors; Design; Theory; K.4; K.4.m

INTRODUCTION
Cities are becoming fertile grounds for smart technology interventions, from new network infrastructures to sensing technologies embedded everywhere [32]. But who are these interventions for and who benefits? Moreover, to what extent are communities who live in these cities involved with them? Our research is concerned with how urban sensing can be appropriated at the grassroots level and for the common good. Our focus is on how citizens, especially those from disadvantaged communities, can participate in the collection, sharing and use of data to tackle issues of their own concern, including noise pollution, housing conditions, or social isolation.

One of the problems with existing approaches is that they can be piecemeal and rely too heavily on projects being researcher-led. This can hinder the sustainability and societal impact of socio-technical interventions (cf. [63]), as research funding structures and agendas make it difficult for communities to continue the interventions and appropriate the resulting tools and practices [4]. Against this backdrop, researchers working on civically-engaged projects [9, 35, 41] and advocating for a turn to openness in participatory design [44] increasingly aim to promote empowerment by demonstrating, and handing over to people toolkits, technologies and know-how for them to appropriate, reuse and adopt for their own situated purposes [13, 55].

Our goal is to provide a framework that helps communities, researchers, and/or city councils plan and run innovative sensing interventions to tackle local issues. This entails, starting with matters of concern, supporting the development of technical skills and data literacy in communities, negotiating data ownership and governance, and creating opportunities for local entrepreneurs. Our framework builds on the Participatory Action Research (PAR) [71] phases (plan, act, observe, reflect), and also integrates principles of participatory design [26, 47, 59] and user centred design [8, 9, 14, 58]. Moreover, it comprises two novel attributes: (i) a simple unified structure that is easy to follow, communicate and enact by experts and non-experts; (ii) a reinterpretation and articulation the PAR phases around the development of a *city commons*, galvanising participants around values of openness and ownership [25]. It further shows how each phase in itself contributes an output to the *city commons*, which aims to increase the contribution of participants, who may not be able to take part in all the phases.

The framework was developed in collaboration with stakeholders and was first used in Bristol (UK). Here we describe how it evolved and its application in a project called *Dampbusters,* where sensing technologies were co-designed to address the problem of damp homes in an area of the city where residents face challenges such as fuel poverty and unemployment. The case study demonstrates the effectiveness of having a framework as an orienting and communication device, providing a common language for engaging citizens to participate in technology innovation for the common good. It also highlights the value of galvanising communities around a shared vision that fosters joy and empowerment [57].

CHI 2017, May 06 - 11, 2017, Denver, CO, USA

ACM 978-1-4503-4655-9/17/05...$15.00
DOI: http://dx.doi.org/10.1145/3025453.3025915

BACKGROUND

Corporations and city councils increasingly roll out technologies that collect large amounts of data to manage and control resources and services from the top-down [32, 34, 66]. While top down approaches can contribute to the development of technical infrastructure for urban efficiency, they have often been criticised for leaving humans out of the loop, or overlooking the citizens' concerns and aspirations [31, 65].

At the same time, several community groups at the grassroots level are adopting civic technologies and participatory frameworks to address local issues [24, 67, 68, 50, 69]. In the process, they also strengthen relationships within the group, learn and share skills, and shape their localities [17, 22, 27, 33, 38, 53]. A way in which citizens are contributing to addressing issues is by engaging in citizen sensing; harnessing the capabilities of mobile phones [49, 53, 62, 67, 72] and low-cost sensing devices [2, 23, 38] to collect and share data on phenomena of common interest [20, 30].

Citizen sensing was initially linked to research and citizen science, the latter being a form of crowdsourcing typically instigated by scientists [10, 70]. However, more recently there has been a growing motivation for citizens to engage in citizen sensing without necessarily being recruited by scientists [12, 36, 29]. Such bottom-up participation usually emerges when citizens share a matter of concern and the purpose to effect collective action [29, 41, 54]. Recent examples of bottom-up initiatives are monitoring water pollution in Massachusetts [51], radiation in Fukushima [38], or air quality in Amsterdam [36].

However, there are challenges associated with the scalability and sustainability of citizen sensing. Research has shown, for example, that people often lack the skills required to operate sensing technologies [24], and struggle to make sense of the data collected [4, 72]. Crowdsensed data has often raised accuracy, privacy and security concerns [30, 60, 73]. Promoting the sustainability of bottom-up sensing interventions goes beyond the design of technologies and the organisation of deployment pilots [4]. There is a need to have an approach that galvanises people around a shared purpose, fosters capacity building [39] and the development of technical skills [46]; as well as a sense of shared ownership [19, 63] over the intervention. Community championing and participatory orchestration have been identified as helping sustain engagement in such interventions [4].

A number of frameworks have been proposed to help steer and design participatory sensing campaigns. But most of this research has focused on the technical aspects of the systems (e.g. [18, 21, 74]) rather than on delivering frameworks that address the orchestrational (cf. [4]) and strategic aspects involved in embedding citizen sensing into the wider socio-economical context of localities. An alternative approach is to decentralise the control over the intervention and the resulting data and technologies [20]. On the one hand, researchers can contribute know-how and advice [37] to communities by handing over or *open-sourcing* their toolkits and methods [55] in order *"for laypeople to not only participate but become active instigators of change in their own right*" [13: p1]. On the other hand, data and technologies can be made open to use and re-appropriated by diverse stakeholders (cf. [42]).

