Matching Technological Societal Innovations: The Social Design of a Mobile Collaborative App for Urban Noise Monitoring

Bruno Lefèvre, Valerie Issarny

Matching Technological & Societal Innovations: The Social Design of a Mobile Collaborative App for Urban Noise Monitoring

Bruno Lefèvre, Valerie Issarny
Inria, France
{First.Lastname@inria.fr}

***Abstract*—Mobile Phone Sensing offers a great opportunity toward the large scale monitoring of urban phenomena, such as the exposure of the population to environmental noise. Our research aims to make available a supporting mobile application together with the associated platform for the analysis of the contributed observations. The technological issues arising have been partly solved but a gap remains between the need for the massive collection of relevant data, and the quantity and accuracy of the measurements that are actually gathered.**

This paper presents our iterative research process to tackle this challenge, which combines technological innovation and social design. The presented research results contribute to a better understanding of why and how people use mobile phone sensing applications; the results also inform how to best leverage mobile crowd-sensing in the development of smart cities and how it may serve addressing urban challenges related to, e.g., public health or urban planning.

***Index Terms*—Mobile Phone Sensing, IoT, Noise data, Crowd-sourcing, Smart cities, Social design, Collaborative digital science.**

I. Introduction

The ability of a city to "*integrate communication and information technologies in all the strata of economical life on its territory*" defines the –at least digital– smartness of a city [2]. The "*use of digital and telecommunication technologies*" is assumed to make the traditional urban networks and services "*more efficient*", for "*the benefit of its inhabitants and businesses*"[1]. Ultimately, the local socio-economical characteristics drive the implementation of the "*smart-city*" concept. Still, both public and private decision makers acknowledge that the gathering, analysis and exploitation of the supporting urban data are among the significant issues facing smart city initiatives.

Monitoring the exposure of the population to environmental noise illustrates the inter-relation of the technological, environmental and societal challenges facing smart city projects. In Europe, more than 30% of the population is exposed to levels exceeding 55 dB(A) at night, while excessive noise exposure causes many health diseases, stress and has economical costs estimated to about 3% of the GDP (57 billion Euros for France)[2]. For western Europe only, more than one million healthy life years are lost every year from traffic-related noise[3]. Toward a better understanding of the problem, European cities are legally bound to provide public noise data and maps. Currently, the required urban noise maps are generated out of mathematical models that take as input the available data about the geography, the topography and the main noise sources –esp. traffic– of the urban environment. Static and spatially anchored sensors then provide real-time measurements that are used to correct the simulated noise maps. However, these noise levels data suffer from uncertainty and unpredictability. More recently, *Mobile Phone Sensing* (*MPS*) –aka *mobile crowd-sensing*– establishes a third source of measurements of noise levels using the microphones of smart-phones [13], [25].

Worldwide, as of 2017, about 2.3 billion people use a mobile phone[4], which makes MPS a significant source of knowledge toward smarter cities. Physical sensing through MPS paves the way for the gathering of urban observations at a massive scale across time and space [13], [15], [19], [27]. Nevertheless, decision making based on the analysis of MPS contributions requires that a critical mass of reliable data (noise measurements in our illustrative example) be made available for the urban area under study. This questions the capacity of mobile users to produce and source accurate data, massively.

The literature documents well the related technological issues [8], [23], while only a few social studies help us to understand why and how urban mobile users get involved in MPS, such as for the collection of noise observations [11]. Indeed, most of such collaborative MPS systems faces a gap between: (1) the requirements of producing quantitative and qualitative data at scale, and (2) the limited deployment and use of the supporting mobile application (app for short). The gap is partly due to the technological research being the primary driver of innovative smart city apps although the social practices and contexts are as fundamental design elements for the target apps. It follows that the developers of MPS-based apps tend to assume that the end-users have interest in collecting and making available observations massively, independent of the actual social practices. The "user" is contemplated ideal-

[1] https://ec.europa.eu/digital-single-market/en/policies/smart-cities
[2] https://tinyurl.com/zo6tuyv
[3] https://tinyurl.com/y8dp3aft
[4] https://tinyurl.com/hy2skfk

istically, through stereotyped and profiled behaviors that match the specific purpose of the app. However, acknowledging the importance of participatory design and open data movement toward smarter cities [17], the development of collaborative MPS-based smart city apps must be part of a social process and not limited to a technology-driven exercise. In particular, social design suggests to deeply integrate the aim of changing social uses and practices in technology-oriented research programs [1].

The usage of a smart city app involves a large range of heterogeneous dynamics and phenomena, which relates to the subjectivity of the end-users regarding their cultural, social and political trends, both individually and collectively. Further, cities are characterized by complex urban ecosystems that involve many interdependent actors [10] together with interactions among social, biological and physical components [21]. The design of MPS-based smart city apps and supporting middleware must account for such complex ecosystems so as to tackle the related challenges of: (1) getting people to communicate massively about the phenomena under scrutiny, and (2) aggregating knowledge that adequately informs urban policies.

