Conveying a Civic Issue through Data via Spatially Distributed Public Visualization and Polling Displays

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ABSTRACT
The proliferation of Internet-of-Things devices in urban environments empower citizens to appropriate data for civic purposes. Simultaneously, public visualization has shown to engage a wide audience with data by situating its graphical representation within the actual environment of its measurements. We thus propose a public visualization and polling system that enables residents to co-author a civically-motivated data-driven narrative and distribute it over multiple wireless displays located at different physical locations. Through an in-the-wild study, we studied how passers-by and residents engaged with the system by applying a user engagement evaluation model that maps the social and spatio-temporal context into interactions between the content, the environment and the infrastructure and two distinct user types, i.e. the residents who hosted the displays and the passers-by. Our findings show how the tacit social relationships between the user types, the social factors between passers-by, various temporal aspects, and several contextual factors affect user engagement with our spatially distributed public visualization and polling displays.

Author Keywords
Public visualization; in-the-wild study; smart cities; urban computing; public display; citizen science.

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION
Internet-of-Things (IoT) devices such as the Smart Citizen Kit [8] or the Air Quality Egg [15] allow citizens to appropriate data for various civic purposes [3]. Whether they are monitoring sudden changes in sound levels around Heathrow airport [27] or capturing the daily patterns of air pollution in Amsterdam [21], the resulting data streams can be leveraged to provide real empirical evidence in addressing a pressing local issue, to form a critical yet quasi-objective basis for discussion with local governmental organizations [2], or to orchestrate local political action by exploiting the data as a catalyst for community-driven dialogues [3]. Instead of the more common practice of opening data and its discussion on a dedicated online platform, we propose to convey the data within the public space itself, that is in the vicinity of the actual location of its measurement. Such 'public visualization', often supported by polling devices to stimulate discussion and debate [22], has already shown to open opportunities for a wide range of citizens and civic groups to engage with data [40], such as raising awareness on particular hyperlocal matters of concern [12, 13, 35].

Figure 1. Our public visualization attached to a shopping window in Santander, Spain.

We thus propose a custom public visualization and polling system to support citizens in triggering civic participation on a locally relevant and data-related issue. While most past efforts in this direction focused on single-display interventions on publically funded infrastructure, we aimed to make explicit the shared authorship and relevance of the messages by spatially distributing multiple displays over several residential home facades. In order to elicit interactive forms of public engagement, some displays were equipped with a public polling functionality, allowing passers-by to express their personal opinion on the data by pressing a button. Yet little knowledge exists on how passers-by interpret or engage with a public visualization

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Figure 2. Mock-up in a public library in the city of Aarhus.

and polling system that is spatially distributed and hosted by residents themselves, in that we believe that the perceived ownership and trust shifts from the common public domain to the socio-cultural reality of the community residents themselves.

We thus present the design, development and evaluation of 'Data on Site' (DoS), a public visualization and polling system consisting of multiple 'sets' of wirelessly networked and battery-driven e-ink displays. Each public visualization set contained six individual displays. Informed by the outcome of initial co-design sessions, each of these display sets were connected to a particular part of the data by way of a graphical or textual representation, such as a line graph, an infographic or an anecdotal textual quote. These representations were linked in a meaningful way as each set was able to present a unique data-driven narrative, such as how green areas positively affect air pollution. Some display sets featured three embedded push buttons that represented a sequential sentiment, such as a happy, neutral or sad smiley icon. The display sets were spatially distributed over several neighboring streets. Local champions, who aimed to raise awareness on a local issue, were thus able to leverage the deployment of DoS in order to encourage other residents to 'host' a set onto their facade. The DoS system aimed to reach a wide range of citizens, including other neighborhood members that did not directly partake in the system, as well as passers-by. Guided by an in-the-wild study and a custom evaluation framework, we present a number of design considerations.

RELATED WORK

Examples of public visualization, i.e. data representations in public space, mostly present data that is captured via public

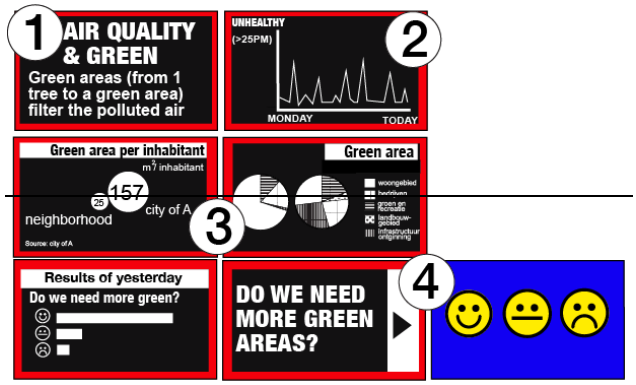

Figure 3. Narrative on how green areas impact air quality and the lack of green in the particular neighborhood.

polling devices [4, 22, 35, 37, 38], with the aim of supporting social discussion and reflection on local issues in the community (e.g. [19, 22, 35]). Yet public visualization can also represent other data sources to the same effect, such as open data from civic platforms (e.g. [9]) or energy monitors (e.g. [6, 37, 39]). These data sources provide opportunities to inform citizens more extensively on local issues, or even reveal their share in the issue [37].

Passers-by tend to be enticed to discover insights through public visualization when the personal relevance of the issue is high and the boundaries for use are low [33]. One promising approach to increase personal relevance through reflection [9] are visualizations of narratives in which data is conveyed as stories [32]. These narratives seem to ease the learning curve of interpreting the visualization [7] and support citizens to share their own perspective [16, 32].

The public environment offers distinct contextual clues that help the sense-making process of a visualization [40, 41]. For instance, local inhabitants who are familiar with the socio-cultural dimension of the environment, may connect tacit and experiential aspects to the data that is visualized in that environment [42], which in itself implies social and political values and assumptions [14, 23] Attaching public displays to the façade of citizens' homes also encourages passers-by to interpret the content in the context of the pre-existing, complex social relationships of the neighborhood [46].

A public visualization can be divided into multiple yet connected representations. As such, multifold small-scale displays dispersed in public space can be used as miniature carriers or bite-sized information to keep track of personal and highly localized data [29]. However, to the best of our knowledge, these kinds of deployments have so far only been explored in home and office contexts [34]. On an urban scale, examples of distributed displays mostly exist of networks of identical screens, e.g. [11, 28], and less frequently within a single public space, e.g. [10] or neighborhood, e.g. [22].

Research has demonstrated how the public context affects how passers-by engage with public displays, such as how the honeypot effect encourages people to interact [45] or in contrast, how passers-by can become embarrassed to interact [31]. Other dimensions of the public environment, such as social pressure, can also impact the interaction behavior [43].

