Citizens as Sensors

Human Sensors as a Smart City Data Source

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***Abstract*—This paper discusses how citizens can play the role of sensors, using their perceptions to discover and report problems using some kind of digital platform. The use of human sensors is connected to the concept of "smart cities". After a literature review, the paper presents two platforms and their use in detail: "FixMyStreet" and "Sauberes Wiesbaden". The two case examples are used to discuss the concept of human sensors in further detail. The paper concludes with proposals for further research on the topic presented.**

Keywords-citizens as sensors; human sensors, fixmystreet, Sauberes Wiesbaden, smart cities.

I. INTRODUCTION

Research on electronic participation has mainly focused on political participation as some form of discourse- and text-based deliberation [1]. But citizens may participate in other capacities, as experts (sharing their competence) and as volunteers (sharing their time) or both.

This paper focuses on citizens as sensors. Citizens collect data using their own senses and make an action to report their observations, but they can also be sensor platforms by carrying sensors around. We define a "human sensor" as a citizen that helps collect data about his/her surroundings. Citizens may also collect data about themselves, such as health condition data, sleep pattern data, or physical activity data, but such activities are outside the scope of this paper.

The concept of "citizens as sensors" is closely connected to crowdsourcing and crowdsensing. Crowdsourcing implies that a (large) crowd works on solving a problem, while crowdsensing focus on observations made by a (large) crowd. Citizen observatories are projects where citizens observe and report. This paper focuses on the sensor activities of the individual, not as a larger crowd.

The rest of the paper is structured as follows. Section II presents results of a literature review on citizens as sensors. Section III uses two specific case examples to show how human sensors can be supported by digital platforms. Section IV discusses the findings, while Section V provides the conclusions and plans for future work.

II. LITERATURE REVIEW

The main inspiration for our research on "human sensors" came from Villatoro and Nin [2]. The authors presented a vision of citizen sensor networks based on two different scenarios: Tracking citizens as passive entities to understand and optimize smart city functions, and citizens as active entities motivated by their common sense and using their mobile device to communicate the sensed sample.

Berntzen and Johannessen [3] introduced "citizens as sensors" as part of a discussion on the role of citizens in the smart city. This paper focused on political participation, but also discussed other possible roles, such as "human sensors".

Gil, Cortés-Cediel and Cantador [4] also discussed various forms of citizen participation in smart cities, including examples where citizens collect data to inform their government. They use FixMyStreet as one of their examples.

A search for literature on projects relying on data collected from citizens provided examples from public transport, smart parking, air quality monitoring, waste reporting, urban planning and development, and crisis/emergency response. The following subsections provide insight into how citizens act as sensors.

A. *Public Transport*

Holleis et al., described Tripzoom [5], an application implementing a new approach to urban mobility management and developed as part of the European FP7 project "Sustainable Social Network Services for Transport" (SUNSET)". Citizens shared personal mobility patterns, optimized their mobility needs using recommendation and personalized traffic services from the city authority, shared travel-related information with buddies on social networks and got rewarded for sustainable behavior. The authors point out the opportunities for city authorities to obtain detailed mobility profiles of its citizens that can be used for assessment of current infrastructure use and future mobility needs. Optimal use can be encouraged by incentives. The Tripzoom app was tested in selected areas in Enschede (NL), Gothenburg (SE) and Leeds (UK) [6]. The Tripzoom app was offering the following value proposition to its users [6]:

- *Be informed.* Tripzoom shows exactly how you travel. Where, when, how long and what it costs. Master your own travel behavior.
- *Be smart.* Tripzoom gives you insight into the way you have traveled and helps with personal suggestions to make the right travel choices.

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- *Be rewarded.* Tripzoom gives you rewards based on the way you travel. Take the challenge and be rewarded.

Tripzoom is one example of how citizens act as sensors and also directly benefits from information produced by the submitted data.

