Environmental Data Sensing Through Participatory Urbanism. A Best-Practice Analysis and City-Administration Perspective

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Abstract

The number of easy-to-use artefacts for environmental data collection is rising. Various scientific projects and private initiatives are addressing how to measure urban data in dense sensor networks by applying devices to public infrastructure or by using citizens. The latter is often done to raise both public awareness and that of administrations and governments. Best practices that use or collect environmental parameters and measurements related to the quality of public spaces (e.g., noise, heat, particulate matter) are central. This work presents data points, analysis parameters and a structured overview of best practices in this field. The results show applications of best practices, ranging from permanently mounted sensors mainly driven by municipalities, to participatory urbanism approaches, where users actively collect environmental data. Additionally, the example of the City of Vienna gives an administrative perspective on incorporating co-creation approaches. Supporting factors for cooperation with private initiatives operating participatory sensing projects are shown; challenges arise when urban participation meets administrative structures.

Keywords:

environmental data collection, participatory urbanism, sustainability, dense sensor networks, quality of public space

1   Introduction

Climate change and the increasing need for a climate-conscious lifestyle require awareness-raising, by society as a whole, of environmental conditions and of the quality of public spaces. This work aims to determine how easy-to-use sensors can be used to increase the awareness of air quality in public environments. Cities traditionally rely on data from a few authority-driven, calibrated monitoring stations (Muller, Chapman, Grimmond, Young, & Cai, 2013). Dense sensor networks for collecting environmental data are still few but increasing in number, using new technological devices such as ones related to the Internet of Things (IoT). Dense sensor networks and user-friendly data representations enable an overview of the

ecological conditions of one's personal surroundings. Users can retrieve the environmental conditions of their favourite parks, cafés or playgrounds, and this can raise awareness of aspects of climate change and the quality of public spaces. Devices in this field of data collection originate from industrial manufacturers but are also invented and used by do-it-yourself initiatives and communities.

Traditionally, urban environmental data, especially air quality data, are retrieved by meteorological weather stations sparsely distributed across cities (Muller et al., 2013). For example, a 50 x 50km² area in Bejing is covered by just 22 stations, London is covered by 14 stations (Xie et al., 2017), and Vienna has 17 stations to measure air quality (Stadt Wien, 2023). This low density in data collection requires various modelling techniques, such as spatial interpolation, land-use regression models and dispersion models, to estimate the situation in areas that are some distance from the meteorological stations. Nevertheless, fine-grained data retrieved by dense sensor networks are needed to inform city administrations and citizens in more detail (Xie et al., 2017). Dense sensor networks allow air quality data to be measured on a neighbourhood scale. The Array of Things project, for example, aimed at installing 500 stationary units across the city of Chicago (Catlett, Beckman, Sankaran, & Galvin, 2017). The sensing power of *mobile* vehicles was quantified by modelling the results from sensors on fleets of taxis. For Vienna, the model shows that 1,010 taxi trips are needed to scan half of the scannable street segments (O'Keeffe, Anjomshoaa, Strogatz, Santi, & Ratti, 2019). Such data enable research in urban microclimates and on the health impacts of air pollution, and can support awareness-raising of the quality of public spaces (Prophet, Kow, & Hurry, 2018). Urban environmental data can be captured by stationary sensor networks on public infrastructure like lamp posts or traffic lights (Catlett et al., 2017). In addition, driven mainly by companies or city administrations, the number of projects directly involving citizens in collecting urban environmental data is growing. Recent developments in low-cost and easy-to-use sensors, and data protocols such as LoRaWAN® (LoRa Alliance, 2023), enable IoT devices to measure weather and air quality in dense networks. "Citizen science" is well-established in this field, although citizens are mainly included in data collection but not usually in actual scientific work (Dourish, 2010). Therefore, the terms "participatory urbanism" (Paulos, Honicky, & Hooker, 2008) and "participatory sensing" (Burke et al., 2006) are more appropriate to characterize the participation of citizens. Since such data are often connected to geographic positions and GPS information, Goodchild (2007) coined the term "volunteered geography" for citizens' involvement in collecting position-related data. Citizens' use of sensors to provide data is realized in many ways. For example, mobile phones can be connected to cardiac devices to gain insights into user stress in urban environments (Rodrigues, Aguiar, & Barros, 2014), revealing the users' actual experience of the quality of urban spaces.