CO-DESIGN

In the context of OrganiCity, a European H2020 project that aimed to facilitate experiments on how citizens can collaboratively work with urban data towards solving locally relevant challenges, we held two iterative co-design sessions within three central neighborhoods of international European cities, i.e. London, Aarhus and Santander, each differing in size, character of the area and demographics of

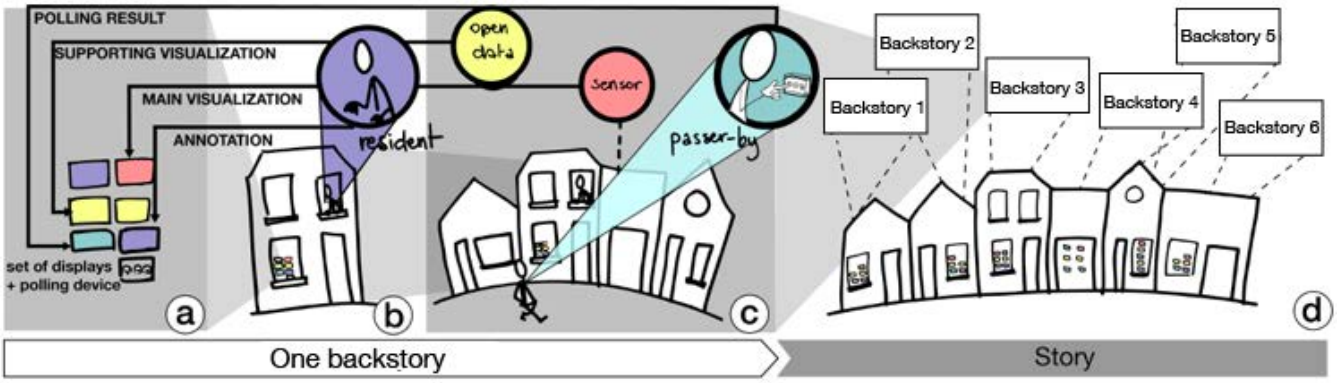

Figure 4. Interaction design: visualizations presented on set of displays (a) on the window of a residents' house (b) in a neighborhood (c) are guided by one backstory. In a neighborhood, several backstories exist, which form one narrative (d).

passers-by. In each city, we focused on a local issue from a particular neighborhood: in London and Aarhus, we visualized data concerning the issue of air quality; in Santander, we showed data that conveyed the local shopping habits. To ensure a mix of local champions (stakeholders driving a civic cause) and citizens that were less concerned with the local issue, we recruited passers-by in the street, but also via online and a professional recruitment agency. In order to gain a deeper understanding of how citizens imagine themselves hosting a public visualization that presents a local issue, we organized several co-design sessions on the street, such as by presenting participants a mock-up as shown in Figure 2. Then we asked the participants how they would present the issue to others on the mocked-up public visualization displays. Comments were noted on post-its and attached next to the mock-ups. We analyzed and thematically categorized the results in terms of content, carrier and environment [42], via a grounded theory approach [18].

First iteration. In London (21 participants, 17F, avg. age 38), we learned to incorporate personal anecdotes and the 'evidence' of the issue, e.g. '*I have to clean my façade every year because of the filthy polluted air'* as a way to personalize the presented data. We also learned that displaying several infographic-style bitesized facts and statements was perceived to be easy to remember, such as '*Air pollution is responsible for 80% of premature deaths'*.

In Aarhus (32 participants, 17F, avg. age 30), we encountered similar insights, and learned to annotate the data with solutions that promote actions towards the issue, e.g. '*Share your car'*. Also, meaning could be added to the visualized issue by locating the displays at particular locations, such as a cargobike, as its spatial context demonstrated a practical way to potentially help solve the issue. Here, we also learned that polling features that request a call-to-action might encourage active contribution possibilities for passers-by.

Second iteration. Based on these learnings, we developed a simple, interactive polling interface to accompany the displays (Figure 1). The co-design efforts in Santander were more focused on the actual deployment of the public visualization mock-up, as we asked four participants (2F, avg. age 41) to come up with annotations for the data and a polling question, which were deployed on daily basis for four consecutive days. Here, we noticed a difference in the socio-cultural context as participants were more hesitant to present local issues through data in public. Together with the participants, we searched for ways to reveal different aspects of the issue, which was then solved by a narrative structure of introductory text and annotations supporting the data [32].

Overall, we thus learned there exists a need to contextualize data via: 1) the type of visualization and its annotations, guided by a narrative approach; and 2) the meaning of the display device that carries the public visualization.

THE DATA ON SITE SYSTEM

Interaction Design

Each set of six displays (see Figure 4) presented a particular perspective on a local issue by way of a specific thematic backstory [32]. Data for each backstory originated from local sensor streams or was derived from open data repositories, as well as more qualitative opinions from participating residents and passers-by (see Figure 4). Each backstory consisted of: 1) a title that introduces a theme within the issue (e.g. Air pollution and the impact of green areas); 2) a main visualization graphic (e.g. a historic line graph on one-week particle matter measurements); 3) supporting smaller visualizations or textual annotations (e.g. a textual annotation stating the impact of green combined with an infographic on the number of green areas in the neighborhood, see Figure 3); 4) polling results presented as a bar chart (e.g. on the desire to have more green areas); and 5) a textual annotation. On a display set equipped with a polling device, this annotation consisted of a question as formulated by the residents hosting that set. On the other sets, this annotation was a personal statement based on reflecting upon the visualized data by the resident household. Passers-by were able to select a happy, neutral

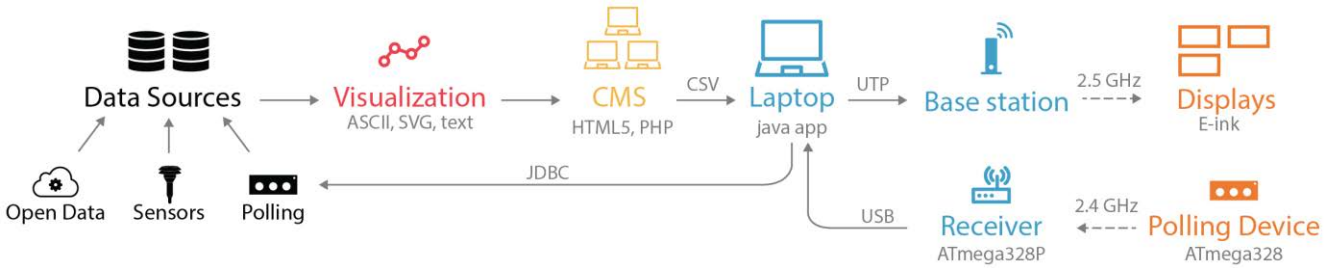

Figure 5. The DoS system aggregates data and creates visualizations that together form backstories. These backstories are shaped and reflected on through a CMS and subsequently spread to distributed displays through a base station connected to an on-site laptop. Polling devices that are positioned beside the displays collect opinions, which become data sources in the backstories.

or sad smiley by pushing a button, which then caused an integrated LED to light up to confirm their interaction.