Others have argued in favour of adopting Participatory Action Research (PAR) principles in the pursuit of more democratic and inclusive civic technologies (e.g. [28]). Forms of PAR have been used in urban informatics [7] and community technologies [15]. PAR can facilitate the development of horizontal governance infrastructures and practices for civic engagement, as well as to provide a framework for researchers and communities to collaborate on equal footing in the pursuit of positive social change [28]. Nevertheless, as a method PAR can be underspecified, making it difficult for non-experts to apply its phases in practice: What should be planned? When does technology come in? What value should be created in each phase? How and when can the outputs of an intervention be opened up and become useful to the broader community?

Our approach builds on the PAR phases (plan, act, observe, reflect), integrates principles of participatory and user centred design [8, 9, 14, 26, 47, 58] and a rhetoric of openness [13, 44, 45, 64]. The aim is to create an accessible and actionable framework, that can support communities in building their own tools, while helping them produce and manage their resources in terms of a commons (cf. [52]). The framework also comprises 2 critical components supporting the *why* and *how* of citizen engagement. The *why* is given by the focus on the *city commons* as a narrative and on matters of concern as a purpose to engage people and foster prosocial behaviour [5, 6]. The *how* is facilitated by breaking down a complex process of technology co-design and deployment into a sequence of actions that are easy to follow. The framework also describes the means by which groups can co-organise, rather than being managed by the researcher. The role of the researcher, therefore, is to explain, fire-fight and help, but not to control or manage.

THE DEVELOPMENT OF THE FRAMEWORK

The framework was developed over two stages. An initial stage comprised a long investigation of community engagement with bottom up technology interventions, in particular, citizen sensing [3, 4]. This phase revealed crucial factors associated with the sustainability and scalability of participatory technology interventions. These were: (i) enable participatory dynamics to foster community ownership and meaningfulness; (ii) support the development of technology skills and data literacy among communities of non-experts; (iii) provide engagement opportunities derived from focusing on local matters of concern; (iv) enable collaboration among diverse

stakeholders; and (v) support community champions who can orchestrate complex collaborations throughout.

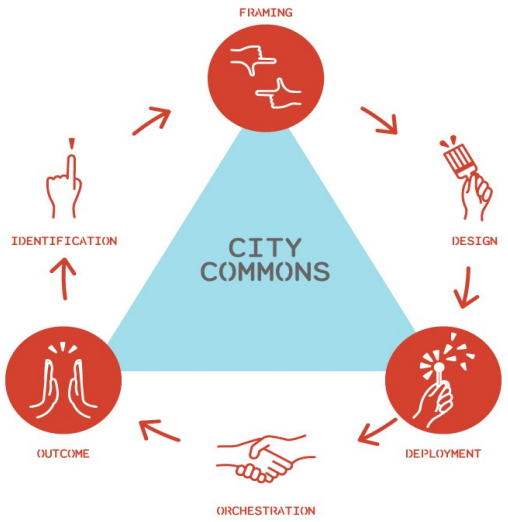

Figure 1. A *city-commons* approach to citizen sensing.

A second stage of development was organised in response to the needs of the non-profit organisation Knowle West Media Centre (KWMC), who had support from Bristol City Council to deliver an inclusive and sustainable citizen-sensing programme in Bristol (UK). KWMC is based in Knowle West, a community that experiences challenges such as low education attainment, poor heath, under employment, and fuel poverty. Since 1996 KWMC has been working with residents, local organisations and young people to develop new and creative models for achieving positive social change. A factor that differentiates KWMC's approach from those followed by other organisations is their focus on media arts, creativity and activism.

In early 2015 KWMC contacted the first author to collaborate in the design of the citizen sensing programme. The stakeholders were: KWMC, the researcher, Bristol City Council, and the innovation think-tank Ideas for Change. The stakeholders agreed on the need to synthesise the previous research findings in an actionable framework that would enable KWMC to run the programme on their own terms, communicating stages and requirements to a range of people. The stakeholders engaged in an action research project in order to design and deploy the framework, that would achieve the following goals: (i) draw engagement from matters of concern and communities of interest; (ii) follow participatory methods to create a sense of ownership among participants; (iii) support the development of technical skills and data literacy to increase the appropriation and sustainability of the intervention; (iv) produce open and shared resources (i.e. data, technology, skills and know-how); (v) encourage discussions on data privacy, ownership and governance; and (vi) foster entrepreneurial opportunities. Here we describe a 16-month long cycle, which consisted of planning action, taking action, evaluating and reflecting [16].

A commons approach was chosen to foster sustainability and participation in the governance and ownership of data and technology for public use. A commons is an alternative to the traditional private/public forms of ownership and management of resources, and is characterised by attributes such as community governance and openness [25], altruism and prosociality [6, 52]. Examples of commons vary from community gardens to Wikipedia and Creative Commons [43]. In agreement with these principles, the framework promotes the development of a *city commons* – in terms of broadly accessible capital (from assets like data and technology, to skills, knowledge and social relations) that is managed by a community of contributors.