Air quality is measured by equipping shared bikes with sensors, using the bikes themselves as IoT devices (Wu et al., 2020). People wear backpacks, including sensors, to monitor ultrafine particles while travelling through the city (Bekö et al., 2015). Helbig, Ueberham, Becker, Marquart and Schlink (2021) provide an extensive overview of scientific work on using

wearable sensors to gather urban environmental data. Various stationary devices mounted on users' balconies or in gardens are also available, such as the AirKit (Mahajan, Gabrys, & Armitage, 2021). In addition to sensor-driven approaches, subjective perceptions provide valuable insights into the quality of urban areas (Dörrzapf et al., 2016). Overall, participatory sensing projects promote a better understanding of environmental data, using low-cost sensors to provide higher resolution in city-wide data sampling (Miskell, Salmond, & Williams, 2017). Through the use of sensors and by making the data collected publicly available, public awareness regarding urban air quality and climate change can be raised. Research on awareness of sustainability, and understanding of ecology and the environment is carried out by providing households with relevant information (Mattheij, Szilvasi, de Beer, Rakiman, & Shahid, 2011), or by using augmented reality to visualize environmental data (Prophet et al., 2018).

In this work, we present a structured review of technological artefacts and ecological sensors that show potential for a dense collection of urban environmental data. A broad array of devices and initiatives that collect and visualize data are identified and classified in a best practice review showing how such approaches can raise awareness. The presentation and processing of the data that they capture and measure are central elements in this review. Furthermore, how participatory sensing and citizen involvement can be integrated into city administrative structures and processes is also presented. Current challenges and promising approaches are introduced for participatory best-practice operators and the city administration of Vienna.

2   Best practices in participatory urban data sensing

Identifying best practices follows a set of criteria to be classified as a best practice, defined mainly by the framing conditions and research requirements in which this work is embedded. The following criteria were used for the identification and analysis of best practices, devices, commercial solutions, scientific projects and co-creation approaches:

- Environmental data are gathered using technical artefacts (sensors) or subjective reports directly from citizens or the local administration.
- Data are measured in dense sensor networks, where citizens or municipalities drive many easy-to-use sensors.
- Data are made accessible via online services, either publicly or for limited user groups.

2.1 Environmental data points and analysis parameters

Best practices were identified through an iterative approach, including a scientific literature review, an online review of products and non-scientific approaches in this field, and by testing solutions. During the research process and the screening of best-practice candidates, a set of parameters emerged that allow a consistent characterization of solutions for gathering weather

information and air quality data. The most relevant environmental data points are categorized in Table 1.

Table 1: Environmental data points collected by best practices.

weather	temperature, humidity, barometric pressure, indoor air quality (IAQ), soil moisture, soil temperature, wind speed, wind direction, cloud cover, surface temperature, rainfall, air quality index US (AQI US)
gases	carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NO_x), ammonia (NH_3), ozone (O_3), sulfur dioxide (SO_2), volatile organic compounds (VOCs), hydrogen sulfide (H_2S), odour
matter	particulate matter (PM 1, PM 2.5, PM 4, PM 10)
sonic	noise (dBA)
light	light level (lx), ultraviolet light (UV), sunshine hours, visibility (distance)
traffic	Total vehicle count, bus count, truck count, van count, car count, motorcycle count, bicycle count, pedestrian count, vibration, traffic flow, parking spaces
other	magnetometer, subjective perceptions

In addition, a collection of analysis parameters (or descriptors) emerged, as illustrated in Table 2, which was used to categorize and describe the best practices.