Spatial Distribution of Displays

As shown in Figure 7, each display set allowed to be arranged in terms of layout, in order to adopt to the spatial context, such as: 1) how the façade is visible for passers-by from further away or when they are seated on a bench at the public square; 2) how the facade is situated in a specific rhythm of neighboring displays (e.g. each third façade); or 3) the social meaning of the facade, such as the home of the person championing the local issue, or being community newcomer.

Multiple display sets were spatially distributed over multiple façades in a neighborhood. The spatial succession of the different sets gave the chance to develop a cohesive narrative that potentially signifies the sharing of concerns of multiple neighbors. Next to the set of displays, A5-sized printouts introduced the workings and motivations behind the intervention. A dedicated webpage offered a more detailed description of the project, and pointed to an email address for any inquiries or comments.

Technical Infrastructure

The electronics were encapsulated by a custom 3D printed casing (see Figure 1), which was designed to be attached to the façade either externally through fixating the casing to a glass pane, or internally by gluing the casing to the inside of the glass window and fitting a sticker hiding the edges.

As shown in Figure 5, real-time data (e.g. from sensors and polling devices) were automatically collected daily and rendered in pre-defined visual representations. Static data from other open data sources (e.g. green areas in the city) were generated manually beforehand. Through a custom web-based content management system, residents are given daily the opportunity to select one of these backstories and provide a personal annotation or polling question related to that backstory.

The display devices for the distributed visualizations were based on existing technological advances commonly used in electronic shelf labels in shops. Each display device consisted of two components that operate with very low energy usages; an e-ink display (i.e. 2.9 inch, 296x128 pixels, dot matrix) and a radio to enable wireless networking capabilities (2.5GHz). E-ink displays provided good readability even in bright daylight and have become relatively affordable, making them ideal to be used within the volatile conditions of public space. The displays were updated via a custom base station broadcasting on 2.5 GHz, which is connected to an on-site laptop. Therefore, a researcher toured the neighborhood with this equipment every day to update all the displays wirelessly. Other custom base stations connected to the on-site computers wirelessly received the button presses on the polling devices. The presses were inserted as votes in an online database through a Java database connector.

DATA COLLECTION AND ANALYSIS

The in-the-wild case study applied a mixed method approach, in order to capture the impact of the system on two user types: 1) the residents, and 2) the passers-by.

Residents. We provided DoS to local champions to empower them to raise awareness around a local issue that was evidenced in one or more sources of locally captured data. These champions recruited other community members in the neighborhood to host a display set. We interviewed residents in an informal way at least 2 times during deployment. Afterwards, semi-structured interviews were conducted with the hosting residents, which took approximately 45 minutes and revealed their overall experience with the public visualization system, any gained insights on the daily backstory, and the perceived influence on public debate.

Passers-by. DoS engaged different types of passers-by, including non-participating neighbors, visitors and daily commuters. One researcher observed the behavior of passers-by in a concealed way, such as by sitting on a bench or acting as a casual pedestrian. The engagements of passers-by with the DoS system were categorized according to the PACD model, which is already established in public display evaluation research [24]. In practice, we interpreted *passive engagement* as turning one's head towards a display, *active engagement* as stopping to take a look and/or reading a single display, and *discovery* as reading (parts of) the backstory and/or pressing a polling push button. When passers-by who engaged with DoS left its vicinity, we approached them for a semi-structured interview (approximately 5 minutes), asking "*what they had*

Figure 6. DoS 6: Receiver of polling devices connected to mini computer behind the window (left) and researcher with laptop and base station (right) to update the displays.

discovered". This broad formulation encouraged passers-by to describe any immediate insight or finding they could recall. Passers-by who did not engage with the DoS system were asked if they had noticed the displays, and why they ignored them. We also queried all passers-by about their expectations, and any motivation or inhibitor to actively engage with the system [33]. Lastly, we asked if they noticed the displays on a previous occasion, and noted down their basic demographic information. Two researchers independently coded the data insights of participating passers-by (and residents) according to whether they referred to the environment (e.g. *"The pollution levels are high because there were a lot of cars today"),* to their personal situation (e.g. *"Maybe I should not have gone outside with my baby yesterday as air pollution impacts his health"*), or to the content in general (e.g. *"Air pollution is not really a problem in this city"*).

STUDY

The neighborhood committee of street A. (see Figure 7) in the city of Antwerp is concerned about the levels of local air pollution. This concern is scientifically evidenced by a one-month citizen science study [47] that revealed very unhealthy PM25 values for their street according to WHO standards [44]. The committee's aim is to change local political decision making in so far that the often-congested street should become blocked for non-local traffic. As such, the committee showed interest in collecting more and also real-time data on the actual air pollution, and wanted to share these measurements with the greater neighborhood in order to raise additional and more widespread awareness for the issue. Accordingly, we considered it fair to reward their role of local champions for the DoS deployment by donating a professional-grade outdoor PM25 sensor, from which the data was also used in the public visualization. For this study, two residential members of the committee were approached and recruited for participation, six others were recruited by the researchers who explained the idea of DoS and the overall goal of the committee.

As illustrated in Figure 7, eight sets of DoS were distributed around a central public square where street A crossed streets B and C. This public square is visited by members of the wider neighborhood, as it hosts public waste containers, three skate ramps, benches, a large tree and a grass field. Accordingly, we considered this neighborhood role and its available urban infrastructure as ideal comfort and social spaces [17] that could empower and motivate passers-by to interact with the system. First, we selected three locations for DoS around the public square, i.e. DoS 3, 5 and 6 (see Figure 7), of which 3 and 6 was equipped with the extra polling display. Second, the locations of DoS 4, 7 and 9 were chosen to amplify the spatial distribution by creating a rhythm, although unforeseen circumstances caused DoS 9 to drop out the study. Third, the choice for the last remaining locations was based on the social situatedness of the system, as DoS 1 and 2 were the homes of local champions, and DoS 8 was the home of immigrants.

RESULTS

The DoS system was deployed for 23 continuous days, of which the first three days of deployment were considered as a pilot study to test the robustness of the technical functionalities, during which a number of networking issues were fixed. Resident 1 (R1) left on holiday after 13 days of deployment. His display set was adopted on request by the household of DoS 8 who continued the study for the last seven days. We observed the public square for 13 hours, divided over nine days of the deployment. In total, 30 semi-structured interviews were taken of which 20 with passers-by (7F, 41 avg. age, 19 SD) and ten with residents (including 2 interviews in pairs). Of those 20 interviews, seven turned out to be neighbors living in the same streets (their homes are indicated with squares on Figure 7). Eight interviews were conducted with passers-by that casted a vote, eight with passers-by that only engaged with the visualization and four with passers-by that ignored DoS.