Our research is more specifically focused on how to leverage together social practices and technological innovations in the development of smart city participatory apps based on MPS. In particular, many implicit rules, experiences and interactions frame the related social practices. This paper reports on our research findings using the experience learned with the development and deployment of the collaborative Ambiciti app. The Ambiciti app (initially called SoundCity) was developed by Inria as part of the CityLab@Inria project-lab to study the application of MPS toward smarter cities. The app specifically aims at gathering and sharing knowledge about environmental pollution in the urban environment; it was initially focused on environmental noise and was then enriched with air quality data. The app is free for download on the Apple App and Google Play stores.

The contributions of the paper are as follows:

1) We report on our research methodology to combine technological and societal innovations as part of the social design of a MPS-based smart city app (Section II).
2) We detail the observed technological and social, opportunities and impediments, to the massive crowd-sensing of noise data of adequate quality. We summarize key points from these observations in relation with the current version of the app (Section III).
3) We underline the relevance of re-designing the app interface so that the app may meet the various, relevant social contexts of use (Section IV).

II. Fostering Mobile Participatory Sensing: An Iterative Research Methodology

Our aim is to close the gap between: (1) an innovation that is both technological and societal, and (2) the effective massive usage of that innovation to produce new practices and urban knowledge in cities. Our research more specifically focuses on leveraging a MPS-based app –Ambiciti– to inform our knowledge about the exposure of the urban population to noise.

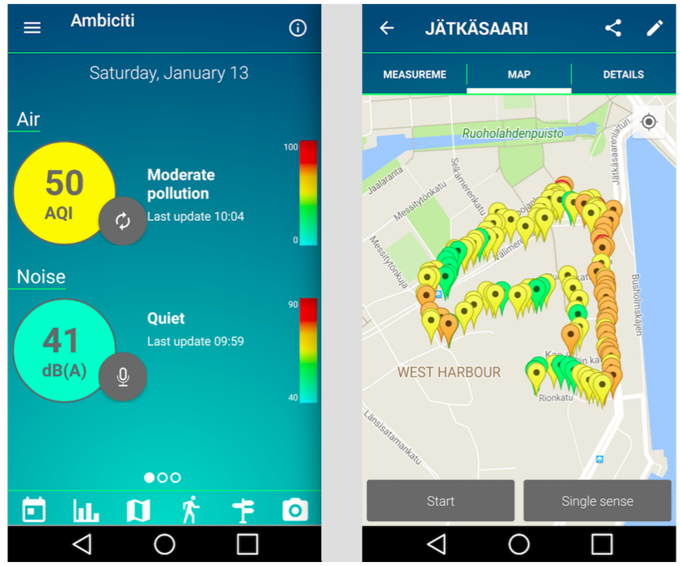

Fig. 1. Screenshots. Ambiciti provides instantaneous noise observations (left) and a mapping of the contributed observations over time (right).

A. The Ambiciti app for noise pollution monitoring

The current version of Ambiciti informs users about their exposure to noise and to atmospheric pollutants, providing generic information about the impact of such exposure on public health (see Figure 1). The app displays information about the environmental noise (resp. air quality) based on mobile measurements using the microphone (resp. numerical simulation implemented on a dedicated server). While running, the app makes automatic background noise measurements and keeps track of the user's location –if the user grants the permission– so that it may accurately inform the users about their exposure over time.

Beyond the monitoring of one's exposure, the app offers a number of additional functions among which: the "*journey mode*" allows the user to pro-actively collect noise measurements at a chosen frequency to map a a given district, possibly collaboratively; the "*map function*" visualizes the environmental pollution on a map; and the "*optimized route*" computes the less polluted itineraries with respect to the user's exposure to the noise and/or atmospheric pollution. The users may access these functions using the menu either at the bottom or at the top left of the screen. The latter menu further provides access to the management of the app parameters, including the calibration of the noise sensing function, and to the data generated by the user. The data collected by the app are stored locally and shared with the Ambiciti server if and only if the user grants the necessary permission and the network connectivity allows.

In order to ensure that the development of Ambiciti did not give precedence to the technological perspectives over the societal ones, and conversely, we undertook a social design process [1] involving an interdisciplinary team of researchers in digital and social sciences. Over three years, the design process specifically iterated along both axes of technological and societal innovations. As we were introducing new technological features to the app, we were gathering the feedback of users as well as analyzing the societal environment in which the new functions got used together with the accuracy of the contributed observations.

