frontiers | Frontiers in Environmental Science

TYPE Perspective
PUBLISHED 14 August 2023
DOI 10.3389/fenvs.2023.1228487

OPEN ACCESS

EDITED BY
Joana Magalhães,
Science for Change, Spain

REVIEWED BY
Gefion Thuermer,
King's College London, United Kingdom
Carolina Moreno-Castro,
University of Valencia, Spain

*CORRESPONDENCE
Christoph Raetzsch,
craetzsch@cc.au.dk

†These authors have contributed equally to this work and share first authorship

RECEIVED 24 May 2023
ACCEPTED 31 July 2023
PUBLISHED 14 August 2023

CITATION
Raetzsch C, Hamm A and Shibuya Y (2023), Mainstreaming civic tech and citizen sensing: a research agenda on co-creation methods, data interfaces, and impact pathways.
Front. Environ. Sci. 11:1228487.
doi: 10.3389/fenvs.2023.1228487

Mainstreaming civic tech and citizen sensing: a research agenda on co-creation methods, data interfaces, and impact pathways

Christoph Raetzsch[1]*†, Andrea Hamm[2†] and Yuya Shibuya[3†]

[1]Department of Media and Journalism Studies, Aarhus University, Aarhus, Denmark, [2]Weizenbaum Institute for the Networked Society, Research Group Digitalization, Sustainability, and Participation, Berlin, Germany, [3]Center for Spatial Information Science, The University of Tokyo, Tokyo, Japan

In this perspective article, we propose an interdisciplinary research agenda that addresses citizen science approaches embedded in civic tech initiatives and citizen sensing scenarios. The proposed agenda builds on the multi-level perspective framework (Geels, 2004; Geels, 2019) to inform research on how such 'niche innovations' like citizen sensing become mainstreamed in broader socio-technical systems and modes of governance. To support research across use case scenarios and make analyses more comparable internationally, we identify three core areas of interdisciplinary future research and practice development: 1) uses of co-creation methods to develop project objectives and align stakeholders; 2) designs of interfaces for gathering, communicating, and archiving civic data for different types of users; and 3) modeling impact pathways of individual projects that include civic tech activists and citizen scientists, academic researchers, journalists, and policymakers. For impact pathways, we highlight the importance of collaborations with data-driven approaches in journalism.

KEYWORDS

civic tech, citizen sensing, citizen science, data journalism, comparative framework, data interface, civic data

1 Introduction

Citizen science has been a growing global approach to include non-experts in the creation of scientific knowledge. It is employed in diverse fields covering different types of activity, e.g., as an outreach strategy of public research institutions, as a form of collective environmental monitoring [e.g., in urban spaces (Longo et al., 2020) or radioactivity after the Fukushima disaster in 2011 (Brown et al., 2016)], or by crowdsourcing labor-intensive, repetitive scientific tasks (Raddick et al., 2013). In their extensive overview of citizen science definitions, Haklay et al. (2021) mention core elements such as "the generation of scientific data," being based on "(engaging) volunteers over a large area," and "(addressing) a politically relevant issue" (Haklay et al., 2021: 14). The authors admit that there are tensions between "descriptive, instrumental, and normative elements" in many definitions (Ibid. 22), which poses "an inherent challenge in providing an exhaustive definition of citizen science" (Ibid. 14).

These tensions highlight that collaborative knowledge creation in citizen science differs from established methods of academic research and science communication. Citizen science approaches often seek to involve (and also empower) citizens in the scientific understanding of social, environmental, and political issues. In this perspective article, we propose an

interdisciplinary research agenda that targets citizen science approaches employed in certain types of civic tech projects (Schrock, 2019; Harrell, 2020), and in particular, in citizen sensing projects, i.e., the crowdsourced collection of environmental data through citizens (D'Ignazio and Zuckerman, 2017; Coulson et al., 2021). Based on the established multi-level perspective framework (Geels, 2004, 2019), we consider civic tech and citizen sensing approaches as 'niche innovations' which seek to affect and change broader socio-technical regimes, e.g., science, local governance, or democratic culture.

Civic tech and citizen sensing projects show elements of citizen science, yet often are deliberately developed as activist and political interventions. They often involve the development of platforms or technologies that make civic data collections available for multiple uses, e.g., strengthening local knowledge, informing policy, or fostering reuse through journalistic media. Civic data, in this study, are defined as any data—whether original or derivative and whether provided by public authorities or through civic tech projects—"providing citizens means and knowledge to act upon (. . .) local pressing environmental issues affecting them and future generations" (Hamm, 2022: 13). Because the conditions of the stakeholders, available resources, and scope of civic tech and citizen sensing projects can vary greatly in practice, we propose a comparative analytical framework that addresses common elements across typical stages of such projects: 1) co-creation methods for the identification and alignment of stakeholders; 2) data interface designs for different types of uses (and users); and 3) models of impact pathways for mainstreaming civic tech and citizen sensing approaches through affiliations with policy, journalism, or local governance. The article will draw on illustrative examples from local and global civic tech and citizen sensing initiatives. Section 2 presents definitions of key concepts, and Section 3 presents the three core elements of the research agenda.