Table 2: Analysis parameters for best practices.

sensor type	stationary (permanently mounted), portable (can be moved), mobile (designed to be moved), customizable, modular, DIY/tinkering, official public sensor
project type	commercial, non-profit, scientific project, privately funded, publicly funded, temporal, permanent/established, online platform, association, citizen sensing/participatory urbanism
Application context	high-risk regions, vehicle fleet, attachable (e.g. on a belt or bag), public infrastructure, no specific context
target group	municipalities/city administration, professional environmental data collectors, initiatives/associations, businesses, citizens, software developers, education, city/spatial planners, scientists, journalists, policy makers, no specific target group
data accessibility and handling	dashboard, digital map, open data, limited access, downloadable datasets/raw data, AI & machine learning, GIS support, background information, developer support (API, IDE), output on device, static data presentation

An illustration of the mapped data points and analysis parameters for one best practice, *The Smart Citizen Kit*, is given in section "Participatory sensing and do-it-yourself practices".

2.2 Resulting best practices

A collection of best practices was identified based on the criteria and analysis parameters. Categories emerged from the iterative evaluation process; an overview is given in Figure 1, including overlaps between categories.
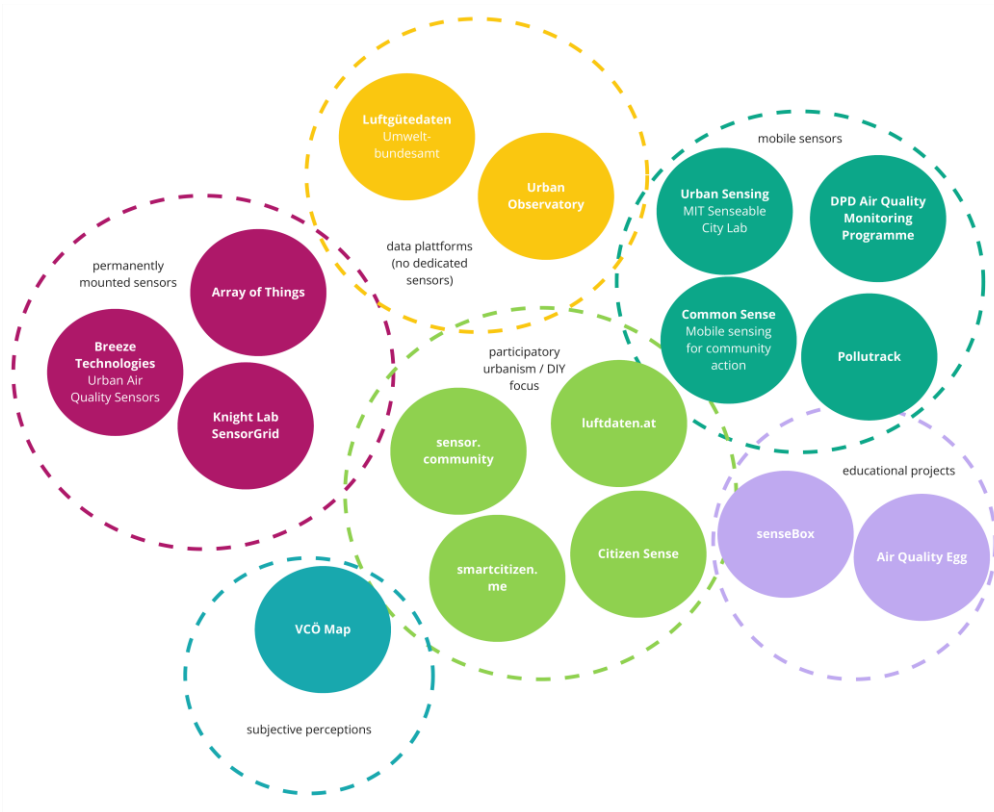
Figure 1: Categorization and exemplary representatives of best practices.