To structure the complex interplay between the different user types, our results and discussions are structured according to an existing model of the contextual aspect of media in the public domain [24]. As such, we map the relationship of the passer-by or the resident with the content, the carrier and the environment of the DoS system, as depicted on Figure 8.

Passers-by and content

We observed how passers-by, when confronted with multiple displays showing a range of content types, seem mostly interested in 'bite-sized' forms of data visualization. Eight interviewed passers-by (N=20) declared how they first read the title, glanced over the line graph on particle matter (PM25), and then noticed the text of the last display, which contained the personal opinion of the residents hosting the display set. Four of those passers-by told how they skipped the displays featuring data visualizations as they already felt sufficiently informed on the matter, while four other passers-by reported to be mainly motivated by the personal opinions and infographics as they thought the line graphs to take too much effort. In contrast, the prospect

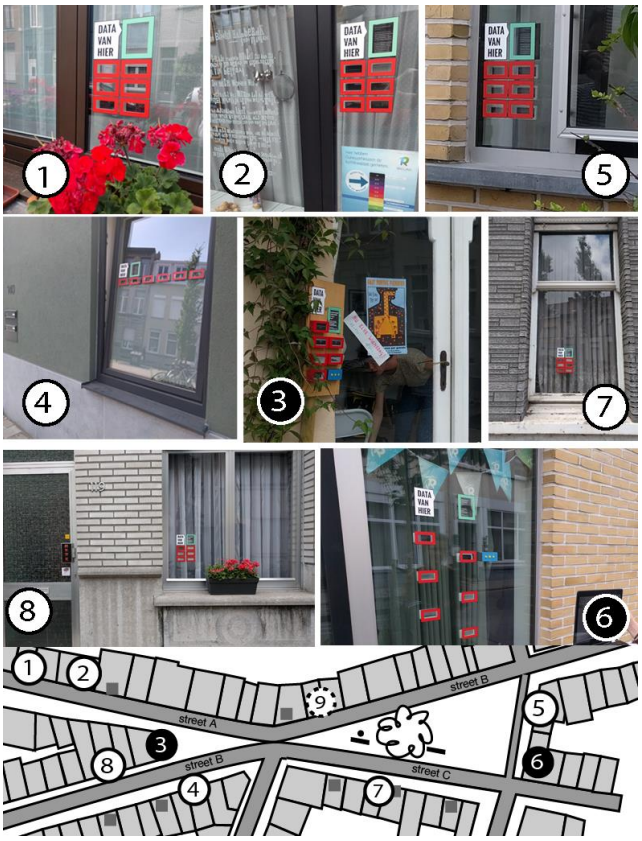

Figure 7. Neighborhood in A. The black and white circles present the DoS locations. The residents of the black circled number deployed the polling device.

of interpreting the data visualizations was a key motivation for two other passers-by (N=20).

Passers-by actively engaged with the public visualizations by interpreting them in hyper-contextual ways. For instance, as the weather conditions were stable during the first two weeks of deployment, with steady ambient temperatures and no rain, the visual representations did not reveal unhealthy conditions of air pollution. Accordingly, P8 stated that *"I saw it displays the amount of rain, but it hasn't rained for the last 5 days, so I do not need to look into that"*. Other passer-by related their interpretation of the air pollution to the time of year (e.g. P4 *"summer holidays just started, so less cars that pollute")* or particular events (e.g. "*the road works result in less cars")*. The data visualizations were used to base decisions upon, as seven passers-by (N=8) who casted a vote inspected the graphs before pressing a button, e.g. *"I want to be sure I have the right information to vote"*.

Passers-by and carrier

The physical location of the displays affected the active engagement behaviors. As evidenced in Table 1, discovery and active engagement occurred most at DoS 3. Five passers-by reported they were passively engaged with DoS 5, 6 or 7 but did not want to actively engage with the content, as it would appear they were trying to look 'inside' the homes. In two occasions, we observed how passers-by took a picture of the display constellation, which was an unexpected strategy enabling them to read and study the content later and in the privacy of their own homes. At DoS 6, four passers-by reported to feel unsure they were allowed to press a polling button, as they reported the size of the displays to imply it to denote a personal device, or that its outer design resembled that of a doorbell, causing them to doubt what would happen after a button press.

Passers-by and environment

Passers-by tended to relate the overarching issue to the assumed social status or intentions of the residents hosting the display sets. As shown in Table 2, seven insights of passers-by reflected on the personal relevance of the overall issue, e.g. "*It is important to know the air quality levels for the health of my children"*; six on the relationship with the resident e.g. "*They [referring to residents] want us to stop polluting by our car*"; or ten about the city, e.g. "*The city council only measures the air pollution when it is summer, but then there is no pollution, just as now"*. Four insights revealed how passers-by reflected on the characteristics of the resident in relation to the data, e.g. *"I think there must be a doctor living here, as it is about health and air pollution"*. The contextual status of the residents also influenced how passers-by trusted the content, as the data shown at DoS 3 should be taken *"with a grain of salt, as it's at the artists' place*" (P14). The same participant, however, equally reported how the system was *"meant in a serious way as the engineers also display it*", (at DoS 6). Reflecting on the insights also led to personal reflections, like feelings of guilt, such as *"I own a car but I do not use it often!"* (P7).

The motivation to engage with the public visualizations was influenced by the (perceived) personal social relationships of the passer-by with the residents hosting the display sets. R2 (of DoS2) reported that her friends said they did not engage with her set of displays because they expected it to be "activist". Yet these friends mentioned to her they engaged with DoS 4, e.g. *"they did not expect of that owner, they were surprised in a good way by him and that made them interested in the issue, which made them question me about the issue"*. Similarly, three participant-neighbors were not interested in the issue at a first glance, but became motivated because their neighbor, who they trusted, put a display set up. However, such a relationship can also lead to inverse consequences, as P20 did not

DoS	3	5	6	7
Passing	170	330	162	210
Passive	0	9	6	8
Active	6	2	2	2
Discovery	5	/	2	/
Votes	41		79	

Table 1. Observed number of passers-by at DoS 3, 5, 6 and 7 for a total of 13 hours, categorized to PACD model [25].

engage with DoS because she felt their neighbors were already judging her for the car use intensity: "*I feel how they look at me when I am trying to park my car, but I cannot afford a fancy job in the city center like them, I need to drive to industrial sites outside the city"*.