B. An inter-disciplinary research process

We articulated the social design of Ambiciti around four main steps, from 2014 to 2017:

1) Starting in 2014, we implemented a first version of the app –named SoundCity– which was specifically dedicated to sharing collaborative noise measurements through MPS. This first instance of the app was intended at assessing the relevance of the underlying technological innovations in the digital sciences areas of MPS middleware and data assimilation [12]. SoundCity has been disseminated worldwide on the Google Play store in Summer 2015 and then the Apple App store in Autumn 2015. We carried out the first formal launch in Summer 2015 with the support of the city of Paris[5].
2) From the initial launch till mid-2016, we organized public events in collaboration with the city of Paris, which contributed to the in-depth study of the actual usage of the application [13]. This step included holding events as part of the annual "*Journée sans voiture*"[6] or "*La semaine du son*"[7]. Citizens were encouraged to participate to measurement journeys and, then, to visualize on a map the noise levels data that they sourced. Such a collaboration with the city of Paris was renewed in 2016 and 2017. We observed: (1) the performance of environmental noise monitoring using MPS from a technical perspective, and (2) the social dynamics and urban policies that SoundCity may support.
3) Following, we produced a second version of the app, with significant technical optimizations (e.g., wrt calibration and energy consumption) and new features. SoundCity became Ambiciti as the app and underlying data platform generalized to a global environmental data service, and resulted in a technology transfer to the Ambiciti start-up company[8]. Since September 2016, the Ambiciti app provides its users with various functions to contribute and access to environmental knowledge.
4) Since Spring 2017, we have been developing a number of social tools to observe and analyze the usage of MPS-based smart city apps, with Ambiciti serving as our use case. Our study has been taking into account the cultural and societal contexts that the usage of environmental crowd-sourcing could feed, spanning health, quality of life, education, and urban policies. We carried out an online survey from June to December 2017 to which 60 users answered (see Figure 2 for an overview of the panel of contributors). In addition, we ran fifteen interviews with users and local actors in Europe, i.e., France, Belgium, and Finland. Last but not least, we supported the organization of ten workshops, in French and Finnish cities, to raise awareness about noise measurements using MPS. Each workshop lasted approximately two hours and brought together an average of eight participants. All the workshops were organized the same way and decomposed into: (a) An introduction to the impact of noise pollution on public health and to MPS-based noise pollution monitoring, (b) The calibration of the participants' phone, (c) A walk where the participants collectively and pro-actively collect noise observations in a chosen nearby district, (d) A presentation of the resulting enhancement to the district's noise map so that the participants may witness and exchange about the contribution of their collective data sensing.

Characteristics	**Value**
# Contributors	60
Gender	60% men 40% women
Age	12% under 25 yo 71% 25 to 50 17% over 50
Context of use	65% have used Ambiciti in a personal context 35% in a professional context
Mobile platform	67% Android 33% iOS
Sector of Activity / Expertise	28% Environment & Sound 22% Public policy & Urban planning 28% IT 22% Miscellaneous

Fig. 2. An overview of our online survey panel [06/2017-12/2017].

III. Mobile Participatory Sensing in Practice: Technical and Social Perspectives

We have been analyzing the impact of the technological environment and of the social context on the usage of the app for which we have combined quantitative and qualitative studies over 2017. The interested reader is further referred to [13] for a detailed analysis of the quantitative data gathered about the usage of the Ambiciti app in the [07/15-04/16] period. The results we present in this section are structured around four inter-dependent key-points:

1) The technological context of the crowd-sensing of noise observations;

[5] https://tinyurl.com/y89z2kug
[6] https://www.paris.fr/journeesansmavoiture
[7] http://www.lasemaineduson.org/
[8] https://ambiciti.io

2) The quality of the collected data in relation with the observed practices of the users;
3) The heterogeneity and the subjectivity of the observed usage of the app;
4) The meaning of MPS-based noise data sensing for users and the concordance of such practices with more global social dynamics in the cities.

A. About the influence of the technology solution

Ambiciti was firstly designed to provide an adequate technological solution to the mobile crowd-sensing of noise measurements using the users' smart-phones. We thus targeted the two most popular mobile platforms: Android and iOS, which cover almost 100% of the mobile phone market as of end 2017. From the 15,600 downloads of the Ambiciti app, we observe that 70% run on Android and 30% on iOS. Even if no statistical analysis was expected owing to the few respondents of our survey, the same distribution applies for the results of the online survey (see Figure 2).