Permanently mounted sensors

Lamp posts, traffic lights or other infrastructure can be used for permanent installations, and existing power sources can be accessed if necessary, but this type of assembly requires a robust device design and easy interchangeability of components (Catlett et al., 2017). Public administrative units usually implement such systems in cooperation with manufacturers or scientific institutions. One best practice here is the *Array of Things*™ project (Array of Things, 2020), which is a cooperation between the University of Chicago (US) and the administration of the city of Chicago. Sensors mounted on public lamp posts transmit data wirelessly to an associated data platform. The so-called AoT™ nodes contain sensors collecting weather, air quality and traffic data, pedestrian counts, and vibrations. The modular design includes a computing unit that processes the information directly in the device and only transmits pre-

analysed data to a server (Beckman et al., 2017). The system is aimed at public administration and scientific institutions, which analyse the data using AI and machine learning (Catlett et al., 2020). In addition, the publicly visible sensors aim to promote the interest of young people in science and technology (Catlett et al., 2022). The *Knight Lab Sensor Grid* (2017) was developed at Northwestern University (US) and is aimed at communities, journalists and citizens. The devices used by Knight Lab enable measurements of particulate matter, and are inexpensive, accurate and efficient. Breeze Technologies provides a commercial solution named *Urban Air Quality Sensors*, aimed exclusively at municipalities. The sensor unit can be customized to the requirements of the client (Breeze Technologies, 2021).

Mobile sensors

Here, we include artefacts designed explicitly to be permanently on the move. Solutions attached to vehicles or people are the most relevant representatives of best practices in this category. A dense network of measured values within an area can be realized with a sufficiently large fleet of vehicles (or number of people).

The logistics company DPD runs an *Air Quality Monitoring Programme* and uses parts of its electrically powered vehicle fleet to measure particulate matter. This project is aimed primarily at municipalities and city administrations; the data are not publicly accessible (DPD Group, 2022). Four hundred electric vehicles in the fleet of an energy company in Paris were equipped with sensors developed by Pollutrack to continuously measure air-borne particulate matter in the city. Through these measurements, it should be possible to identify where counter-measures are needed and to define so-called low-emission zones (Pollutrack, 2022). Luftdaten.at is currently running a project in which schoolchildren use mobile sensor devices attached to their schoolbags or clothes to gather particulate matter data on their way to school (Luftdaten.at, 2023).

Participatory sensing and do-it-yourself practices

This category encompasses best practices aimed directly at citizens in a participatory approach. Traditionally, the category includes such activities as collective bird counts, but more recently collecting environmental data with electronic sensors has become increasingly popular. Some sensors are offered as do-it-yourself solutions, assembled by users. The *Citizen Sense* (2021) project explores practices for measuring environmental data involving citizens (Houston, Gabrys, & Pritchard, 2019). *AirKit* is a sensor that records air quality, measuring weather and particulate matter values. The sensor can be assembled by users (Mahajan et al., 2021). Fab Lab Barcelona (2022) operates the *smart citizen®* project, offering two sensor systems and a data platform. The project targets citizens, administrative units, and scientific and educational institutions. One sensor, the Smart Citizen Kit, was designed for private use, mainly for weather data. However, it can also be customized by adding more data points, including particulate matter sensors. The project offers open interfaces, APIs, and many 3D models for housings as downloads. The platform presents the data in a user-friendly, accessible way and offers background information on the values measured. An illustration of the characteristics of this project is given in Figure 2.

Figure 2: Illustration of the Smart Citizen Kit and Smart Citizen Station, including data points and analysis parameters.

Educational best practices

This category encompasses approaches explicitly aimed at the education sector. Some projects address teachers and students, involve assembling electronic components, and point out the importance of environmental sensing. The category also includes ludic approaches that encourage active measuring and curiosity about measuring environmental data, using ready-made sensors for use in classrooms and outdoors. *senseBox* (2021) is a spin-off from a publicly funded German research project. This modular electronics kit comprises sensors for measuring environmental data. It offers three different sensors (and variants thereof), one of which is explicitly aimed at the educational sector: the *Sensebox.Edu.* The accompanying website offers teaching materials, instructions, background information and further resources. To simplify software development, an online code editor is available, with which pre-defined code elements and program parts can be put together very quickly. The collected data are displayed

on a digital map, which is publicly accessible, and the data can be exported or downloaded to be processed further using other applications.