Building on PAR, the framework comprises 6 cyclical phases: identification, framing, design, deployment, orchestration and outcome. While well known in the HCI community, their rationale and sequencing need to be understood by those who are to follow them. To aid this process of adoption, a diagram (see figure 1) was iteratively developed. The goal was to achieve an object that could be used to follow and communicate the *why* and *how* of the intervention without relying on complex terminology. Simple and memorable shapes (triangle and circles) were used to highlight the 3 core phases that produce *city commons* (i.e. a map of issues, technologies and data, and skills and know-how) and 3 sets of actions that are required to achieve each phase. A set of icons was developed using human hands to convey the centrality of the human factor in the process. Below, we describe in more detail each phase of the framework.

(i) Identification

The 1st phase involves identifying matters of concern that citizens care about and are prepared to give their time and energy to address and/or communities that already have well established matters of concern [40]. This includes mapping out communities, organisations, businesses and other bodies that are affected by the issues and who might be interested in working together towards a solution. This phase was done primarily by KWMC in coordination with stakeholders such as neighbourhood associations, community groups and residents. The role of the researcher is to suggest methods for engagement and documentation (cf. [19]).

(ii) Framing

The 2nd phase involves exploring the resulting issues in more detail: identifying how technology and data can be utilised to help tackle it, uncovering existing commons and resources that can be drawn upon, and noting if there are any gaps in resources or knowledge that need to be filled. Framing a matter of concern helps to identify what can be done to solve the issue and to manage expectations, which

is known to be crucial in fostering engagement with participatory projects [1]. This phase includes workshops where scenarios and futures techniques [8, 48] are used to foster the collaborative development of new solutions to social problems. The role of the researcher is to provide guidance based on existing suitable tools and interventions and to suggest methods to frame the issue and envision viable solutions.

It was important that a group of stakeholders, coordinated by KWMC could come together at this stage to share the sense of ownership over the intervention, agree on its overall goals and timeframe, discuss what results are expected and how they will be assessed, and consider any funds that might be needed. The contribution of this phase to the *city commons* is a map of framed matters of concern.

(iii) Design

The 3rd phase involves designing the tools and interactions that are needed to tackle the issue at stake. To ensure that people can effectively contribute to the intervention, the stakeholders must identify the skills that are necessary for communities to develop and use the technologies and then design the actions that are necessary to enable such learning [46]. Additionally, this stage requires the creation of a governance and management protocol for the resulting data and technologies [52]. This phase draws from User Centred Design and Participatory Design (e.g. [14, 58, 47] to co-design situated ICT that take into account users' requirements and aspirations. The role of the researcher is to support the co-design process by recommending methods and tools, and helping negotiate design tensions.

(iv) Deployment

The 4th phase involves the deployment of technologies to be tested *in situ,* iterated and improved. By testing technologies in the wild the participants can collect data on how people interact with the tools in their natural environments and without instructions [19, 56]. They can also identify security and privacy concerns, and address them, taking into consideration the needs and views of the community. The researcher can provide advice on how to test the tools, collect data and make sense of the findings. Key to this phase is the organisation of events to enable social interactions between community members with different levels of expertise and experts who can contribute knowledge about the technology and the issue at stake. The goal is to support social cohesion and the development of skills to ensure uptake and appropriation. This phase contributes to the *city commons* documentation on open source technologies, open data, and new skills.

(v) Orchestration

The 5th phase involves sustaining the engagement of the contributing community as well as scaling it up to engage a broader group of people. This is done by organising events (i.e. data jams, hackathons or meetups) where participants with diverse skills can meet and use the data that has been collected during the deployment to create visualisations or discover correlations. The aim is to instil a sense of meaningfulness by demonstrating the usefulness of the co-created resources. This phase draws from the findings of previous studies such as [3, 4, 19 and 46] that signpost the need to *infrastructure* [41] and enhance collaboration by assigning resources, supporting social interactions and the development of skills, as well as organising celebrations [35]. The role of the researcher is to suggest engagement strategies, support the development of skills, and to help expand the network of stakeholders by raising awareness about the intervention.

(vi) Outcome

The 6th phase involves reflecting on the intervention and assessing if and how the goals were achieved. It includes finding out what participants have learned, and sharing insights gained from using the framework. It also involves ensuring that the resulting technologies and collected data are accessible to third parties. The aim is to support external appropriation leading to the creation of new solutions for the issue at stake, the identification of entrepreneurial opportunities, and or changes to the available infrastructure. For example, if the community is addressing a problem in mobility and shares pedestrian navigation data, the Council could use it to plan new public transportation routes while car owners could make earnings by covering non-serviced trajectories through a ridesharing platform.

Here, the role of the researcher is to support the process of data collection and analysis to assess the outcomes of the intervention. This phase contributes to the *city commons* new open and community managed solutions to local issues, new social collaborations and relationships, and know-how on how to apply the framework.

THE APPLICATION OF THE FRAMEWORK

The framework was first applied during a 10-month activation phase focusing on two neighbourhoods where a large proportion of residents face challenges such as fuel poverty and unemployment. It was coordinated by KWMC through its media arts producers (here sometimes referred to as community coordinators). 45 events and workshops were run, with over 717 participants aged 13-80. The large number reflects the level of interest and diverse groups who were interested in adopting the approach. Here we report on one of the three outcomes from this stage: the *Dampbusters intervention* that sought to address the problem of damp housing in the city.