The influence of calibration: We know that the dB(A) values at which the low noise levels peak occurs varies significantly across device models [8], [13]. A calibration of the app is necessary to tackle this heterogeneity of the noise sensing using the microphone of the smart-phone. The Ambiciti app supports 3 calibration modes: (1) manually with a reference sound level meter, (2) manually through a bias entry, and (3) automatically using the already known bias for the given phone model –if available (the Ambiciti database had referenced 45 Android and 10 iOS phone models in mid-2017). The automatic calibration is the default mode. About 20% of the surveyed users declare that they did not notice this step and did not calibrate their phone (or ignore that they automatically did it). In practice, the analysis of the contributed observations show that 65% are from automatically calibrated devices. Still from our survey, 30% of the users consider that the calibration process is easy and that it makes them "*more responsible and confident in producing reliable data*". The organization of workshops featuring calibration sessions and walks (e.g., see Section II-B) was a useful vehicle to raise the awareness of users about the noise measurements process and related parameters [25]. As the automatic mode is the calibration method that is primarily used, increasing the the number of phone models that is referenced in the Ambiciti database is key to enhance the usefulness of the contributed observations.

The influence of energy consumption: The energy consumption is known as a major factor impacting the adoption of a mobile app [26]. The energy consumption profile of the Ambiciti app has been enhanced over time, including through the buffering of data to minimize remote communication, and the ability to parameterize the frequency of measurements and remote communication. However, users still remain concerned about the energy consumption due to Ambiciti. In particular, 30% of the surveyed users declare that battery consumption makes them not use the background mode or even not launching Ambiciti, fearing that this would affect their other usage of the phone. This feeling must be balanced with the user assessment of the efficacy of the offered service, which is a key condition for any MPS user to keep the app active [9]. Indeed, 15% of the surveyed users consider Ambiciti as "*anecdotal, as many other apps*" they have installed. This means that the application behavior, including energy consumption, should be adaptive to the expectation of each user regarding noise measurement and data sourcing, but also the user's profile concerning the usage of apps (games, social, etc.) and MPS services.

The influence of location accuracy: The accurate location of the contributed measurements is a prerequisite for their assimilation in the production of knowledge about the urban environmental noise. An accuracy that is less than 15 meters is expected. The mobile location sources are: GPS, network or both. GPS provides the best accuracy (less than 20 meters). We previously observed that 86% of the localized observations are network-based [13], providing an accuracy in the 20-50 meters range. For energy saving reasons or because of distrust, a few interviewed users never activate GPS on their mobile. Nevertheless, a Parisian woman involved in a neighborhood association declared exceptionally activating location for using the app. Overall, we analyzed that only 10% of the collected observations are located under a range of 15 meters.

Although the above technical issues have been partially settled, we observe that their handling mainly depends on the user's practices (location, energy saving) and usage (calibration and measurement context). Therefore, the ability to gather an increasing number of observations of adequate quality involves both: (1) getting access to more accurate sensors (possibly via calibration) and (2) an adequate use of the app.

B. About the quality of the collected data

A second key outcome from our analysis concerns the quality of the noise data produced and sourced through MPS. From mid-2015 to fall 2017, 100M measurements data have been sourced and recorded on the Ambiciti servers, out of which 82% are produced from Android devices and 18% from iPhones.

Among the collected observations, only a small fraction are relevant for assimilation, which is directly related to the measurement mode used for the production of the data. In practice, 95% of the data is produced through automatic background measurements (i.e., passive measurements) and 5% using the journey mode (i.e., proactive measurements). However, due to the measurement conditions, about 70% of the data collected in the journey mode are analyzed as reliable, whereas this ratio falls to less than 10% with automatic measurements.

We have identified 3 major factors that lead to the contribution of unreliable data. First, a bad or inexistent calibration of the microphone makes 40% of the collected data inconsistent. That risk appears as being much more likely when the app is used individually than when used as part of collective events including calibration parties, technical information and measurement journeys. Second, the absence or inadequate location data (provided by GPS or network) induces an insufficient reliability for 80% to 95% more data if the desired location accuracy is limited to 15 meters maximum. This shows that some users do not activate location system on their phone or deny the app to get access to this information. External reasons (e.g., physical context) can also explain a bad location accuracy. Third, meta-data allow discarding non desired measurements as we focus on outside environmental noise: in vehicles, inside, or when the proximity sensor is activated.

Concluding, the relatively small ratio of accurate data among the collected measurements explains by technical reasons and by the behavior of users. Unreliable measurements are mostly due to the absence or a low accuracy of the location information. It follows that the collection of noise measurements through MPS delivers useful data mostly when used in a proactive data gathering mode (i.e., the Journey mode of the Ambiciti app). This further suggests to promote such use toward relevant stakeholders, as well as to investigate automated approaches to the correction of observation errors (e.g., see [22]).

C. About the diverse usage of the app

Through the analysis of the gathered observations as well as through our user surveys, interviews and workshops, we aim at better understanding the reasons why users decide to use Ambiciti and how, both practically and culturally. Our objective is to assess the matching between the actual social behaviors and the expected ones, with respect to the overarching goal to foster massive data sourcing of adequate quality, and urban environmental actions.