Platforms without dedicated sensor devices

Here, the best practices deal primarily with communicating environmental data, without offering dedicated devices. Data are retrieved from various sources, such as do-it-yourself devices operated by citizens and publicly recorded data that is openly available, and summarized. The *Urban Observatory* project was created by the University of Newcastle (UK) (2022). The platform, implemented as a web service, provides an extensive range of values and data from the Newcastle area, from the weather and air quality data already known from other best practices, through traffic data, to seismic data and river levels. The platform offers interfaces through which individual sensors can be registered to provide data. The project's target group includes research institutions, software developers and businesses, citizens, and the education sector.

Subjective perceptions

The subjective perception of public space can not only be measured by electronic sensor devices; it can also be determined by citizens describing their perceptions when assessing the quality of public space. Subjective perceptions can include, for example, feel-good factors in a space. They can be used as an addition to numerical values collected by sensor devices, for example in describing the perceived noise level. The *VCÖ Map* (Verkehrsclub Österreich, 2022) represents this category's best practices. Here so-called problem areas were collected as subjective descriptions by citizens over a limited period and then presented on an interactive map. These textual descriptions relate primarily to noise pollution from different types of traffic (e.g. motorways and air traffic).

3   The City of Vienna: An administration perspective on participatory environmental data collection

In addition to the identification and classification of best-practices of easy-to-use environmental sensors, research was conducted on how best practices, in particular citizen-driven approaches, could be linked with public services. The potential and challenges of integrating participatory urbanism in the administration processes of the City of Vienna were the subject of expert interviews (Meuser & Nagel, 1991), providing insights from one of the co-founders of a local best practice (IP1), an urban development and innovation expert (IP2), a mobility expert (IP3), and a municipality IT practitioner (IP4). The interviews focused chiefly on the participatory collection of environmental data. The results revealed key aspects of participatory sensing approaches and challenges that arise when such approaches meet (or come up against) established administration structures. The interview data were analysed thematically (Braun & Clarke, 2006), resulting in eight main themes, each including several sub-themes, as illustrated in Figure 3. The results show several claims, challenges and requirements, from the administration's perspective, of embedding participatory data collection in its processes.
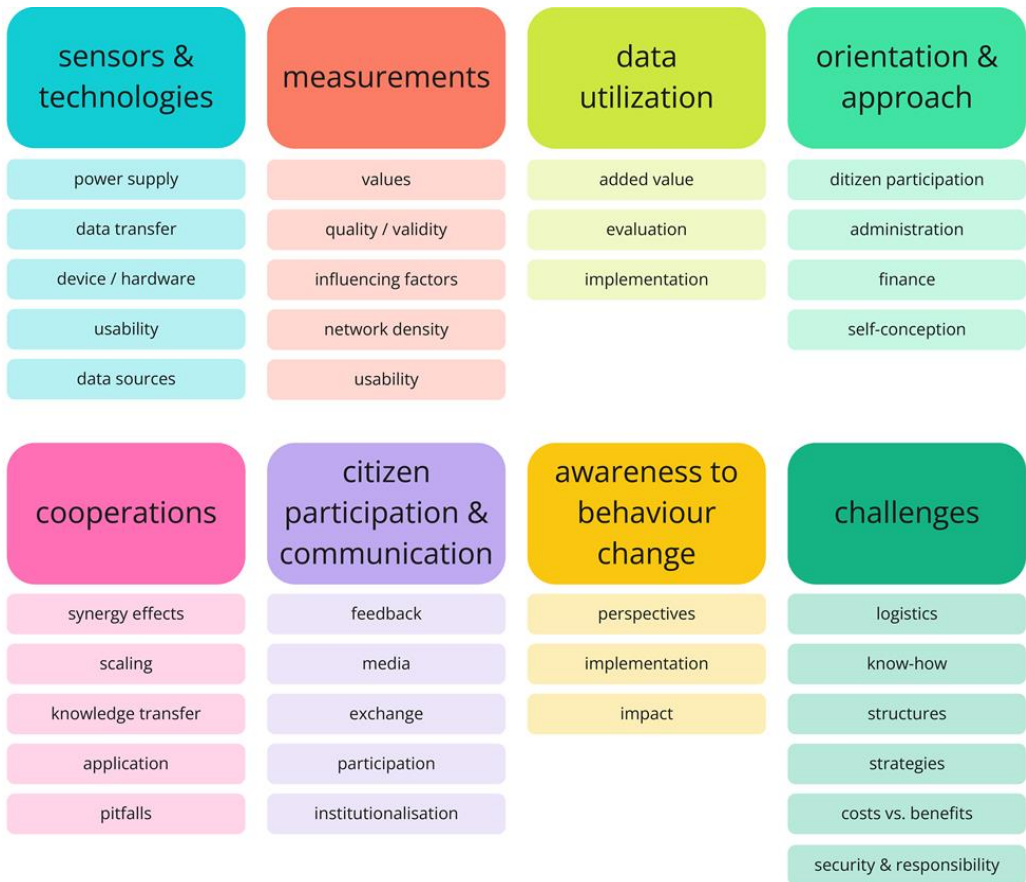
Figure 3: Resulting themes and sub-themes from the expert interviews.