Fieldnotes were collected by the researcher and the media arts producers, through direct observation of the activities and conversations that took place during the workshops and events. The focus was on how well the activities in each phase supported the aims of the project and what type of difficulties were faced by the community. Additionally, 12 interviews with community coordinators and participants were conducted and two group debriefing sessions were organised to reflect on the overall experience. The scale of the activities performed and participants engaged meant

that decisions had to sometimes be taken on-the-fly, and that we had to be selective in the data collection process.

FINDINGS

We present examples of the activities and tensions that took place during the 6 phases (along with their duration) that led to the *Dampbusters* project and the themes that emerged as a result of the thematic analysis [11]. Informants are identified by initials and their role in the project.

Phase 1: Identification - Duration: 4 months

Activities. The goal was to identify issues that people care about and are prepared to spend time and energy in addressing. KWMC carried out 3 key activities for this:

(i) A city-wide network analysis involving direct phone calls and visits to neighbourhood partnership meetings and with stakeholders from charities, community groups and a range of City Council departments. This led to the creation of an initial map of existing neighbourhood priorities.

(ii) Conversations in hotspots with residents were then conducted by two artists, commissioned by KWMC. This entailed talking to people in places where they congregate such as at tattoo parlours, bingos, cafes and nail bars. This method provided a more nuanced understanding on the local matters of concern and the everyday experiences of people affected by them. It also revealed the general climate in the areas, often marked by a feeling of exclusion and disenfranchisement. As described by one of the artists: *"There's a geographical divide of course (the river), but a much greater social and cultural one"* [PH].

(iii) A Networking event was organised by KWMC in partnership with a local HackSpace and university, where people with diverse skills (from technology to community work) were invited to experiment with sensors and learn about the framework and contribute to a "commons wall chart" that logged things people were willing to share such as skills, technology, data and time.

Community engagement: social interactions

Throughout this phase a large number of meetings took place between neighbourhood associations and residents. The media arts producers and researcher also attended many meetups and other events to present the approach and build relationships. Although time-consuming, these face-to-face meetings helped to raise awareness about the approach and resulted in much engagement:

"Face-to face conversations and direct visits to existing groups meant that we raised a lot of varied interest in the project and for the first workshop had about 60 people attend, and more register their interest " [MK].

As a result, a broad group of participants were engaged:

- **Technology volunteers:** members of HackSpace, employees of technology companies (e.g. Altitude and Toshiba), Bristol & Bath Things Network Meetup group, comprising experts and hobbyists interested in electronics and robotics;
- **Data volunteers:** people working at small enterprises and institutes such as Data Unity, South West Data Meetup group, Open Data Institute Bristol, IF Project, Networked Planet, and a data privacy lawyer;
- **University volunteers:** researchers and students from disciplines such as geography, politics, computer science, and engineering;
- **Artists:** performers, fine artists, makers, interaction designers, residents at PM studios Bristol;
- **The City Council:** Futures team, Environmental health, Housing, Volunteering, Bristol Is Open, etc.;
- **Schools:** 30 children aged 8 and 9.

Tensions: negotiating matters of concern

The media arts producers acknowledge that the identification phase took longer than expected and that a line had to be drawn for the project to move on. This was done after having identified a number of recurrent issues that were supported by groups of people. As indicated by the director of the media centre: "*We knew we had limited time and resources (…) Once a number of issues were identified we 'sense' checked them internally – had they the potential to be sensed?"* [CH]. However, this raised concerns regarding the transparency of the process behind the selection of the issues. As explained by one of the community coordinators:

"Some issues were so complex that focusing and framing them caused divisions (…) it is essential to be transparent about the likelihood of issues being taken forwards (…) A clear criterion for assessing, determining and eventually choosing 'sense-able' issues is needed." [MK].

Phase 2: Framing - Duration: 3 months

Activities. Questioning matters of concern. An initial table of issues was made and narrowed down based on the answers to three key questions that were proposed by KWMC in an effort to establish criteria for the selection of issues: (i) How active is the issue, i.e., is there a large enough group of people interested in this area and would they be able to participate in workshops? (ii) How applicable is the issue to sensor technologies, i.e., could sensor and data help tackle the issue? (iii) Is the issue realistic in scale, i.e., could a prototype tool make a real change by the end of the pilot phase? Is it scalable? The issues explored were: damp homes, use of high streets, and the correlation between city biodiversity and health.

Contacting and (re)visiting community groups. Once the issues were selected, the media arts producers contacted issue specific groups that they thought would be interested in participating, including those who had been involved in the previous phase.

A *workshop day* was organised by KWMC to explore the approach, data, sensing and how to frame the issues. Around 60 people from 13 to 80 years old attended this

event. Early on it became apparent that the issue of damp homes had more momentum and interest than the others. Damp homes contribute to a range of health issues and social stigma, and the perpetuation of poor quality housing stock, which is often low in value because the problem is not owned or dealt with.