The users' expectation: In about 70% of the surveys, users declared that they intended to use Ambiciti to ”*measure sound levels at a specific time and place*”, and 50% to ”*contribute to producing accurate data about sound levels*” in their city. This ratio is consistent with a dominant altruistic motivation observed in other studies [11]. Only 15% expected Ambiciti to ”*make them able to choose optimized routes with low levels of noise and air pollutants*”. Two thirds of the users consider the aim of Ambiciti is easy to understand, but only a half estimates the app's functionalities easy to master. 80% of the surveyed users run Ambiciti less than five times a week, or never, even if they had installed it. So, only a small part of the people who installed the app refer to Ambiciti everyday (less than 10% respondents) or more than five times a week. These usage trends have a direct impact on the quantity and the quality of the sourced data. Better characterizing the reasons why most users do not use Ambiciti more actively or frequently is thus essential and an area for future studies.

The users' appreciation: In practice, 60% of the respondents to the survey consider Ambiciti to be relevant to ”*a better knowledge of the place*” they live in. For 40%, the app provides useful ”*information to minimize their exposure to noise and air pollutants*” (Air Quality information is provided by the app since mid 2016) and changes the way they consider their district and the streets they live in. ”*It is very eye opening*”, says a Finnish user who works in environmental urban planning.

Fig. 3. A noise measurement journey from students in Vaujours, France, 12/2017. 1719 data were sourced, from 7 contributors during a 24 minutes walk.

Another one declares ”*I now realize that my neighborhood is quite noisy; I wasn't aware of that before using the app*”. Through singular and subjective forms, Ambiciti seems to participate to the sensitization of people who are little –if at all-aware of noise pollution. Many users stressed a gap between the urban noise environment they feel and the measured noise levels, often over 75 dB(A). In the current version, Ambiciti does not provide such a service that would make people able to compare the actual and felt noise level. We experimented such a feature, through direct interactions, in French and Belgian school environments during winter 2017. 30% of the surveyed users consider using the app is prompting them to protect more efficiently against noise or air pollutants. Some say they will now use Ambiciti to get help to choose their next living place. In contrast, using Ambiciti seems to have only limited effects on mobility mode or on their own noise and air pollutants production reduction.

The usage diversity: We noticed a very large range of usage of the app. Many of the described motivations and usages could be considered like ”deviant”, compared to the expected ones, even if mostly altruistic [3]. A Parisian guitar player uses Ambiciti as a sound level meter in his flat. Finnish biologists study the impact of the noise due to construction works on animals communication and reproduction in an urban zoo[9]. Parisians inhabitants make frequent noise levels measurements in bars and public spaces around where they live. Some teachers integrate journey measurements in their lessons, related to physics as to biology or environment (See Figure 3). These examples are not statistically relevant, but their diversity and their heterogeneity underline the ”poaching” creative process by which people take advantage of a given app

[9]https://tinyurl.com/AmbicitiZoo

or service to develop their own use [24]. The design of future versions of the app must address this key point so that the app increasingly matches individual and collective practices.

The user experience: Besides underlining the usage diversity, we also investigated the user experience, that is, the way the user navigates functionally, and perceives the interface of the application. Practically, an average Ambiciti session lasts about 38 seconds, and concerns a bit more than 5 screens[10]. Thus, users spend little time browsing the app interface and expect to reach quickly the information they need. One must recall that the default noise measurement duration is currently fixed at 5 seconds. A shorter duration would make the measurement less accurate but a longer one could be irrelevant to the effective practices of the users. Also, 50% of the surveyed users declare Ambiciti is "*easy to use, both for opportunistic measurements and information*", and 30% consider it is an "*efficient tool for urban management with inhabitants contribution*". Nevertheless, 30% estimate the app is "*useful, but not very convenient to use*". The survey and interviews show that users who work in a technological sector or have a scientific culture (22% surveyed), specifically when related to sound or physics, feel globally comfortable with the interface and its graphic design. On the opposite, less inclined users (50% surveyed work in environment or urban planning, 28% in other sectors) consider the app is complicated to use, not enough "*minimalistic*", and for some with a "*crappy design*".

The users' practices and relationships to IT are influencing the way they interact with, and perceive, the app [14]. With the aim to prompt people to source noise data, an important challenge for the design of Ambiciti is to be able to reconcile on the one hand a very heterogeneous base of users and contexts of use, and on the other hand a set of technically advanced features that serve other purposes than the ones a priori envisioned.

D. About the use of Ambiciti for more global practices

The noise experts that we interviewed consider that the Ambiciti measurements have "*a low technical reliability*", due to the low accuracy of the phones' microphones for the purpose. These data also have "*no legal value*" due to the "non-expert" status of users, says a citizen but also urban social actors that we interviewed. These two key points are not specifically related to the app but to the technological device on which it is running. Still, this questions the potential impact of the app to influence the noise reduction or health policies. Most of the interviewed technicians and decision makers argued that such data were not reliable because of the conditions under which they were produced: by non-experts and trough mobiles' microphones.