Regarding the development of sensors and the use of specific technologies, IP1 reports that creating easy-to-use devices requires a certain degree of independence in power supply and data transfer. They also claim that depending on local conditions makes it difficult to establish a constant data stream to the web service because many users turn off their WiFi at night or unplug the sensor. Using batteries raises the barrier for users, due to the need for regular charging. Therefore, future developments will aim to use LoRaWAN® (Long Range Wide Area Network) – instead of private WiFi – and a battery-driven sensor combined with automated reminders for charging (IP1). Additionally, context-oriented devices which are integrated more seamlessly into users' daily routines are planned, such as sensors for bicycles (IP1). The City of Vienna has implemented a city-wide LoRaWAN®, but this is used only for internal administrative procedures and is not accessible for public use. IP4 states that, technically, this system would have the capacity to include further services, such as participatory environmental data collection, but the decisions for integrating further services from external partners are made on the political level.

Experts from the city administration understand aerial data as politically sensitive (IP2, IP4). IP4 states clearly that "there is the fear of incorrect data"[1] and refers to EU regulations on how valid environmental data have to be measured. Additionally, IP4 refers to official measuring stations and the quality of existing models that already derive information for each location in the city. From this point of view, there is no actual real need to incorporate data collected by citizens through dense sensor networks. IP4 warns that "The accuracy of such measurements can never be high enough, because the conditions cannot be controlled." IP2 emphasizes that processes still need to be defined, within the city administration, which would enable the inclusion of high-quality citizen-generated data into the city's systems, with citizens potentially providing up-to-date data more frequently than the city currently obtains from its traditional sources. However, in order to prevent an overall loss in accuracy, the high-quality data from official monitoring stations must not be mixed with citizen-generated data (IP2). IP1 states that, at the time the interview was conducted, 200 active sensors had been distributed across the city of Vienna. To investigate the city intensively, and for a dense sensor network that provides a valuable contribution to city planning, IP1 estimates that the system needs to be scaled up – to 1,000 sensors.

Regarding data utilization, IP2 states that simply collecting environmental data and making them available is not enough. Data collected by citizens has to result in positive effects in the real world, for example in the redesign of street. Otherwise, citizens' trust in the administration decreases, and trust is a crucial factor on the political level. Appropriate interfaces that support the inter-departmental availability and sharing of data are needed (IP2). IP3 refers to health issues caused by air and noise pollution. They identify the potential to use data from dense sensor networks to inform people about risks and to lower subsequent costs to the health care system. Additionally, the real estate industry is interested in using environmental data from dense networks to promote properties in specific city locations (IP1).