2 Civic tech, digital civics, and citizen sensing as niche innovations

Niche innovations are defined by Geels (2004) as "'incubation rooms for radical novelties." They can be "small market niches" or "locations where it is possible to deviate from the rules in the existing regime" (2004: 912). Civic tech and citizen sensing are examples of such niches. From the perspective of activists, civic tech is a heterogenous, global movement, which seeks to critique, build, and use digital technologies for civic purposes. It encompasses such diverse practices as prototyping new data platforms or lobbying for open software and transparent platform governance (e.g., through institutions like the Open Knowledge Foundation, Mozilla Foundation, and Wikimedia Foundation).

However, Schrock (2019) cautions that civic tech is difficult to define only as an activist movement since it covers a range of practices that seek to "humanize technology and integrate it within systems of governance to improve social conditions" (127). Civic tech often exhibits an interventionist (or "hacker") ethos that "situates administrative reforms as participation" (128), using technological interventions as an instrument of reform and instance of critique of public digital solutions. In what Schrock calls "technical pluralism," civic tech interventions are always political, combining hacking practices and technological development as well as community organizing (129). Civic tech activists seek to "open up space between government and community, changing the political system as a whole" (131) with a broad and inclusive understanding of (digital) public goods. For the US-American context, Cyd Harrell defines civic tech as "a loosely integrated movement that brings the strengths of the private-sector tech world (its people, methods, or actual technology) to public entities with the aim of making government more responsive, efficient, modern, and more just" (Harrell, 2020: 17).

Recently, civic tech has contributed to the design-led discourse and practice of "digital civics". Using "design as democratic inquiry" (DiSalvo, 2022), digital civics interventions "create relationships in participatory experiences between public officials and citizens based on mutual learning, empowerment, and co-creation" (Corbett et al., 2018: 9). They are often initiated by designers, activists, and researchers to address social and political inequalities affecting local communities. The approach is often participatory, experimental, and co-creative and uses technological designs as iterative contributions to broader processes of bottom–up "infrastructuring" (Le Dantec, 2016; Le Dantec, 2019). Importantly, digital civics "(aims) to support citizens becoming agents of democracy with and through technologies and in dialogue with the institutions that can actualize public will" (Vlachokyriakos et al., 2016: 2). In the context of smart city developments, for example, civic tech activists are a "political pioneer community" for creating responsive and sustainable civic infrastructures (Bieber, 2018: 190). These interventions allow citizens to assume varying roles and degrees of involvement (Przeybilovicz et al., 2022) to foster "collaborative city-making" (de Lange and de Waal, 2019).

Civic tech and digital civics converge with citizen science approaches in the growing field of projects around citizen sensing. This development can be attributed to the availability of low-cost, easy-to-use sensing devices for measuring environmental conditions as well as the widespread use of mobile, digital media in everyday lives of citizens (Goodchild, 2007; Gabrys, 2014; Gabrys, 2019; Coulson et al., 2021). Using smartphone apps, data platforms, or other (often self-built) technologies, citizens are invited to contribute to knowledge creation. Citizen sensing allows, to a certain degree, a "democratization of data" on environmental conditions (Coulson et al., 2021: 2) by employing citizen science principles to the communal collection and interpretation of data. Academics and practitioners in this field regard citizen sensing as a "modality of citizenship that emerges through interaction with computational sensing technologies used for environmental monitoring and feedback" (Gabrys, 2014: 32). Citizen sensing projects introduce new communal and data-driven practices that could "*complement* institutional monitoring of risks" (Suman and Anna, 2018: 260.) and are interesting from a research perspective because they link citizen empowerment with technological innovations to policy development.

Given the fair recency of many of these approaches, though, D'Ignazio and Zuckerman caution that "the world of science, journalism and communities using environmental data and sensors is a messy one" (D'Ignazio and Zuckerman, 2017: 201). Recurrent concerns about the impact of citizen science and civic tech projects relate to the quality of data, citizens' skills and competences to work together, to political biases in project designs, and missing opportunities for trainings (Callaghan et al., 2019; Strobl et al., 2019; Stylinski et al., 2020). Balancing civic, journalistic, or scientific goals often results in collecting only "good enough data" (Gabrys et al., 2016). We propose to assess citizen sensing projects at different stages from the perspectives of design, implementation, and legacy and impact (Coulson et al., 2021).