The above reaction of the political actors and experts raises two issues regarding how MPS-based smart city app may influence local political actors.

The first issue relates to the legitimacy of physical observations from mobile phones (or even low-cost sensors at large) compared to observations from high-end sensors that are by design more accurate. Technologically, this lower accuracy is accounted for in data assimilation processes. However, from a social perspective, the promise of massive civic participation to a more accurate monitoring of environmental noise finds its limit, which is exacerbated by the high heterogeneity of the quality of the gathered observations.

The second issue lies in the difficulties that still face decision makers for effective actions and strategies against noise pollution, despite their optimistic consideration of this urban dimension. The environmental officer of a French city underlines the relative novelty of noise awareness, even in local institutions and environment policies, except around very specific areas like airports or heavy traffic roads, often not directly managed by local actors. Another city officer considers that, compared to air quality, noise is still considered, by people as well as by policy-makers, as "*understandable and admissible*" in the urban environment. "*City life is noisy*", declares a student; "*If you want calm, live in the countryside*" he says. The awareness of environmental noise impact on public health seems still low in the population, may be because the relevant accurate knowledge is only beginning to become widely available.

E. Concluding remarks

We have shown that a MPS-based noise measurement app can contribute to new individual and collective practices in smart cities contexts and, more globally, in urban areas. As a few collaborative apps, Ambiciti seems to be an opportunity for governance and societal practices changes, towards environmental and sustainability issues, but also participative governance. Nevertheless, barriers arise, not only technological but also social, with respect to the aim of massive and relevant data sourcing. Batteries efficiency, MPS energy management and microphones accuracy remain to be improved. We observed that, thanks to a stronger involvement of users for quality measurements, collective sessions result in more accurate data than individual and opportunistic uses.

Furthermore, the technological or environmental culture of the users, their practices and their relationship to collective and local policies bear directly on the volume, frequency and reliability of their noise measurements. The heterogeneous social context for using such a collaborative app is as much an opportunity as a source of complexity. This can be observed specifically from the standpoints of the interface design and of the user experience. Lastly, the crowd-sensing of noise data remains sparsely integrated in more global urban dynamics and policies, which have to be taken in account with regards to the aim of the massive sourcing of data of sufficient quality.

IV. Outlook: Engaging Users through a Customizable Interface

Increasing the use of an MPS app like Ambiciti requires to improve technical and functional issues, in close relation with the heterogeneous and changing contexts of use [5]. As much as the technological features, the interface is a crucial

[10]Source: Google Analytics. October 2017

Why ?	What for ?	Concerns	Usage	Design	Interface
(What are the reasons why I expect to use it ?)	*(And after ? How do my uses enrich a more global project ?)*	*(How do I consider noise levels data?)*	*(How do I socially expect to use these data?)*	*(What kind of design would be convenient to me?)*	*(What the interface should provide me first?)*
Out of curiosity	No a piori project. One shot.	Social, geek	Network	Trendy, High tech	Original graphism and Data vizualisation
To know more about my personal noise exposure	An individual noise tracking	Health, Quality of life	Personal	A simple and efficient tool	Streamlined and reliable
To reduce my personal noise exposure	I get valuable tips to reduce my exposure and check it is positively changing	Health. Mobility.	Personal.	An accurate partner and adviser.	Indicators about the danger levels related to my exposure. Help services.
To get new kind of information for a better health protection	Evaluating my personal exposure regards to standard levels and inherent risks	Health	Personal, Network	Relate measurements and information and notifications	Indicators that contextualize and give meanings to my measurements
To produce new knowledge about the place I live or work	To mobilize my neighbors or colleagues to collectively minimize excessive noise exposure	Health, Quality of life, Citizenship	Network, Policies	Relation to perceived noise, to territorial visualization, to social comments	Space and time contextualized measurements, global information about pollutants. Social network
To contribute to producing new knowledge for urban action	I share my measurements. I expect a collective action.	Citizenship, Environment, Urbanism.	Network, Collaborative	A customizable multi-features tool. Connected to others.	Easily customizable interface, responsive. Maps and social network
To make choices including noise pollution	For many cases (mobility, choice of a living area, militant action), I need opportunistic measurements.	Citizenship, Environment, Expert.	Personal, Network, Collaborative	A multi-resource tool	A functional tool, customizable, qualified data. Maps and social network

Fig. 4. A usage-centric approach to the design of a new Ambiciti interface.

mediation place [18]. It must allow the user to negotiate (it is the user experience) the balance between features and protocols, culturally anchored subjective practices and a societal context. Thus, for a collaborative app to ensure an appropriate data sourcing, the social, cultural and political local contexts [2] and issues have to be taken in account.