Tanas and Herrera-Joancomartí [7] proposed a smartphone sensing application *Incidéncies 2.0*, enabling users to notify and stay informed about incidents of the public rail network in the Barcelona metropolitan area. Their idea was to take advantage of the widespread use of smartphones combined with their sensing capabilities to gather sensory data from the environment and then send the sensed information back to a central data collection facility using cellular network technology. They suggested using the data retrieved from the application to analyze the potentials of new sensor network paradigm.

In Southeast Norway, a consortium of private, academic and public partners developed a system for monitoring use of public transport. The Trafpoint [8][9] system provides real-time information about passengers on buses. Some data is collected through cameras and motion detection algorithms. Public transport users can download an app. The app includes elements of gamification to reward users for using public transport [8]. The rewards can be shared on Facebook. The app also provides public transport planners with valuable information for changing bus routes and schedules.

B. Smart Parking

Koster, Koch, and Bazzan [10] developed "*wePark*", an Android app for smart parking based on citizens observations. Citizens could report free parking spaces, and the app would direct drivers to a free spot. An earlier attempt by Google "*Open Spot*" used the same approach but failed. The authors proposed to use the app to investigate motivation for users to report free parking spaces. However, no follow-up study was found.

C. Air Quality Monitoring

Several projects have used human sensors to report on air quality. The Green Watch project [11] distributed 200 smart devices to citizens of Paris. The devices sensed ozone and noise levels as the citizens lived their normal lives, and the results were shared through a mapping engine. The project showed how a grassroot sensing network could reduce costs dramatically, and also engage citizens in environmental monitoring and regulation.

I Trento, Italy, Leonardi, Cappellotto, Caraviello, Lepri, and Antonelli developed SecondNose [12], a mobile device to report air quality. The authors made the following observation: "*Official authorities use to monitor and publish air quality data collected by networks of static measurement stations. However, this approach is often costly, hard to maintain and not scalable in the long term*". They also argued that fixed station provides "*a lack of accuracy in the intra-urban air pollution maps*". The device was distributed to 80 persons in Trento. The initial use was high but declined over time. The authors explain: "*Users said they were curious in the beginning, but soon learnt the characteristics of the places they measured"*. This observation indicates potential limitations of using dedicated mobile devices for sensing the environment.

Dutta, Chowdhury, Roy, Middya, and Gazi [13] made a similar approach by developing "AirSense", a wearable unit to measure air quality. Again, the authors cited an inadequate number of fixed monitoring stations as the reason for implementing their project.

The EU-funded project CITI-SENSE [14] also made a handheld sensor platform for air quality monitoring: "*Little Environmental Observatory*" (LEO). The project also developed a smartphone app to let citizens report on their perception of air quality. CITI-SENSE ran from 2012 to 2016.

Ishigaki, Tanaka, Matsumoto, Pradana, and Maruo developed a mobile sensor to measure particle pollution. [15]. The sensor was tested in different cities in East Asia, partly by mobile sensing and partly by installing the sensor in fixed locations.

A somewhat similar approach is used by AIRALERT, a service provided by CivicAlert, a Romanian NGO [16]. They use a handheld sensor platform "*AirBeam*" with Bluetooth connection to an Android smartphone. Volunteers collect data, and results are shown on a map.

Pan, Yu, Miao, and Leung [17] used a different approach, by using smartphone cameras to detect air pollution through artificial intelligence techniques to determine particle pollution. This solution requires humans to do measurements actively.

Migliore [18] developed a platform mounted on a bike, "*SwarmBike*", to measure air pollution. The unit has a Global Positioning System (GPS) receiver, a GSM module to handle communication, and sensors for barometric pressure, temperature, humidity and a CO sensor. His thesis describes other types of sensors for measuring air quality.

The problem with hand-held units is that someone must carry them around. Several solutions require Android smartphones. This requirement excludes a large number of Apple iPhone users. Users may also be reluctant to provide access through their own phones. It seems that most of the projects described above lasted for a limited period.