Reviewing existing and missing knowledge. KWMC contacted experts from the UK's Open Data Institute and energy and retrofitting specialists to collaborate in identifying the tools that could help tackle damp, from sensors to data that was available to use or learn from.

Community engagement: purpose

There were many reasons why people felt motivated to address the problem of damp, and this shared purpose supported a strong sense of engagement. As workshop participants explained:

"[Due to my work] I spent a lot of time dealing with people living in housing which is not good enough but I never had the money to solve it (...). This project opens up ways of solving the same old problem but with a new approach. It gives the control back to people" [ST]

"I came here to see how we can create things to help people living in horrible conditions." [MA].

Moreover, experts engaged because they saw value in collaborating with others to support their causes, and to have access to tech expertise and a community of engaged citizens. Finally, the idea of the *city commons* attracted people and gave them a shared vision to work towards to. As a workshop participant said: *"The concept of the commons interests me greatly - that's what brought me here."* [II]. A media arts producer explained: *"The notion of a 'city commons' brings people together and inspires them to (...) work together to make change"* [MK].

As a result, a diverse community of stakeholders were galvanised to address the problem of damp houses. They named themselves *Dampbusters*, giving them a sense of identity and purpose. They all agreed to chart the houses with damp to demonstrate the scale of the problem and to develop sensors that could measure temperature and humidity (these data are crucial to assess if there is condensation resulting from normal household activity or there is a structural damp problem). To cover some of the costs of the intervention KWMC allocated funds from a grant provided by the City Council, and it was agreed that the project would run until August 2016 using this funding.

Tensions: matters of concern and a common language

While identifying a matter of concern is a powerful way of harnessing the energy of communities, this also means that expectations and urgency to address it are high, which can be hard to manage: *"It was difficult to manage workshop participants' expectations. Some seemed to want to go much further with solving the issue in the first workshop."* [ME]. Furthermore, during the framing activities, it became evident that demystifying complex notions such as data and sensors was crucial to make participants feel involved. As explained by one of the community coordinators:

"The decision to delay any tech introduction was effective in bringing people together and creating an open inclusive environment (...) Each table was given a 'jargon buzzer', a bell, to be rung when any one started using language that was specific to a particular niche background" [MK].

Contribution to the city commons

The selection of identified issues and communities of interest were then shared through an online open innovation platform (madeopen.co.uk) where people can further discuss them and possibly work towards tackling them.

Phase 3: Design - Duration: 4 months

Activities. KWMC organised *workshops*, *group maker sessions* and a *data hack day*. The innovation think tank, the researcher and KWMC organised a workshop aimed at enabling collaboration between citizens, housing associations, the City Council, data, energy and damp experts and the contributing community to discuss scenarios where new collaborations among them could help to solve the problem. During the workshop, participants brainstormed ideas to prototype a "commons damp-busting tool" which could map damp homes, measure temperature and humidity in homes, trigger and enable actions (e.g. issue a report or recommendations to landlords/tenants), and keep the data secure considering privacy implications.

Technology co-design. Based on the outcomes of the conversations with the damp and technology experts and the people who have damp at home, a prototype sensor was designed and built. Various designs were created and critiqued in a co-design workshop. During the workshop, many good ideas were suggested: "*There were a lot of ideas for the box, including variants of a dancing sunflower* [NL]. The participants agreed that the sensors should be suitable for homes with children, adults and pets. Eventually it was agreed to develop one that had widespread user appeal – one that looked like a frog – and affectionately became known as the Frogbox (in figure 2).

Five devices were built using Raspberry Pi3 and DHT22 temperature and humidity sensors. Due to time and funding constraints, the group decided to make and test a few sensors before scaling up to larger numbers. One volunteer with software development skills took the lead in coding and making the sensors. His motivation to participate was *"doing good"*, as he had recently purchased a Raspberry Pi to tinker but thought that *"making something useful that will help people"* was better than "*playing around*" [NL].

The Frogbox was designed to collect data every five minutes using a Python script. It was then saved to a local MySQL database. This sampling was considered sufficient to obtain data about changes in moisture. A simple website running on each box was developed to provide users with access to the data. It was first decided that the Frogboxes

would relay data to a web platform but the community had to scale down their expectation to ensure that it was accessible to all: *"... we could not guarantee that the households we deployed to would have access to the internet"* [NL]. The first basic prototype of the frog box was created a week after the workshop, and then developed over the following two weeks until the final working prototypes were created. The overall design lasted just under 6 weeks. A member of the community who has experience working at a Maker Space led the fabrication of five green frog-shaped enclosures built using plastic and Velcro tape. Additionally, one participant, also using open source tools, built a prototype for an online damp reporting tool, which was tested and is currently under further development.

Data annotation. It was suggested that keeping a diary could help people understand what tenants can do to reduce damp at home. For this, the Frogboxes were designed to sit on cardboard lily pads for people to annotate the timestamp of events that might lead to condensation such as taking a shower, cooking, or drying clothes on a radiator.

Figure 2. Side and rear view of the Frogbox sitting on a cardboard Lilly pad.