The local best practice provider (IP1) is bottom-up oriented and provides sensors that are assembled in workshops jointly with citizens; user feedback is a relevant source for further innovation. The citizen-science approach appears promising because direct contact with citizens raises awareness and motivation. By using do-it-yourself sensors, people come into contact with issues of which they were unaware and gain information through participation (IP1).

The city's administrative structures developed over decades and are mainly organized as a top-down hierarchy. Decision-makers trust in well-established internal capabilities and know-how is relatively high, leading to acting and thinking within these known parameters (IP2): "The immediate impetus for reaching out and integrating people as early as possible, 'to practise open innovation more radically' […], is limited" (IP2).

The administration of the City of Vienna understands itself as the main provider of services of general interest, and therefore many solutions are developed in-house, without recourse to cooperation with external partners or service providers. If necessary, the city relies on a well-established network that integrates local universities and companies closely aligned with the city administration (IP2). Nevertheless, IP1 reports, there is a certain interest in collaboration

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[1] Direct quotations from interviews were translated from German to English by the authors.

in traffic planning, because the data from dense sensor networks can help optimize specific streets. IP3 underlines this from a mobility perspective but admits that in the mobility domain, citizen participation is still realized largely by traditional analogue means, where citizens and stakeholders meet in person.

A higher level of citizen participation and user-centric thinking could loosen the top-down structure of the city administration (IP2). In city planning processes, there is a growing effort to raise participation levels, although the administration of the City of Vienna does not always succeed in including citizens' perspectives centrally in projects. IP2 emphasizes that the administration's trust in its own existing competencies is relatively high, thus creating a hurdle to involving citizens in processes at an early stage. Although there is regular analogue citizen participation in some areas, digital participation needs to be fostered. The City of Vienna institutionalizes citizen participation through "living labs" to stimulate technological and social innovations – a form of "soft" policy making (Tellioğlu, Wagner, Habiger, & Mikusch, 2019) (IP2).

Gamification and nudging (Thaler & Sunstein, 2008) are promising approaches for raising awareness and triggering changes in behaviour. Nudging is seen as a positive measure to change people's behaviour and is often preferred to force and strict regulations. The participative collection of environmental data by citizens allows individuals to contribute to, and to be part of, a process and actual change (IP3). IP1 plans to regularly provide reports to keep users motivated and committed to the project. IP2 emphasizes that nudging always needs to be done in a positive way. The administration wants to incentivize citizens for sustainable behaviour and not penalize or shame them. IP3 points out that using rewards works better if it is adapted to local conditions – for example, by providing vouchers for local shops or services.

A significant challenge for the administration is setting up supporting processes within its structures to guarantee that citizens' requests are processed and lead to an actual outcome or change. Otherwise, trust in public services would decrease. Such processes require investing effort and resources in their planning and operation (IP2). The administrative and political levels need more courage to make data available publicly without knowing in advance how the data will be used and applied (IP4).

Comparing costs and benefits is also particularly relevant for administrative units. As IP2 emphasized, many use cases are tested, but only a few turn out to be profitable. The costs arising from incorrect measurements or outliers are also viewed negatively. This could be used detrimentally by the media and harm the image of a city (IP4).

In conclusion, the results of the expert interviews reveal political and strategic concerns in terms of integrating citizen-collected data into well-established public services, but also show fundamental interest in participation processes in certain areas.

4   Discussion

The implementation contexts of the best practices show how devices are integrated into specific use cases and users' routines, and how their design follows the requirements of the

context. The results show that it is by no means always possible to assign the best practice to a clear context. Mobile sensors are mainly used on vehicle fleets, as in the *DPD Air Quality Monitoring Programme* (DPD Group, 2022); there is still a need for specially designed sensors for cyclists, as stated in the interviews. Sensors that need to be mounted permanently are primarily aimed at public infrastructure, as is the case with the *Array of Things* (2020). Devices that have been designed to be used on the go do exist. These are easy to attach to clothing or backpacks, but many of the devices and platforms presented here do not follow the principles of contextual design (Beyer & Holtzblatt, 1997).