D. Pollution and Waste Reporting

The Irish Environmental Protection Agency has developed the app "See it? Say it!" to let citizens report on waste dumping/littering and other environmental issues [19]. A similar application has been piloted and tested in the city of Dhaka, Bangladesh [20]. Dhaka is a major city with challenges related to pollution (water, soil, noise, thermal, air) and waste dumping. The application was tested over a two-week trial period and showed promising results. In Kinshasa, another pilot was developed and tested, also with promising results [21]. However, this pilot revealed some possible issues related to data quality and acceptance from government agencies who were reluctant to proceed with full-scale implementation. All three examples are similarly structured: They are based on geo-location, and users are asked to report on specific categories with the option to upload images and a text-based description. Pollution and waste reporting are also handled by our two case studies presented in the next section.

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E. Urban planning and development

In Norway, the Norwegian University of Science and Technology (NTNU) developed an Android app for The Norwegian Public Roads Administration to manage and monitor bicycle routes [22].

City planners make assumptions about cyclists´ behavior based on insufficient data. The app provides more accurate information on which routes to improve based on feedback from cyclists. The app also provides information about such things as speed and relative frequency of use of bike lanes. Field testing was done in Trondheim, Norway, and at the end of the trial period more than 50 people had downloaded and installed the app and uploaded more than 100 trips. The collected data is visualized in a web-based interface and provides city planners with valuable information for planning purposes.

In Turku, Finland, the city created a mobile app, Täsä, to let citizens participate in urban planning [23]. Citizens can download the app to report issues or present ideas for development. The app allows users to pin an issue to the map, take photos and upload text. It is also possible to discuss the proposals made by others. A first trial found that this engaged hundreds of citizens who used to app both to report on problems and present new ideas.

Goodchild [24] discussed the concept *volunteer geographic information* (VGI) and used case studies of OpenStreetMap, Flickr, and Wikimapia to show how citizens volunteering and contributing to GIS sites laid the foundation for other human sensor work such as FixMyStreet.

On the conceptual level, Resch, Summa, Sagl, Zeile, and Exner [25] proposed a system using human sensors to capture citizen perception of public places. They model a combination of geolocation, wristband sensor to measure "emotion" and social media mining to aggregate data on citizens' attitudes, emotions, and perceptions of public places. The results can be used in planning processes of new areas, or as input for regulating and changing existing places.

F. Crisis/emergency response

Several authors discuss how crowdsourcing of data using human sensors can be valuable for crisis management and emergency response. According to Liu [26], the 2010 Haiti earthquake was the first-time researchers became aware of the potential of citizens crowdsourcing information. Based on experiences from Haiti, they have designed a framework for spontaneous crowdsourcing in emergency and disaster areas.

Kamel Boulous et al. [27] did a review of applications and use cases for citizens as sensors, and mentioned areas such as fire prevention, medical information, routing of CPR-trained personnel to emergencies, drug safety and disease outbreak mapping as examples. They also present GIS-based tools that can be applied to create other applications

In Brazil, Degrossi, de Albuquerque, Fava, and Mendiondo [28] described a pilot study on how human sensors can contribute data related to flooding, a significant problem in parts of the country. Evaluation of the case showed that this had significant positive impact on flooding data in the areas where the pilot study was conducted.

III. CASE EXAMPLES AND FINDINGS

Two case examples are used to illustrate how human sensors use platforms for reporting their observations. The first case is the Norwegian version of FixMyStreet: FiksGataMi. This version was developed and is maintained by the Norwegian Unix User Group. The second case is "Sauberes Wiesbaden", a mobile app developed in cooperation with the municipal waste services operator ELW and the RheinMain University of Applied Sciences in Wiesbaden, Germany. The two cases were selected based on the availability of data for analysis.

A. FixMyStreet (FiksGataMi)

This subsection presents our study of the Norwegian version of FixMyStreet: FiksGataMi. FixMyStreet [29][30] is a web application allowing citizens to report issues and problems related to infrastructure and waste to local authorities. It was developed by mySociety, a British NGO with a mission to make citizens more powerful in the civic and democratic parts of their lives. The original FixMyStreet was launched in 2007. The application is location based. The user may pinpoint the location on a map. Typical problems are holes in the road, broken light bulbs in street lighting, abandoned vehicles, broken water pipes, etc.