The physical location of the polling devices versus familiar urban infrastructure seemed to influence the number of polling results. As shown in Table 1, 79 genuine (i.e. each vote casted within five seconds of previous vote were discarded) votes were registered at DoS 6, which was located next to a large square where citizens hang out, versus 41 votes at DoS 3, which was located on a smaller square with garbage cans where citizens tend to spend less time standing still. Here, we observed groups of people voting together, after they first were hanging around at the public square. At DoS 3, we observed how citizens noticed DoS during casual civic acts, like when disposing waste at the garbage cans, and engaged with DoS by casting a vote after this act, resulting in votes that are spread over the day.

The polling seemed influenced and thus was potentially biased by how residents interpreted the impact of the answer to the household who was perceived to ask the question, instead of the question itself. Although two passers-by wanted to vote 'unhappy' on the question *"What do you think of children playing during traffic hours?",* they reported to feel uncomfortable to vote this way, as it would express a 'negative' feeling towards the residents. As a result, one of them voted 'happy', and the other did not vote. Passers-by weighed the relevance and their engagement with the issue to current hyperlocal events. After the first week of deployment, riots between a young, foreign population and the police continued in the neighborhood for five days. Four passers-by reported these riots to be more important than the issue of air pollution, because *"this is happening at this very moment and not somewhere in the future"* (P5).

Resident and environment

Fixed, daily update moments caused room for social discussion next to the system itself, as neighbors and residents requested more information on the project during the daily update moments. Five neighbors regularly (i.e. more than three times) approached the researcher to ask about the project in general, or specific *"whether there is sufficient proof of the air pollution yet"* (P7). In five occasions, these informal question moments caused further discussions between neighbors. Despite the vicinity of all display sets, two residents reported they would like an overview of the opinions and questions of other residents, as this would help them to 'feel part' of the bigger project.

Residents and carrier

Designing and determining the layout of the displays on the facades was a non-obvious task for residents hosting the sets. Residents of DoS 2, 3, 4, 6, and 8 decided for themselves the location and arrangement of the set behind their windows or unto their façade, and based their designs on

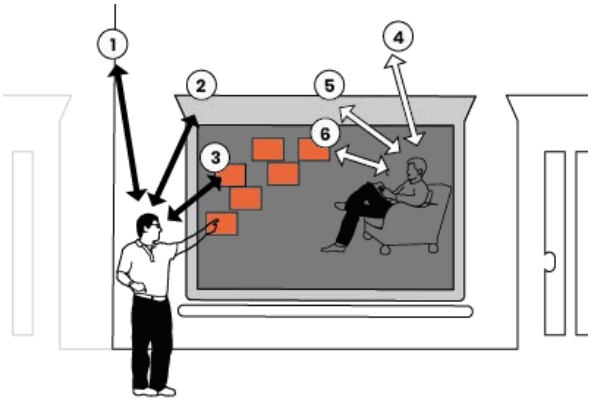

Figure 8. Relations between passer-by and (1) environment, (2) carrier and (3) content, and resident and environment (4), carrier (5) and content (6).

previous encounters with passers-by or experiences of hanging posters. The remaining three residents asked the researcher to do it for them. In case of R3, we had to consider the lack of windows facing the square, for which we constructed a custom wooden notice board. R4 and R6 personalized the arrangements by spreading the displays over the entire window. R3 and R8 reported after the deployment period how they would extend the DoS system with tailor-made casings as a way to hold specific viewers' attention. R8 would have liked to be able to add Arabic characters on the displays as this would appeal to a broader and multicultural audience. R1 and R3 requested bigger displays to target car drivers passing by, as they formed the actual cause of the local issue.

Residents and content

The personal opinions uploaded by residents, which were shown on a dedicated display in the set, showed hyperlocal relevance, such as by making links to current events. Five residents regularly (>7 times) updated their opinions in relation to the given backstory. R5, R6 and R7 consciously contemplated every other day (ten times in total) on the opinions, e.g. "*As a young adult, I think it's normal to be healthy. What about the future? What am I doing by choosing to live here?"*. The opinions were often linked to hyperlocal situations in the neighborhood*, e.g. "The road works cause less traffic and thus less pollution. For how long though?"*. After a week of deployment, residents were allowed to choose their own backstory. Six out of eight residents chose the theme of health and children, while two others chose health. Three residents only updated the opinions once or twice. R6 reported to have moral issues to pose a question that implies a negative answer, and found it difficult to rephrase some questions in a positive way without losing the expression of a concern.

DISCUSSION

Based on the structure depicted in Figure 8, we discuss the design considerations for crowdsourced, bottom-up public visualization of civic concerns evidenced in data on distributed displays.

1. Impact of environment on engagement of passers-by

Social relationships encourage reflection. Public visualization encourages passers-by to reflect on the overall local issue – more so than the data trends and patterns that are revealed in the visualizations themselves. The social relationship of the passer-by with the display-hosting resident affects the perceived relevancy of the overall issue. Some passer-by found personal relevance in the issue when they noticed particular neighbors hosted the public visualization, e.g. *"I did not know my neighbors find this topic so important, I should deepen into the problem as well"*. This social relationship is influenced by the social reputation or occupation of a resident, and particularly impacts the issues of trust, such as *"When the 'engineers' (i.e. hosting residents of DoS8) put it up, it must be serious"*. This relationship can result in adverse effects, such as when passers-by consider the social standing of residents negatively or when the content is interpreted in the shared social experience between neighbors: some neighbors felt embarrassed towards the hosting residents about their own stake in the issue, thus prohibiting proper engagement or unbiased polling with the system. For instance, some passers-by felt it would be hypocritical of them if they participated in the poll, as they had the impression the residents were pointing an accusing finger.

Consider social dimensions in distribution. By distributing a public visualization over different, distinct types of resident statuses, such as local champions, owners or tenants, newcomers, immigrants, etc., a socially expanded *landing effect* can be created. Typically, the landing effect is limited to the area directly in front or between two public displays, where the interactivity with the first encountered display is only noticed when passing it, causing the passer-by to stop at the second or return to the first display [26]. We noticed how a passer-by might be inhibited to engage because of a social conflict with a resident, or inversely, might feel surprised and encouraged by the participation of another resident. Accordingly, we propose that distributing a public visualization over well-considered physical and socially meaningful locations, can give cause to motivational aspects and interaction flows that increase participation, engagement and trust.