Community engagement: ownership

From the conversations in the workshops it emerged that people were less concerned about where their data would go than how the issue would be solved *("If it helps us move towards solutions we would gladly share our data with the community"* [NN, community member]). The community decided that those who participated in the project were contributing to a shared resource and therefore the data had to be open. An exception was considered for more private data (i.e. geo-located reports), which would need to be aggregated and anonymised. While deciding where the data would be hosted, "*[They] seemed more comfortable with the idea of data being held by a not for profit organisation than by the City Council."* [MK]. Regarding the ownership of the technologies, it was agreed that they would use and produce open source tools. Moreover, to cover the cost of the Frogboxes (and later for the deployment), KWMC allocated a further small sum of money (£300) from a grant given by the City Council. Participants administered the funds following a participatory budget approach, using the online voting tool, stickymoose.com.

Tensions: orchestrating co-design

While co-design sessions were fruitful for brainstorming and creativity, the media arts producers agreed that it was sometimes tedious to make collaborative decisions on every step of the process, and often only a small group of participants ended up doing the more sustained making. Moreover, the decision to choose one technology over another caused tensions in the community: a group of Arduino enthusiasts left the workshop after it was decided to use Raspberry Pi. This was not effectively dealt with in situ, resulting in a group of technology skilled volunteers disengaging. However, the community later discussed this event and agreed to, in the future, encourage parallel lines of development (known as forking) for participants to contribute using the tools that they were familiar with.

The media arts producers noted that travel was sometimes a barrier for attendance to co-design workshops. After much discussion it was agreed that workshops needed to be held in the local area. They also suggested that a tool to aid co-design should be developed to allow them to share documents and pictures for people to participate in the design process on their own terms. These findings, tensions and recommendations on how to address them were documented to ensure that learnings could be aggregated and contributed to the *city commons* in the final phase.

Phase 4: Deployment - Duration: 2 months

Activities. An 'on the ground' engagement team was assembled who had existing relationships with neighbourhood residents and were able to recruit people to test the sensors in their home. This was partly achieved because since the beginning of the project KWMC developed good relationships with local organisations such as energy and neighbourhood associations and charities through inviting them to workshops and keeping them updated. The community agreed to use a part of their budget to pay to Easton Energy Group (EEG), a social enterprise helping local residents to reduce energy poverty, to involve residents that they knew in order to test the Frogboxes. They also announced the deployment in local newsletters and neighbourhood partnership meetings, and sent emails to interested parties.

Testing sensors in the wild. The Frogboxes were deployed for two weeks in 5 homes in the neighbourhood. These were selected by the community in collaboration with EEG because they were severely affected by damp. The tenants were trained to understand how the technology worked and the data was collected. They signed a data agreement that had been co-created in the design phase.

The media arts producers and the participants involved in the deployment of the sensors collected users' feedback. For example, they found that while people enjoyed having the sensors at home they wanted to have an easier way of visualising the data and to acknowledge the state of the sensor. The participants are currently working on a new version of the Frogbox that relays the data to an online

platform and comprises LEDs to indicate if the sensors are on, off, reporting data, etc. The notes taken in the lily pad journals helped people understand how little behaviours can make a big difference to reduce condensation at home. For example, some people didn't like taking a shower with the bathroom window open, but they discovered that opening it up right after the shower has the same effect and is something that they are willing to do.

Community engagement: meaningfulness and skills

The community, in particular those who participated in the design and deployment, felt rewarded due to the positive evaluation of the Frogboxes. As two participants mentioned: *"People were excited to have them in their homes"* [NL] and: *"We were very lucky we didn't have a single house that changed their mind after we started"* [ST]. The sensors worked as expected apart from one that stopped reporting data before the end of the testing period. The community suspected that the children at that house put the Frogbox in contact with water: *"The dangers of making a sensor that looks like a frog!"* [NL]. They also felt inspired by some of the stories that emerged. For example, an unemployed resident not being able to afford to pay for heating in a house seriously affected by damp hosted a Frogbox and an off-the-shelf electricity meter. After learning how to use both sensors he noticed that his energy bill did not correspond to his real consumption. He used the data to confront the energy company and demand a reimbursement, which was granted. This story of empowerment strengthened a sense of community among the participants: *"Just for a story like this our efforts made sense"* [ST].

Developing skills. Face-to-face conversations with tenants and training events were organised by KWMC and a network of partners to ensure everyone understood what the sensors were and how they worked. For example, a half-day workshop was run to train 16 local residents to become 'community damp-busters'; people who are knowledgeable about the problem and able to share expertise with others. The initiative also inspired other groups to organise activities to help build know-how about citizen sensing. The local Hackspace ran a sensor-making workshop and paired 'techy' with 'non-techy' people. A Hackspace in a neighbouring city (Bath) is now running a series of meetups to help people learn sensor and data literacy. An evaluation dinner was held for residents to decide how to improve and move forward. This included sharing of data, data analysis and discussions on how best to make data meaningful.

Tensions: ownership of the commons

A housing association approached the community, requesting to buy the Frogboxes. In response, the community member who had led the development of the Frogboxes launched a business to service the sensors and help tenants tackle damp. While fostering local entrepreneurship is a desirable goal, it was not expected that this would occur at such an early stage of the project. However, it created a tension especially regarding the ownership of the prototype: *"…we have a real example of a situation where we need to think about ownership and sharing data. Whilst we may not have a ready solution it is very useful to have a tangible case study"* [CH].