Figure 1 shows a screenshot of one of the reports, in this case about traffic signs. After reporting an issue, the report is sent to the relevant authorities through electronic mail. Both authorities and users can comment on reports, e.g., that the issue has been solved. It is also possible to see all reports within a geographical area. Figure 2 shows a map with several reported issues within an area.

FixMyStreet is widely used in the United Kingdom, but the software itself is open source and has been adopted by cities, regions, and countries all over the world. When using the application citizens are acting as „human sensors".

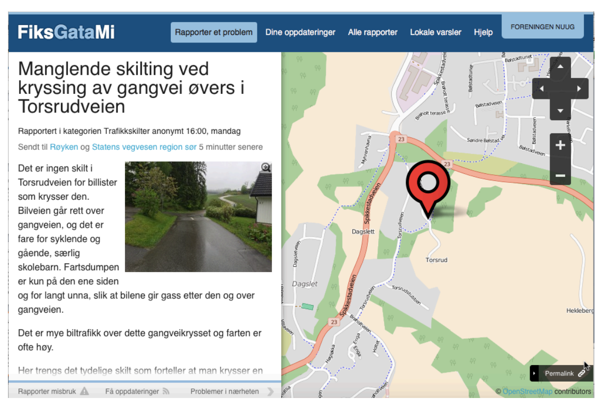

Figure 1. FiksGataMi screenshot.

Our research aimed to find out more about the use of the application, including the number of reports, and the content of the reports. The information was extracted from the "FixGataMi" website by a custom-made web mining application, and extracted information was stored in a MySql database, and then grouped using SQL. The data for report

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recipients and categories is from 2017. The reason is that new recipients among authorities have been added since its launch, in particular, the Norwegian Public Roads Administration regional offices. The sample from 2017 consists of more than 6,000 reports from all over Norway.

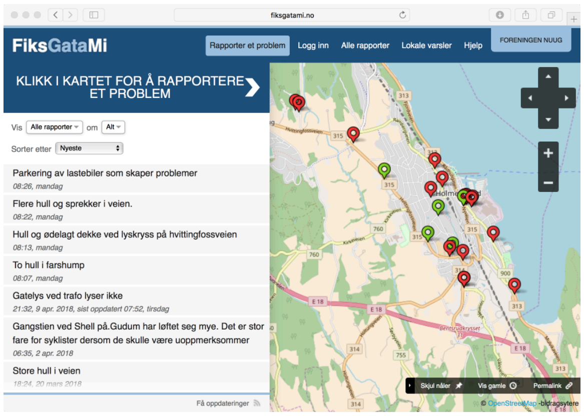

Figure 2. FiksGataMi screenshot (geographical area).

The use has been quite stable since its launch in 2011. The first year had more reports, probably because of novelty and press coverage. Table I shows the number of reports for each year. Each report has a unique id. The numbers are based on first and last registration each year. Some entries have been removed or are reported as unavailable. For 2017 this number is 376, which is close to 5 percent.

TABLE I. NUMBER OF REPORTS

Year	Number of reports
2011	9.751
2012	5.381
2013	6.655
2014	6.016
2015	6.365
2016	6.375
2017	6.932

Table II shows the top ten recipients of reports. Not surprisingly, the regional offices of the public road administration are well represented together with the three largest cities (Oslo, Bergen, and Trondheim). However, also some smaller cities (Hamar and Halden) are represented.

TABLE II. TOP TEN REPORT RECIPIENTS (2017)

Rank	Report recipient (authority)	Number
1	Public Road Administration, region east	2,490
2	Public Road Administration, region west	1,113
3	Public Road Administration, region middle	880
4	Public Road Administration, region south	834
5	Oslo	603
6	Trondheim	490
7	Hamar	472
8	Public Road Administration, region north	454
9	Bergen	357
10	Halden	253

The developers of the Norwegian version added some extra categories not found in the English version to handle specific events relevant for Norway. These new categories are “oil spill”, “snow ploughing”, “bike roads”, “universal design” and “water supply”. “Universal design” is about reporting barriers for citizens with impairments. The list of categories is shown in Table III.