Social factors impact polling behavior. Implied negative social sentiments in relation to the resident can inhibit a passer-by to participate in a public polling. Generally, passers-by felt not comfortable with disagreeing with residents, or even choosing an unhappy smiley icon as an answer on a polling question that was perceived to be formulated by someone they were acquainted with. This conflict could be a significant bias influencing the polling results. Potential solutions include better disclosing the anonymity of the polling process – which is challenging in a public environment, or making the polling questions more neutral – yet probably also less provocative. Some passers-by even voted positively (happy) without reading the question, only to 'like' the project in general or leave a token of appreciation to the residents. Therefore, public polling that links authorship to local and peer-level stakeholders seems to cause particular conflicts of interest, in so far that such polling should probably be hosted in a more neutral and publicly owned part of the urban environment. However, such shift then opens various issues about the perceived ownership of bottom-up initiatives, particularly when they clash with official standpoints.

Spatial distribution blurs narrative structure. The distribution of content via multiple backstories over the physical environment did not cause an equal spatial distribution of passer-by engagement. In fact, we did not encounter a single passer-by that engaged with more than two displays. The difference in backstories over the different display sets was unclear, as passers-by expected all display sets contained the same content. Perhaps we should have chosen a more differing, stepping-stone narrative structure to better exploit the spatial distribution, such as adding a game or quest to discover all displays, or design an overall narrative that only made sense when multiple displays are read. Future work might discover more fitting strategies of spatial content distribution.

2. Impact of carrier on engagement of passer-by

Appearance of carrier influences engagement. Hyperlocal physical aspects like visibility and functionality resemblance influence the engagement with public visualizations. For instance, passers-by tended to be embarrassed to inspect displays attached to windows without curtains, as they felt other passers-by and even the residents themselves would judge them as a 'peeping Tom' – exploiting the opportunity to leave a vote to peek inside the house. Others interpreted the polling feature as a doorbell, and felt unsure what would happen if they would engage. On a social level, when the windows were dirty, passers-by were not motivated to engage because did not want to be perceived as judging a resident's home. We learned how a seemingly simple architectural feature as a window creates complex social situations, as passers-by are forced to actively consider who might be looking (and judging) from both inside as well as outside. On the other hand, the private character of the carrier, i.e. a house façade, gave passers-by the feeling of being personally addressed by the inhabitants. An ideal carrier should therefore establish the physical means to engage in a more 'private' setting, for example by exploiting a protruding wall, or surfaces with less obvious ownership.

3. Impact of content on engagement of passer-by

Polling promotes engagement. The addition of interactive features tends to promote the discovery and sense-making process of a public visualization that is shown alongside. Our results show how the display sets without the polling feature facilitated discovery engagement less often. Designers can therefore deploy interactive features like polling as a strategy to encourage people to engage with multiple data-evidenced facets of the issue. However,

polling is not free of expectations or obligations, as it presents a particular commitment towards participants to take action upon its results, even when residents initiated it.

Different types of visualization promote engagement. Lay users choose to engage with those visualizations that present content in simplified and bite-sized formats. It is known that some visualization types, such as line graphs or scatterplots, or the combination of data sets, are considered as complex by casual users, inhibiting engagement [33]. On the other hand, some passers-by were particularly interested in analyzing statistical results, for instance to underpin their personal opinions with more or objective evidence. Designers of public visualizations should consider facilitating different types of data consumption, as it allows for a varied audience to engage with the issue.

4. Impact of environment on engagement of resident

Support collective engagement of residents. Supporting tools should foster a sense of community action. The lack of overview of all the display sets in the authoring tool that allowed residents to create the visualizations and quotes inhibited more collective forms of engagement. Although we anticipated that residents would physically consult the displays of peers – hereby creating unique opportunities of collaborative action – they rarely did, mainly because of time constraints. As a result, some residents had little inspiration to write an opinion or a polling question, also because they felt their efforts seemed not community-supported. In future work, designers could integrate a comprehensive overview of community efforts.

Researcher promotes engagement of residents. The daily physical presence of a researcher functioned as a 'spark' [45] for social interactions to occur between residents and non-participating neighbors. This phenomenon will potentially disappear with better, i.e. more ubiquitous, wireless infrastructure such as presented by current advancements in IoT. Future research could investigate how a custom interaction design might replicate this effect, such as by providing a unique visual or auditory experience at the update of the displays that alerts all stakeholders.

5. Impact of carrier on the engagement of resident

Physical design encourages appropriation. Residents are conscious of determining the ideal spots on their facade to catch attention of passers-by, yet some have issues with the required designerly tasks. Different design attitudes became apparent, as residents deliberately chose particular display arrangements to be more noticeable or expressed the desire to customize the casings. Intervening on a house façade is sensitive, as residents are aware that passers-by judge its outer appearance [39]. In retrospect, we could have developed co-design methods to actively guide and support residents to choose appropriate layouts, which in turn could strengthen the authorship of the content. The physical design might also better articulate narrative structures, such as the order, context or importance of narrative in a display set, or for multiple sets distributed in the neighborhood.

Insights that refer to:	20 Passers-by	8 Residents
Content	4	8
Environment	16	2
Their Person	7	3
Total insights	**27**	**13**

Table 2. The number of insights coded according to content, environment and person.

6. Impact of content on engagement of resident

Temporal aspects influence engagement. Real-time data proves not always to be the ideal persuasive evidence to convey an environmental issue in public space. For instance, air pollution might not be obvious depending on weather or traffic conditions when they lack outliers, peaks or other apparent trends that tend to encourage people to inspect a public visualization [9]. Although a visualization cannot control the evolution of real-time data, it can still overcome this issue by narrating historical data that contrasts current events with more evoking, timeframes or locations that result in provocative data comparisons. In addition, allowing a narrative structure to be open for other data than the predefined local issue would allow residents to better respond to actual and unexpected situations.

Hosting a public visualization encourages reflection. The co-authoring process of public visualization content causes residents to actively engage with the overall issue, and even discover new insights. By opinionating the backstories that were evidenced on data, residents were forced to reflect on different viewpoints and how these would be perceived by passers-by. Bottom-up public visualization system like DoS therefore not only encourage raising awareness of passers-by, yet can activate the people that deploy the very system. As such, potential strategies might be devised that dynamically spread the hosting of the displays over a neighborhood, or opens up the content authoring over neighbors instead of only the hosting residents.

LIMITATIONS

All the studies in this paper are implemented during a relatively short period of time. More studies are needed to investigate the longer-term effects of displaying content at resident homes, and the scale of their impact over time.

CONCLUSION

We presented the iterative design process of a distributed public visualization and polling system. The in-the-wild evaluation revealed how tacit social relationships between user types impact engagement and polling behavior of the passer-by and affect the distribution potential. The collective experience is a condition for resident engagement, and appropriation is encouraged by the physical design. Lastly, also contextual factors affect user engagement with our spatially distributed public visualization and polling displays.