In a nutshell, the interface of a MPS application must enable diverse and complex interactions and negotiations between technical features, and social and cultural phenomena. This socio-technical problematic relates to the relationship between the application and each user. Considering the specific Ambiciti example, we observed that users, every time they intend to run the application, initiate a negotiation process between the offered features and their needs and practices. Far from forcing the subject to adapt to technological requirements, the UI is expected to make this unpredictable negotiation process possible and easy. Although admitting that the user is not necessarily an ”expert”, the user should be informed enough about what is technologically possible using the app and how to get an acceptable answer to own needs and expectations from the app. In other words, a socially designed application is not user-centric but usage-centric.

Our observations suggest that profiling users can not ensure a successful concordance process. Defining interfaces according to expected usages would conflict with the subjectivity of each urban user. Indeed, even if they remain amateurs [16], users must also be considered as a new kind of ”experts” who, alongside professionals, can contribute to the city governance. Moreover, the rigid profiling of users would make impossible or marginalize any deviant usage, although such usage must be considered as an efficient user involvement opportunity. Adopting a stereotypical framing of usages results in a bid, or an ossifying management, of the user practices so that they match a technologically-driven quest. Conferring authority to users involves them in a constructive process of their actions and meanings.

Our social design work suggests that the Ambiciti interface should evolve so as to not preset how to navigate across the existing functions. Rather, the app interface should allow users to configure their own workspace from articulated but stand-alone features. Such a ”plausibility-based” approach [7] should overcome problems (such as limited contributions) related to the uncertainty of usages. A future organization of the Ambiciti interface could articulate the combination, by the user, of graphic design and enable environments, as autonomous but inter-dependent modules, providing specific features (See figure 4). Each responds to technical prerequisites and is aimed at producing qualitative noise data.

V. Conclusion

The Ambiciti use case illustrates the strong influence of singular cultures and local practices on how users interact with a mobile app [20]. It highlights that innovative products have to embrace uncertainty [7] and allow unexpected uses, to reach its technological goal and to develop new opportunities. The crowd-sensing of noise data is also raising new forms of citizens participation in urban policies. Even if still emerging through digital tools, participation is no more exclusively a political concern but also an every-day commitment [4] through using such apps with respect to binding protocols. The crowd-sensing of noise data produces new knowledge and resources for collective actions. Nevertheless, many complex phenomena interfere and we observed that, even when sensitive to noise pollution issues, people do not sufficiently get involved pro-actively. A collective culture [6] based on private and public shared experience of noise harmfulness (by neighbors, students, workers) is still to be strengthened.

Acknowledgment

The authors would like to acknowledge the support of the Inria Project Lab CityLab and the Inria International Lab Inria@SiliconValley (https://project.inria.fr/siliconvalley/). They also acknowledge the financial support of EIT Digital (https://www.eitdigital.eu/) as part of the Env&You Innovation activity. Last but not least, the authors thank their Inria colleagues who contributed to the development of the SoundCity/Ambiciti app and related platform: Vivien Mallet, Kinh Nguyen, Pierre-Guillaume Raverdy and Raphael Ventura.

REFERENCES

[1] L. Armstrong, J. Bailey, G. Julier, and L. Kimbell. *Social Design Futures: HEI Research and the AHRC*. University of Brighton, 2014.

[2] A. Attour and A. Rallet. Le rôle des territoires dans le développement des systèmes trans-sectoriels d'innovation locaux : le cas des smart cities. *Innovations - Revue d'économie et de management de l'innovation*, 2014/1(43):253–279, 2014.

[3] A. Baruch, A. May, and D. Yu. The motivations, enablers and barriers for voluntary participation in an online crowdsourcing platform. *Computers in Human Behavior*, 64:923 – 931, 2016.

[4] P. Brotcorne. *Les outils numériques au service d'une participation citoyenne et démocratique augmentée*. TECHNOFUTURTIC, Belgium, 2012.

[5] M. Budde, A. Schankin, J. Hoffmann, M. Danz, T. Riedel, and M. Beigl. Participatory sensing or participatory nonsense? Mitigating the effect of human error on data quality in citizen science. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.*, 1(3):39:1–39:23, September 2017.

[6] M. Calvez. Health Hazards Tested by Harmful Effect Proof. The Case of Environmental Health Complaints. *Recherches sociologiques et anthropologiques*, 47(1), June 2016.

[7] J. Derbyshire and E. Giovannetti. Understanding the failure to understand new product development failures: Mitigating the uncertainty associated with innovating new products by combining scenario planning and forecasting. *Technological Forecasting and Social Change*, 125:334 – 344, 2017.

[8] E. D'Hondt, M. Stevens, and A. Jacobs. Participatory noise mapping works! An evaluation of participatory sensing as an alternative to standard techniques for environmental monitoring. *Pervasive and Mobile Computing*, 9(5):681 – 694, 2013. Special issue on Pervasive Urban Applications.