TABLE III. REPORTS AS CATEGORIES (2017)

Category (Norwegian)	Category (English)	#
Annet	Other	72
Buss- og togstopp	Bus and train stops	52
Dumpet skrot	Flytipping	44
Forlatte kjøretøy	Abandoned vehicles	62
Forsøpling	Rubbish (refuse and recycling)	70
Fortau/gangstier	Pavements/footpaths	340
Gatefeiing	Street cleaning	124
Gatelys	**Street lighting**	**1,820**
Gater/Veier	**Roads/highways**	**830**
Graffiti/tagging	Graffiti	0
Hull i vei	**Potholes**	**1,847**
Offentlige toaletter	Public toilets	1
Oljesøl	*(Oil spill)*	1
Park/landskap	Parks/landscapes	50
Parkering	Car parking	75
Snøbrøyting	*(Snow ploughing)*	195
Sykkelveier	*(Bike roads)*	106
Tette avløpsrister	Blocked drainage gullies	119
Trær	Trees	116
Trafikklys	Traffic lights	83
Trafikkskilter	Road traffic signs	195
Ulovlige oppslag	Flyposting	4
Universell utforming	*(Universal design)*	13
Vannforsyning	*(Water supply)*	16
Veinavn-skilter	Street nameplates	31
	- No category -	290

FixMyStreet is an appropriate name from the reports it contains. The three top categories are potholes (1,847), street lighting (1,820) and roads/highways (830). Also, most reports are sent to the Public Roads Administration. The categories unrelated to roads have fewer reports, but all categories, except Graffiti, was used in 2017.

B. *Sauberes Wiesbaden*

The project “Sauberes Wiesbaden App” (Clean Wiesbaden App) was initiated by the project office of the city mayor of Wiesbaden and the municipal waste services operator ELW. The project aimed to promote the participation of the citizens to quickly and easily report illegally dumped garbage and other waste disposal-related problems in the area of Wiesbaden, Germany. An app has been developed to make reporting easy and to supplement the existing, previously telephone-based channel for reporting waste dumping. The app uses the location data from the mobile phone to give the exact position of an issue. The mobile app concept was developed through research cooperation between the ELW

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and the RheinMain University of Applied Sciences in Wiesbaden [31].

The app was developed within about four months based on a user-centered design approach. Project members were employees of the IT department and the call center of ELW, the City Council, and the University RheinMain. The app was to be integrated into ELW's existing complaint management system initially developed for handling phone-based issues reported to a call center team via a hotline. An implementation approach based on a hybrid app (PhoneGap) was chosen to enable rapid development across different mobile operating system platforms (Android, iOS, Windows Phone). The mobile channel for the citizens could not be realized as a website or web app as the technical concept required access to the devices' location and camera. Moreover, the app had to support notifications on status updates about the disposal removal. Implementation of this feature was challenging, as another requirement that emerged during the user analysis was the need for an option of reporting anonymously and without registration.

After a basic requirement specification and up-front user research, a prototype of the app was developed rapidly and used for intensive pretesting. In particular, the localization of waste deposits turned out to be a demanding implementation task. GPS-based location information acquired by the users' smartphones was often not precise enough, reverse geocoding failed (e.g., for green, wooded, or undeveloped areas) or additional information was required by the removal teams to accurately locate the issue. Anonymous reporting was intensively discussed as there was the threat that this could stimulate even more waste dumps or lead to unwanted or fraudulent use of the platform. For this reason, it was decided that all incoming reports are first checked by the ELW team and then approved for viewing on the map to prevent any misuse. A status map was integrated into the app and showed all approved reports and the corresponding removal status. All approved reports can be viewed on a status map. This avoids duplicate messages as a user can see on this map if a specific issue was reported before. Besides, problems reported by a user can be saved on the device in an "automated favorites" list by using an issue ID and then tracked for status changes in separate lists and views. Figure 3 shows the input mask for reporting issues and the status map with the reported issues.