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REFERENCES

1. Carmelo Ardito, Paolo Buono, Maria Francesca Costabile and Giuseppe Desolda. 2015. Interaction with Large Displays: A Survey. In *Proceedings of ACM Computing Surveys (CSUR)*. 46. http://dx.doi.org/10.1145/2682623
2. Mara Balestrini, Tomas Diez and Paul Marshall. 2014. Beyond Boundaries: The Home as City Infrastructure for Smart Citizens. In *Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing: Adjunct Publication*. ACM, 2641557, 987-990. http://dx.doi.org/10.1145/2638728.2641557
3. Mara Balestrini, Tomas Diez, Paul Marshall, Alex Gluhak and Yvonne Rogers. Iot Community Technologies: Leaving Users to Their Own Devices or Orchestration of Engagement? *EAI Endorsed Transactions on Internet of Things* 1, 1 (2015).
4. Moritz Behrens, Nina Valkanova, Ava Fatah gen. Schieck and Duncan P. Brumby. 2014. Smart Citizen Sentiment Dashboard: A Case Study into Media Architectural Interfaces. In *Proceedings of the International Symposium on Pervasive Displays (p. 19).* . ACM. http://dx.doi.org/10.1145/2611009.2611036
5. Alessandro Bendinelli and Fabio Paternò. Design Criteria for Public Display User Interfaces. In *Human-Computer Interaction. Theories, Methods, and Tools: 16th International Conference, Hci International 2014, Heraklion, Crete, Greece, June 22-27, 2014, Proceedings, Part I*, Masaaki Kurosu Ed. Springer International Publishing (Cham), 2014, 623-630. http://dx.doi.org/10.1007/978-3-319-07233-3_57
6. Jon Bird and Yvonne Rogers. 2010. The Pulse of Tidy Street: Measuring and Publicly Displaying Domestic Electricity Consumption. In *Proceedings of Workshop on Energy Awareness and Conservation through Pervasive Applications (Pervasive 2010)*.
7. Jeremy Boy, Francoise Detienne and Jean-Daniel Fekete. 2015. Storytelling in Information Visualizations: Does It Engage Users to Explore Data? In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*. ACM, 2702452, 1449-1458. http://dx.doi.org/10.1145/2702123.2702452
8. Smart Citizen.me. https://smartcitizen.me/. Retrieved March 2018
9. Sandy Claes and Andrew Vande Moere. 2017. The Impact of a Narrative Design Strategy for Information Visualization on a Public Display. In *Proceedings of 2017 ACM Conference on Designing Interactive Systems.* ACM.
10. Jorgos Coenen, Niels Wouters and Andrew Vande Moere. Year. 2015. Wayfinding on Multiple Consecutively Situated Public Displays. In *Proceedings of the 5th ACM International Symposium on Pervasive Displays*. ACM, 182-196.
11. Pedro Coutinho, Rui Jos, #233 and Bruno Silva. 2016. Understanding Media Situatedness and Publication Practices in Place-Based Digital Displays. In *Proceedings of Proceedings of the 5th ACM International Symposium on Pervasive Displays*. ACM, 2915025, 154-160. http://dx.doi.org/10.1145/2914920.2915025
12. Clara Crivellaro, Rob Comber, Martyn Dade-Robertson, Simon J. Bowen, Peter C. Wright and Patrick Olivier. 2015. Contesting the City: Enacting the Political through Digitally Supported Urban Walks. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*. ACM, 2702176, 2853-2862. http://dx.doi.org/10.1145/2702123.2702176
13. Christopher A Le Dantec and Carl DiSalvo. Infrastructuring and the Formation of Publics in Participatory Design. *Social Studies of Science* 43, 2 (2013), 241-264.
14. Marian Dörk, Patrick Feng, Christopher Collins and Sheelagh Carpendale. 2013. Critical Infovis: Exploring the Politics of Visualization. In *Proceedings of CHI'13 Extended Abstracts on Human Factors in Computing Systems*. ACM, 2189-2198.
15. Air Quality Egg.com. http://airqualityegg.com. Retrieved March 2018.
16. Chris Elsden, Sebastian Mellor, Patrick Olivier, Pete Wheldon, David Kirk and Rob Comber. 2016. Resviz: Politics and Design Issues in Visualizing Academic Metrics. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*. ACM, 5015-5027.
17. Patrick Tobias Fischer and Eva Hornecker. 2012. Urban Hci: Spatial Aspects in the Design of Shared Encounters for Media Facades. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, 307-316. http://dx.doi.org/10.1145/2207676.2207719
18. Barney G Glaser, Anselm L Strauss and Elizabeth Strutzel. The Discovery of Grounded Theory; Strategies for Qualitative Research. *Nursing research* 17, 4 (1968), 364.
19. Luke Hespanhol, Martin Tomitsch, Ian McArthur, Joel Fredericks, Ronald Schroeter and Marcus Foth. Year. Vote as You Go: Blending Interfaces for Community Engagement into the Urban Space. In *Proceedings of the 7th International Conference on Communities and Technologies (C&T)*. ACM. http://dx.doi.org/10.1145/2768545.2768553