Technologies and artefacts alone cannot increase awareness or change behaviour. According to the experts interviewed, raising awareness successfully follows from involving citizens actively. Therefore, participatory urbanism is essential in collecting data on people's surroundings. Appropriate processing of the collected data and regular community support for users are also necessary. How solutions are designed and implemented, and the advantages that changes may bring to the users, are further essential factors. Well-established best practices, such as the *smart citizen*® project, provide an explanation of the effects of pollution for users, as well as developer support for practitioners. Nudging, gamification and reward systems help to motivate people to participate, offering them added value, and actively involve them over a more extended period. Barriers to using an artefact must be kept as low as possible, which means that in the best case, a device only has to be switched on or connected to the power supply to start collecting data. Complex installation and maintenance processes, such as connecting to private WiFi networks or regularly charging the devices, represent barriers. Awareness raising on climate change is listed as 13.3 in the UN's Sustainable Development Goals (United Nations, 2015). While citizens profit from increased knowledge and awareness through participation in environmental sensing, municipalities can benefit by integrating citizens in spatial planning processes, enhancing communication, and using geo-located data provided by ordinary citizens (Schmuderer, Zink, & Gamerith, 2019).

The data quality needs to be high, and the measurements' contexts need to be communicated explicitly in participatory projects – requirements which administrations need to incorporate in their workflow for participatory environmental data collection, as the expert interviews show. Citizen-generated data can add value and fill possible gaps in available governmental data, as emphasized by Haklay et al. (2015). However, city administrations face challenges in modifying their existing organizational practices and regulations.

The results show that the City of Vienna is fundamentallly interested in active citizen participation. However, some administrative units are sceptical about integrating external projects or externally sourced data into their structures, since citizens' measurements of environmental data are considered imprecise and error-prone. A very dense sensor network is required for its data to be used in planning processes, which in the best practices examined here is only achieved for specific areas where the sensors are deployed. For this to happen, the cooperation between administration and operators needs to be clearly defined at the start of a project. Achieving dense networks is harder for approaches focusing on the participation of citizens; cooperation between the city administration and others who implement participatory best practices could boost the network density.

5   Conclusion

Our work shows diverse emerging projects and technologies for measuring environmental data in close sensor networks. Identified best practices range from commercial products designed to be attached to public infrastructure and implemented by municipalities, to participatory approaches addressing citizens that use do-it-yourself devices. Measuring weather and air pollution is the most popular function within the best practices identified, but additional data points, such as noise, are attracting more and more interest. Deploying environmental sensors on public infrastructure, such as lamp posts, supports the creation of a dense network. But participatory sensor networks in particular, which depend on citizens' motivation, still need to reach higher densities to allow a deeper analysis of the data of interest and to inform city planning. This work shows that citizen participation is a promising approach for raising awareness. The results of the best practice review reveal a collection of endeavours that use a participatory urbanism approach to sensing urban data in order to raise awareness. However, it is hard to reach a high network density in participatory approaches. Closer collaboration between operators of participatory projects and city administration is recommended to achieve this. Best practice operators need to deliver high-quality data, and the measuring procedures need to be transparent. Quality, validity and trust in data are crucial for a city's administration. In the case of Vienna, the city is interested in participatory approaches and the use of data collected by citizens, but it does not want to risk tarnishing its reputation through the use of potentially imprecise data. To incorporate data collected by citizens, the city needs to develop transparent structures and processes, such as criteria for data quality. It also needs to enable contributions by external initiatives and to support efficient internal use of data across departments. Supportive administrative structures and the good use of highly valuable data provide beneficial outcomes for everyone involved.

Acknowledgements

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