The mobile application was officially launched in the Google Play Store on October 9th, 2015. Versions for other mobile operating platforms followed some weeks later. The initial launch in the Google Play Store was accompanied by a press conference in the city hall and information about the new app on websites of ELW and the city of Wiesbaden, an article in an ELW customer magazine as well as articles in local and regional newspapers.

During the first month, there were more than 1,000 downloads. In this period 469 events were reported. From those, 13% were rejected due to duplicates, poor quality pictures, or because the report was located on a private or restricted area; while 87% were successfully processed. When comparing the app with other methods like calls or emails, the overall number of reports generated by the app has increased by 134% [31].

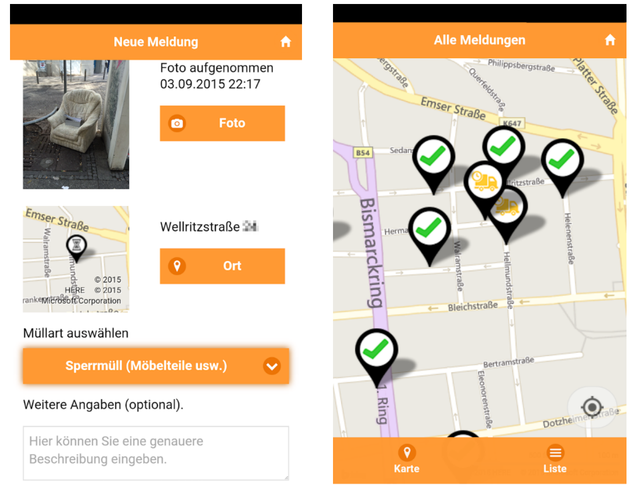

Figure 3. Sample screens of the Sauberes Wiesbaden app.

By the end of 2015, the number of downloads increased continuously. Figure 4 shows the installations of the Sauberes Wiesbaden App for Android and iOS. In May 2018 the total number of installs was 2,318 for Android and 315 for iOS. Statistics for uninstalls were only available for Android. 1,366 uninstalls are reported for the app between September 2015 and May 2018 in the Android Play Store statistics.

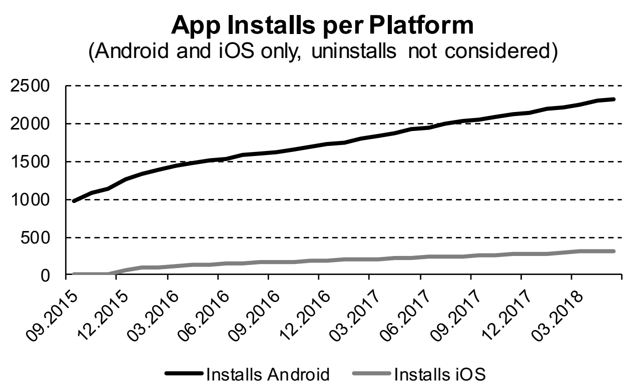

Figure 4. App installs per platform 2015-2018

At the end of the year 2017, 2,154 active downloads were reported via the Android platform. This is a penetration rate of less than 1 percent with regard to the population of the city of Wiesbaden (2017: 290,547) [32] and still below 2 percent, when considering the smartphone penetration (2017: 54m smartphones [33], 82.7m inhabitants in Germany) [34] and the Android market share (for smartphone sales in 2017: 81.5 percent) [35]. A large part of the downloads therefore already took place shortly after the launch. After that, there have been a continuous, but a low number of monthly downloads. This may be due to the fact that more comprehensive app marketing actions (e.g., AdWord or Facebook campaigns) have not yet been conducted. The distribution of the app is therefore strongly driven by references on the ELW websites, the app stores, as well as word-of-mouth communication and user recommendations. Nevertheless, including the test phase, a total of 14,685 issues have been reported since May 2015 (up to May 2018). Figure 5 shows that the number of reported cases is subject to strong monthly fluctuations and that there is no clear seasonal or long-term trend in the total number (app- and phone-based reports) of issues.