[9] M. Foth, L. Forlano, C. Satchell, and M. Gibbs. *From Social Butterfly to Engaged Citizen: Urban Informatics, Social Media, Ubiquitous Computing, and Mobile Technology to Support Citizen Engagement*. The MIT Press, 2011.

[10] E. Goffman. *The Presentation of Self in Everyday Life*. Anchor, 1 edition, 1959.

[11] J. Goncalves, S. Hosio, J. Rogstadius, E. Karapanos, and V. Kostakos. Motivating participation and improving quality of contribution in ubiquitous crowdsourcing. *Computer Networks*, 90:34 – 48, 2015.

[12] S. Hachem, V. Mallet, R. Ventura, PG. Raverdy, A. Pathak, V. Issarny, and R. Bhatia. Monitoring Noise Pollution Using The Urban Civics Middleware. In *IEEE BigDataService*, 2015.

[13] V. Issarny, V. Mallet, K. Nguyen, PG. Raverdy, F. Rebhi, and R. Ventura. Dos and don'ts in mobile phone sensing middleware: Learning from a large-scale experiment. In *Proceedings of the 17th International Middleware Conference*. ACM, 2016.

[14] J. Goldman, K. Shilton, J. Burke, D. Estrin, M. Hansen, N. Ramanathan, S. Reddy, S. Vids, M. Srivastiva. Participatory sensing: A citizen-powered approach to illuminating the patterns that shape our world. *Center for Embedded Networked Sensing, UCLA*, 2009.

[15] C. A. Kardous and P. Shaw. Evaluation of smartphone sound measurement applications. *The Journal of the Acoustical Society of America*, 135(4):EL186–EL192, 2014.

[16] S. Kuznetsov and E. Paulos. Rise of the expert amateur: Diy projects, communities, and cultures. In *Proceedings of the 6th Nordic Conference on Human-Computer Interaction: Extending Boundaries*, pages 295–304. ACM, 2010.

[17] J. H. Lee, M. G. Hancock, and M-C. Hu. Towards an effective framework for building smart cities: Lessons from Seoul and San Francisco. *Technological Forecasting and Social Change*, 89:80 – 99, 2014.

[18] A. Longo, M. Zappatore, M. Bochicchio, and Navathe S. B. Crowd-sourced data collection for urban monitoring via mobile sensors. *ACM Trans. Internet Technol.*, 18(1):5:1–5:21, October 2017.

[19] N. Maisonneuve, M. Stevens, M. E. Niessen, P. Hanappe, and L. Steels. Citizen noise pollution monitoring. In *Proceedings of the 10th Annual International Conference on Digital Government Research: Social Networks: Making Connections Between Citizens, Data and Government*, pages 96–103. Digital Government Society of North America, 2009.

[20] A. Mehrotra, S. R. Müller, G. M. Harari, S. D. Gosling, C. Mascolo, M. Musolesi, and P. J. Rentfrow. Understanding the role of places and activities on mobile phone interaction and usage patterns. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.*, 1(3):84:1–84:22, September 2017.

[21] C.H. Nilon, A. R. Berkowitz, and K. S. Hollweg. *Introduction: Ecosystem understanding is a key to understanding cities.*, pages 1–13. Springer-Verlag New York, Inc., 2003.

[22] F. Sailhan, V. Issarny, and O. Tavares Nascimento. Opportunistic Multiparty Calibration for Robust Participatory Sensing. In *MASS 2017 - IEEE 14th International Conference on Mobile Ad Hoc and Sensor Systems*, October 2017.

[23] S. Santini, B. Ostermaier, and A. Vitaletti. First experiences using wireless sensor networks for noise pollution monitoring. In *Proceedings of the Workshop on Real-world Wireless Sensor Networks*, REALWSN '08, pages 61–65, New York, NY, USA, 2008. ACM.

[24] J. Seguy. L'invention du quotidien t.i, arts de faire. *Archives de Sciences Sociales des Religions*, 80(1):249–250, 1992.

[25] R. Ventura, V. Mallet, V. Issarny, PG. Raverdy, and F. Rebhi. Evaluation and calibration of mobile phones for noise monitoring application. *The Journal of the Acoustical Society of America*, 142(5):3084–3093, 2017.

[26] Y. Xiao, P. Simoens, P. Pillai, K. Ha, and M. Satyanarayanan. Lowering the barriers to large-scale mobile crowdsensing. In *Proceedings of the 14th Workshop on Mobile Computing Systems and Applications*, HotMobile '13, pages 9:1–9:6. ACM, 2013.

[27] A. Zanella, N. Bui, A. Castellani, L. Vangelista, and M. Zorzi. Internet of things for smart cities. *IEEE Internet of Things Journal*, 1(1):22–32, 2014.