Contribution to the city commons

The outcome of this phase was a set of open source technologies documented in free repositories (GitHub), open data about damp, new relationships and skills.

Phase 5: Orchestration - Duration: 3 months

Activities. A data 'hack day" was organised by KWMC where participants (data enthusiasts, damp experts, researchers, designers and citizens with different skills) were provided with datasets, including Frogbox data, self-reported damp homes, City Council health and community data and Land Registry house price information. The goal was for them to discover ways that data can be visualised, layered or mapped to help move towards solutions to the issue of damp. Focal questions were: where are the damp homes in the city and how bad is the problem? What is the damp in the houses and how is it affecting people? What other factors might play a part in the problem?

Celebrating achievements. A big event was organised in a well-known venue in the city (Bristol's Data Dome) to celebrate the achievements of the *Dampbusters*. The event was part of the city's annual biennale; the aim was to explore how technology and data could be used for the common good through a playful performance.

Community engagement: meaningfulness and networks

The participants were highly motivated during the hack day and expressed their enthusiasm in Twitter: *"Great hack day @knowlewestmedia today for #bristolapproach. Smashed this together to show damp home factors #Dataviz" [DB]* and *"an interesting day exploring damp homes data at @knowlewestmedia #bristolapproach…" [MB]*. They found correlations between data on the topography of the neighbourhood and damp reports, as well as correlations between damp and the number of inhabitants in a property.

In addition, new forms of cooperation among stakeholders emerged. People contributed photos to the *city commons* of damp in their and others' homes, and worked with damp experts to identify the type of damp. Other community workers stepped in to provide advice to the participants on how to take action to prevent damp. This entailed, for example, opening the bathroom window after having had a shower, ventilating the kitchen while cooking, and not drying clothes on the heater. KWMC then provided the Council officers with the collected evidence of damp along with proposed new measures on how to improve the situation (i.e. considering change to the licensing of private landlords). Landlords and tenants were encouraged to work together to solve problems for mutual benefit.

Tensions: Developing skills

Although much work has been done to support the development of tech skills and data literacy among participants, sensing technology requires new skills to be learned – otherwise it means only a few being able to make and implement them. How this skills and training process is funded and managed can be a source of tension especially in terms of progressing a project and managing the data. The media arts producers acknowledge that more needs to be done. The director of KWMC was aware of this: *"... We are about to launch a tech and cnc/laser cutting skills programme for 120 community members (...) We see a need to run tech skills programmes alongside the project"* [CH].

Phase 6: Outcome - Duration: 1 month

Activities. The project was perceived to have delivered a successful outcome, by the councillors, local residents and community groups. New partnerships were developed between renters, council workers and damp experts who are collectively tackling the issue of damp homes. The outcome of the Dampbuster project was able to contribute to the *city commons* in the following ways:

- New tools (Frogboxes and mapping tool) were co-designed and shared using open source technologies;
- Open data was gathered to help visualise the prevalence of damp homes and its correlation with other factors (health, house prices, and people's habits at home). The community is negotiating the integration of these data in Bristol's open data platform;
- New networks were created to extend the reach of the project and support inclusive participation;
- Participants developed technical and data literacy skills;
- Business opportunities emerged;
- Learning on how to apply the framework was shared through a "users' guide" that is available online;
- Other communities are looking at using the framework, which has also received media coverage from the BBC, Wired, Dutch National Television, etc. The framework was presented at the House of Lords as an example of good practice of citizen engagement in the UK.

During the debriefing sessions and interviews the contributing participants and the media arts producers often reflected on "the approach" or "the framework itself". They agreed that the framework had helped them guide and orchestrate collaboration while keeping everybody updated, engaged and on board. As this participant suggested:

"Through this approach, people can really start to feel that their voice is being heard and that something is actually being done about it. I feel the framework works well, and is a necessary guide to prevent the project going off course and help guide the activity [FD]".

The framework also provided a narrative that attracted and galvanised people under a shared vision: *"It's given us a way of explaining how we collectively build commons thinking, and put forward a more collaborative city (...). We're building a different narrative to challenge the smart city tech-down thinking."* [CH].

DISCUSSION

The framework was highly successful in galvanising different members of a community to address the problem of dampness affecting several households. It enabled collaboration among diverse stakeholders (from residents living with damp to City Council officers, tech and data enthusiasts, experts and community workers), and the co-design of bottom-up sensing and mapping technologies that played a key role in enabling people to record, visualise and analyse the scale of the problem. However, the findings suggest that the framework was more than just a guide to orchestrate participation. It also became a narrative tool that allowed KWMC to gain support for its work on citizen engagement (in practice often overshadowed by technology). In addition, it enabled people to work towards a shared vision, where the commons acted as a magnet for engagement. The participants felt represented and empowered, and experienced joy in contributing time, resources and efforts to address common issues ([cf. 57]).

The framework also became a boundary object [61], a *lingua franca* that scaffolded the complex collaborations on the ground, allowing KWMC to drive a process that entailed intricate social, political and technological dynamics. Having 6 clear stages helped the community to reflect on the work that was being made, to celebrate achievements and to learn about the processes that were enacted. For example, when someone was talking about planning activities at the design or the orchestration phase it was understood how they followed or preceded other planned ones. The framework works well as a coordination device. However, it requires also taking the following considerations on board.