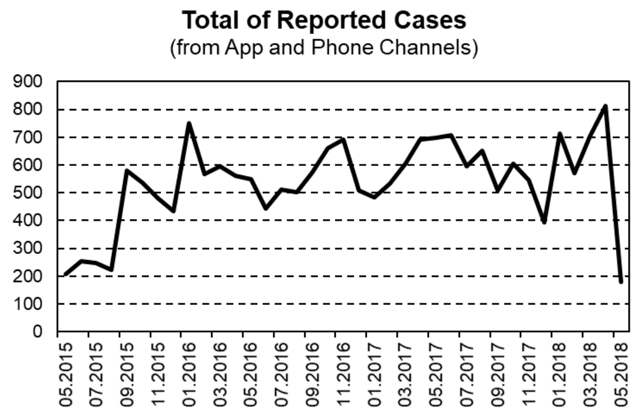

Figure 5. Reported cases 2015-2018.

A similar fluctuation can be observed if only the app-based reported issues are considered. However, in Figure 6 a trend is apparent – the number of app-based reported issues has increased continuously over the last three years.

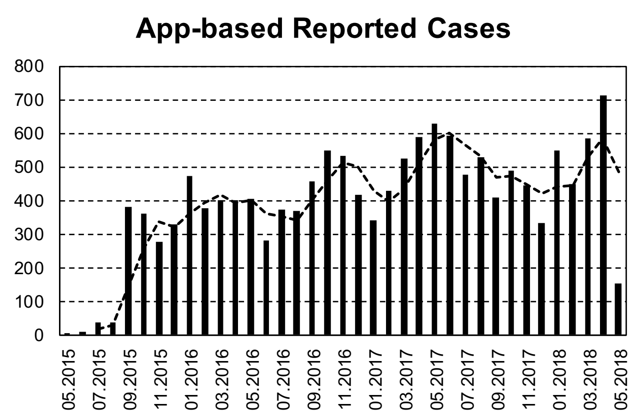

Figure 6. App-based reported cases 2015-2018 (dashed line shows 3-point moving average).

This trend becomes even more apparent when only the share of app-based messages in the total number of reported issues handled by the ELW is shown in Figure 7. The app-share has already reached over 60 percent a short time after launch and has leveled off to around 80 percent in the last few months.

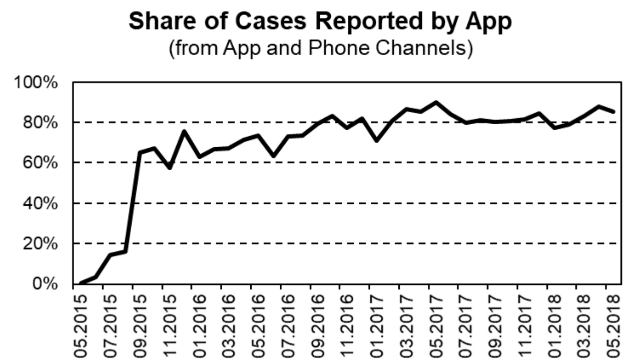

Figure 7. Share of app-based reported cases 2015-2018.

Table IV shows the type of reported issues. Here, it can be seen that a large part of the issues is accounted for by (1) bulky waste, (2) general waste and (3) metal and devices. This seems plausible because this type of waste is the most noticeable in the cityscape.