20. Elaine M Huang, Anna Koster and Jan Borchers. Overcoming Assumptions and Uncovering Practices: When Does the Public Really Look at Public Displays? In *Pervasive Computing*, Springer, 2008, 228-243.
21. Qijun Jiang, Frank Kresin, Arnold K. Bregt, Lammert Kooistra, Emma Pareschi, Edith van Putten, Hester Volten and Joost Wesseling. Citizen Sensing for Improved Urban Environmental Monitoring. *Journal of Sensors* 2016 (2016), 9. http://dx.doi.org/10.1155/2016/5656245
22. Lisa Koeman, Vaiva Kalnikait and Yvonne Rogers. 2015. "Everyone Is Talking About It!": A Distributed Approach to Urban Voting Technology and Visualisations. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*. ACM, 2702263, 3127-3136. http://dx.doi.org/10.1145/2702123.2702263
23. Greg J McInerny, Min Chen, Robin Freeman, David Gavaghan, Miriah Meyer, Francis Rowland, David J Spiegelhalter, Moritz Stefaner, Geizi Tessarolo and Joaquin Hortal. Information Visualisation for Science and Policy: Engaging Users and Avoiding Bias. *Trends in ecology & evolution* 29, 3 (2014), 148-157.
24. Nemanja Memarovic, Marc Langheinrich, Florian Alt, Ivan Elhart, Simo Hosio and Elisa Rubegni. 2012. Using Public Displays to Stimulate Passive Engagement, Active Engagement, and Discovery in Public Spaces. In *Proceedings of Media Architecture Biennale 2012*. ACM, 55-64.
25. Nemanja Memarovic, Marc Langheinrich, Florian Alt, Ivan Elhart, Simo Hosio and Elisa Rubegni. 2012. Using Public Displays to Stimulate Passive Engagement, Active Engagement, and Discovery in Public Spaces. In *Proceedings of Proceedings of the 4th Media Architecture Biennale Conference: Participation (MAB'12)*. ACM, 55-64. http://dx.doi.org/10.1145/2421076.2421086
26. Jörg Müller, Robert Walter, Gilles Bailly, Michael Nischt and Florian Alt. 2012. Looking Glass: A Field Study on Noticing Interactivity of a Shop Window. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, 297-306. http://dx.doi.org/10.1145/2207676.2207718
27. Christian Nold. Micro/Macro Prototyping. *International Journal of Human-Computer Studies* 81 (2015), 72-80.
28. Timo Ojala, Vassilis Kostakos, Hannu Kukka, Tommi Heikkinen, Tomas Linden, Marko Jurmu, Simo Hosio, Fabio Kruger and Daniele Zanni. Multipurpose Interactive Public Displays in the Wild: Three Years Later. *Computer* 45, 5 (2012), 42-49. http://dx.doi.org/10.1109/mc.2012.115
29. Simon Olberding, Jürgen Steimle, Suranga Nanayakkara and Pattie Maes. 2015. Clouddrops: Stamp-Sized Pervasive Displays for Situated Awareness of Web-Based Information. In *Proceedings of the 4th International Symposium on Pervasive Displays*. ACM, 47-53.
30. Peter Peltonen, Esko Kurvinen, Antti Salovaara, Giulio Jacucci, Tommi Ilmonen, John Evans, Antti Oulasvirta and Petri Saarikko. 2008. It's Mine, Don't Touch!: Interactions at a Large Multi-Touch Display in a City Centre. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, 1357255, 1285-1294. http://dx.doi.org/10.1145/1357054.1357255
31. Ava Fatah gen. Schieck, Carolina Briones and Chiron Mottram. The Urban Screen as a Socialising Platform: Exploring the Role of Place within the Urban Space. *F. Eckardt et al., eds., MEDIACITY: Situations, Practices and Encounters Frank & Timme GmbH, Berlin, Germany,* (2008), 285-305.
32. Edward Segel and Jeffrey Heer. Narrative Visualization: Telling Stories with Data. *Visualization and Computer Graphics, IEEE Transactions on* 16, 6 (2010), 1139-1148. http://dx.doi.org/10.1109/TVCG.2010.179
33. David Sprague and Melanie Tory. Exploring How and Why People Use Visualizations in Casual Contexts: Modeling User Goals and Regulated Motivations. *Information Visualization* 11, 2 (2012), 106-123. http://dx.doi.org/10.1177/1473871611433710
34. Faisal Taher and Keith Cheverst. 2011. Exploring User Preferences for Indoor Navigation Support through a Combination of Mobile and Fixed Displays. In *Proceedings of the 13th International Conference on Human Computer Interaction with Mobile Devices and Services*. ACM, 2037405, 201-210. http://dx.doi.org/10.1145/2037373.2037405
35. Alex S. Taylor, Sian Lindley, Tim Regan, David Sweeney, Vasillis Vlachokyriakos, Lillie Grainger and Jessica Lingel. 2015. Data-in-Place: Thinking through the Relations between Data and Community. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*. ACM, 2702558, 2863-2872. http://dx.doi.org/10.1145/2702123.2702558
36. Nick Taylor, Justin Marshall, Alicia Blum-Ross, John Mills, Jon Rogers, Paul Egglestone, David M Frohlich, Peter Wright and Patrick Olivier. 2012. Viewpoint: Empowering Communities with Situated Voting Devices. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, 1361-1370. http://dx.doi.org/10.1145/2207676.2208594
37. Nina Valkanova, Sergi Jorda, Martin Tomitsch and Andrew Vande Moere. 2013. Reveal-It!: The Impact of a Social Visualization Projection on Public Awareness and Discourse. In *Proceedings of the SIGCHI*

Conference on Human Factors in Computing Systems. ACM, 3461-3470.

38. Nina Valkanova, Robert Walter, Andrew Vande Moere and Jörg Müller. 2014. Myposition: A Public Polling Projection Display Designed to Spark Civic Participation. In *Proceedings of the 17th ACM conference on Computer supported cooperative work & social computing (CSCW'14)*. 1323-1332. http://dx.doi.org/10.1145/2531602.2531639
39. Andrew Vande Moere, Martin Tomitsch, Monika Hoinkis, Elmar Trefz, Silje Johansen and Allison Jones. 2011. Comparative Feedback in the Street: Exposing Residential Energy Consumption on House Façades. In *Human-Computer Interaction–Interact 2011*, Springer, 2011, 470-488.
40. Andrew Vande Moere and Dan Hill. Designing for the Situated and Public Visualization of Urban Data. *Journal of Urban Technology* 19, 2 (2012), 25-46. http://dx.doi.org/10.1080/10630732.2012.698065
41. Andrew Vande Moere and Dietmar Offenhuber. Beyond Ambient Display: A Contextual Taxonomy of Alternative Information Display. *Ubiquitous Developments in Ambient Computing and Intelligence: Human-Centered Applications* (2009), 127.
42. Andrew Vande Moere and Niels Wouters. 2012. The Role of Context in Media Architecture. In *Proceedings of the 2012 International Symposium on Pervasive Displays*. ACM, 12. http://dx.doi.org/10.1145/2307798.2307810
43. Vasilis Vlachokyriakos, Rob Comber, Karim Ladha, Nick Taylor, Paul Dunphy, Patrick McCorry and Patrick Olivier. 2014. Postervote: Expanding the Action Repertoire for Local Political Activism. In *Proceedings of the 2014 conference on Designing interactive systems*. ACM, 2598523, 795-804. http://dx.doi.org/10.1145/2598510.2598523
44. World Health Organisation. 2005. Who Air Quality Guidelines for Particulate Matter, Ozone, Nitrogen Dioxide and Sulfur Dioxide. http://apps.who.int/iris/bitstream/10665/69477/1/WHO_SDE_PHE_OEH_06.02_eng.pdf.
45. Niels Wouters, John Downs, Mitchell Harrop, Travis Cox, Eduardo Oliveira, Sarah Webber, Frank Vetere and Andrew Vande Moere. 2016. Uncovering the Honeypot Effect: How Audiences Engage with Public Interactive Systems. In *Proceedings of the 2016 ACM Conference on Designing Interactive Systems*. ACM, 5-16.
46. Niels Wouters, Jonathan Huyghe and Andrew Vande Moere. 2013. Openwindow: Citizen-Controlled Content on Public Displays. In *Proceedings of the 2nd ACM International Symposium on Pervasive Displays*. ACM, 121-126.
47. https://curieuzeneuzen.be/ Retrieved August 2018