(i) Start with a matter of concern and manage expectations

Starting with matters of concern is crucial for gathering engagement and momentum among a loosely connected group of people [24]. Our case study showed how dampness was particularly pertinent to those living in rented accommodation, where collecting evidence of its prevalence through new sensing technology was a powerful vehicle to move the community and the Council into action. However, matters of concern imply urgency and are often contested. It is key to manage expectations from the outset, making sure people accept the timing of the intervention and explore all possible ways of tackling the issue.

(ii) Identify a sequence of actions for each phase

As discovered in the *Dampbusters* project, following distinct phases that have a beginning and an end helped the stakeholders plan, orchestrate and communicate actions. Although phases can overlap and it can be useful to move back and forwards sometimes to revisit actions the framework provides the backbone against which to do this while keeping the process on track. Phases also create opportunities for reflection and celebration of achievement,

while they facilitate the process of sharing learning [35]. Furthermore, the work of community coordinators can be supported by the use of digital tools that enable commons action groups to form, communicate, organise, and make decisions together, as well as map, visualise and make sense of data.

(iii) Role of the researcher: resist the urge to control and embrace openness

Supporting the orchestration of such a complex project in the wild necessitates making decisions with partial (or no) knowledge on tight timescales. There is a balance between structure and having to make decisions on-the-fly. The level of specificity of the framework, which allows for community coordinators to decide what type of activity should be conducted and for how long in each phase is appropriate for this kind of process [61]. The role of the researcher is crucial here as she can suggest methods and tools, fire-fight and support the community in making suitable decisions, foreseeing and helping sort out tensions.

(iv) Foster inclusive engagement by creating networks and supporting the development of skills

Building relationships between existing local communities is an obvious way of increasing and scaling up engagement. But it is easier said than done. Key is to provide an openness to the project, that enables 'on boarding' of people and groups at various stages, who have an investment in the issue at stake or have something to contribute to the intervention. Likewise, it is important to work out how best to leverage existing networks, know-how and resources. Face-to-face encounters, from visits to meetups are central. However, to sustain engagement it is also important to *infrastructure* the community by providing technical skills and data literacy training in a way that is accessible and enjoyable. Strategies to foster social interactions and develop skills include: organising workshops in the local area, adopting a common language to prevent the use of complex and niche terminology, and encouraging interactions between experts and non-experts in a context of horizontal collaboration.

(v) Adopt a commons approach to foster prosocial behaviour and conflict resolution

Due to its strong focus on the commons, as an alternative way of creating and/or managing resources that can contribute to the common good, the framework became a vehicle to discuss tensions that are important when using sensing technologies. For example, the issue of who owns the technology and the data was raised when someone saw an opportunity to develop the frog prototype into a business. Moreover, tensions emerged when deciding which issues should be addressed and what technologies should be used. It also became apparent that the framework was not enough by itself, as other tools for the coordination of participatory processes were necessary to keep people updated and engaged in between events. The community followed an open and participatory approach to resolving such conflicts, enacting democratic and transparent mechanisms for decision making, such as participatory budgeting, voting, and open debates.

The framework should not be seen as a blueprint for community engagement when addressing local or global concerns, such as recycling, air quality, litter, etc. As our case study has shown what it can do is to provide a way of coordinating a multi-faceted process with different expectations, skills, and where challenges and tensions arise along the way. Often community projects fail because such problems arise and are not resolved effectively or where funding becomes the main concern. Our experience has shown how the process of orchestration and infrastructuring can both facilitate and overcome the tensions that invariably arise in these kinds of sociotechnical projects.

Moreover, the case study has shown how it is possible to scale up a community project - not in terms of the number of devices made or deployed per se - but instead with respect to the widespread impact it can have on raising awareness across different community, government and user groups. It also demonstrated how an overarching vision of a bottom-up approach with a central concept of the *city commons* was able to keep disparate processes and actions together as they democratically evolved. This achievement was all the more remarkable as it engendered much good will over a sustained period of time despite the challenges and constant backdrop of limited funding. The researcher's role was key - not as a masterminder - but as a facilitator and a bricoleur, on the one hand, taking aspects of HCI methodology and importing it over to communities to use, and on the other, as a firefighter and fixer, mending miscommunication and tensions as they arose.

CONCLUSION

We have presented a new framework that outlines how communities can design and use sensing technologies to address their concerns and aspirations. The starting point is to tackle community matters of concern and foster citizen contributions while nurturing a *city commons*. The framework can be used by community groups, organisations and stakeholders in governments to guide and scaffold participatory processes. The role of the researcher is to galvanise, assist and offer external help at pressure points, when a tension arises. They can provide the bridge between those who lack technical and data literacy skills, with those who have such skills and want to provide their expertise. The framework comprises six easy to follow phases, intended to be used by different stakeholders, to work together to produce novel solutions for urban challenges. By fostering collaborative practices, the *city commons* approach can promote social innovation and community capital.

ACKNOWLEDGEMENTS

We would like to thank all the people who contributed to the #BristolApproach. This research was made possible by Intel ICRI Cities, Bristol City Council, KWMC, and Ideas for Change.

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