TABLE IV. REPORTS AS CATEGORIES (2015-2018)

	2015	2016	2017	2018 (Until May 1st)	Total (in %)
Dog dirt bag dispenser (empty, defect)	10	21	67	26	0.8%
Metal/electronics (devices etc.)	208	662	670	257	12.2%
General waste	315	1,359	1,585	667	26.7%
Garbage bags/ cartons	83	234	221	108	4.4%
Waste bin (full, defect)	34	129	292	74	3.6%
Hazardous waste (paint, varnish, etc.)	38	133	185	64	2.9%
Bulky waste (furniture etc.)	667	2,411	2,729	1,191	47.7%
Uncategorized	68	83	30	64	1.7%
Total (reports)	1,423	5,032	5,779	2,451	100%

Figure 8 clearly shows that the use of the app does not differ significantly in quality compared to the recording of issues by telephone. Since HY2017, however, the proportion of solved cases in telephone processing has been slightly higher. However, this is more likely related to procedural aspects and not to systematic problems in app-based issue reporting.

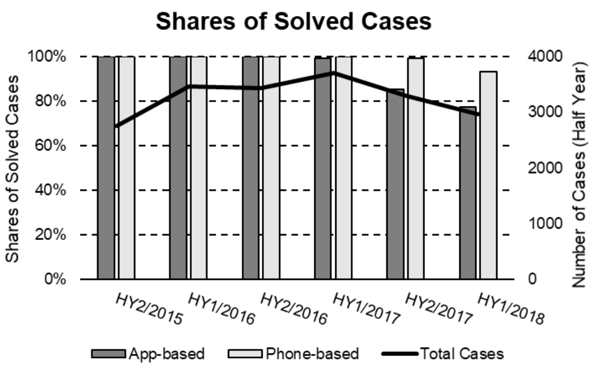

Figure 8. Shares or solved cases (app and phone).

As a result, it can be stated for this case study that the introduction of the Sauberes Wiesbaden App as an additional customer channel at ELW has been very successful. After the introduction of the app, the total number of reported and solved issues has steadily increased. The proportion of issues reported via the app –and thus automatically acquired feedback– has risen continuously. Since the app is available as a feedback channel for the population seven days a week and 24 hours a day, an attractive additional offer for the inhabitants of Wiesbaden has been established. It is interesting that the introduction has been successful even without comprehensive marketing initiatives. However, it can be assumed that the awareness and dissemination of the app can be further increased through appropriate campaigns. Furthermore, it should be noted that the 14,685 reported issues between May 2015 and May 2018 are related to only 2,633 total downloads for the Android and iOS platforms. This corresponds to an average of more than five reported issues per download. In this respect, it can be assumed that apps are a promising instrument to achieve sustainable e-participation of citizens at a local level.

IV. Conclusion and Future Work

Smart cities use information and communication technology to improve performance and decision making. Data may be collected from various sources, e.g., sensors. This paper has examined a specific kind of sensor, the citizen as a sensor. Citizens can use their perceptions to report on issues. The city can use these reports to solve problems proactively.

This paper examined two specific cases: The Norwegian version of FixMyStreet: FiksGataMi and the German app “Sauberes Wiesbaden”. Both applications have proved to be sustainable over time with a respectable number of reports. The two cases were selected based on the availability of data for analysis. We have shown the use and also what kind of reports citizens are making. Both cases provide a feedback mechanism to the people reporting issues, letting them know when the case has been resolved. This is likely important when it comes to retention rates and continued usage of the systems.

The contribution of this paper is more insight into how citizens may act as sensors, and thereby contribute to solving problems in their communities. Smart cities are about increasing quality of life, provide better services, reduce environmental footprint and improve citizen participation. When citizens act as sensors, they contribute to all these aims of smart cities. City services become more effective since the city is alerted to problems, including environmental issues. The citizens participate in improving the city and thereby the quality of life.to improve the city and thereby the quality of life.

Possible future research may include further analysis of the data we have obtained, in particular, to correlate reports to time of year and time of day. Another possibility is to investigate the motivation among citizens that contribute as human sensors. We have currently not addressed security implications of this kind of reporting platforms. This could also be a topic for future research.

Finally, our literature review of similar applications demonstrates several possible extensions to FiksGataMi and Sauberes Wiesbaden: Various forms of pollution, littering and waste dumping are perhaps the most relevant additions based on our literature review, as these are similar categories to the ones already found in the applications. Future research should examine possible enhancements of the two applications.

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