On a design level, the use of co-creation methods for multi-stakeholder alignment contributes to a project's development of objectives and desired outcomes. On an implementation level, interfaces for making data and knowledge available for different types of users can broaden a project's relevance and reach. On a legacy and impact level, different pathways can involve researchers and journalists, policymakers, or non-governmental organizations to contribute to local capacity-building through experimentation (Brynskov et al., 2018). In the following sections, we will briefly outline each of these elements that contribute to understanding the processes of mainstreaming civic tech and citizen sensing approaches.

3 Future research agenda: co-creation methods, data interfaces, and impact pathways

3.1 Co-creation methods for stakeholder alignment

The development of sensing scenarios, identification of empirical approaches, and the possible design of appropriate equipment often take place in a co-creative and transdisciplinary effort involving designers, citizens, researchers, municipal actors, or even policymakers. To achieve concrete "ramifications" (Hamm, 2022; Shibuya et al., 2022) for civic tech and citizen sensing projects beyond their runtime, the design of co-creation methods needs to include dedicated communication channels from the ideation to the implementation phase. As Hecker and Taddicken show in their framework and typology of citizen science projects, researchers' roles are challenged in co-creative arrangements, where communication on very different levels changes traditional and professional norms of science communication (Hecker and Taddicken, 2022). For example, in the Japanese project Safecast, social media was used to maintain multi-stakeholder communication and recruit engaged citizens (Hamm et al., 2021). Examples like the NEWSERA project also demonstrate that the interests of citizens and journalists may differ widely and need to be aligned through mutual learning, co-creating possible outputs from a project rather than only communicating its outcome. Inclusive designs of co-creation methods are a core challenge, especially for target groups not accustomed to assuming public speaker roles (Paleco et al., 2021).

3.2 Data interfaces

Citizen sensing projects are centrally concerned with different forms of data work and thus need to consider the different stages of data throughout a project's life cycle. In each stage, the "data setting," as Loukissas has coined it (Loukissas, 2019), is always "local": data are generated and interpreted by the involved stakeholders, serving their different purposes. Designing interfaces for these different stages and purposes is crucial for achieving a project's legacy and impact. We identify three levels of interface design that need consideration in research and practice.

3.2.1 Interfaces for data collection

The design of inclusive, understandable, and reliable interfaces of data collection (through manual inputs, semi-automatic data mining, or sensing and detection kits) is a technical core challenge, implemented by technical experts. Low-cost sensor kits have flourished, especially in the domain of air quality/noise monitoring, yet setting up kits still relies on considerable technical expertise. Interfaces for data collection can also be included in websites and smartphone apps, e.g., by making use of native GPS sensors for metadata collection. Data collection can also simply use interfaces and features of social media platforms to share photos that are automatically analyzed (Cervone et al., 2016). Contributions from citizens can also be delegated to free apps that are already on the market, e.g., PIRIKA, which features an app to improve cleanliness of urban spaces. Although, in principle, such apps are publicly accessible, we have to ask who is contributing data to a project and who is excluded from it. It is important to understand not just the technical reasons, lack of skills, or knowledge but also the social and systemic ones that create biases for the resulting data and knowledge.

3.2.2 Interfaces for output and communication

The output and communication level of interfaces needs to be attuned to the needs and competences of designated target audiences. Here, it can be useful to seek collaborations with interface and information designers, as well as data journalists. Collaborating for the output and public communication of civic tech and citizen sensing projects can also raise conflicts, particularly when complex datasets are visually simplified. Activists, journalists, scientists, and policymakers may apply different standards for the data they need. Activists often tend to underline their political agenda with visualization or "counter mapping" techniques (Bowe, Simmons, and Mattern, 2020; Hamm, 2020), whereas scientists rather visualize the complexity (and ambiguity) of phenomena (Marx, 2013). Prior work has emphasized that interface design also needs to consider different types of users and provide export formats for later uses of the data in different contexts (Shibuya et al., 2021; Vornhagen et al., 2021; Young et al., 2021). Such demands are not easy to fulfill by civic tech initiatives themselves, where resources and time for the design of interfaces are often rather limited.

One popular interface for exploring civic tech data is data dashboards, which can be used to address local issues through interactive data analysis, policy advice, and real-time monitoring (Williams, 2020; Goodwin et al., 2021). Depending on the use case, dashboards can have various underlying epistemologies built into their architecture and interface, which may not be obvious for citizens or lay audiences (Sadowski, 2021; Vornhagen et al., 2021; Young et al., 2021). Interfaces for public outreach and communication (e.g., dashboards, data maps, or websites) need to embed accessible graphic designs and can also use data-driven narrative forms, e.g., scrollytelling journalism that combines a focus on data and narrative form in an intuitive user interface. Interfaces can also highlight the community-driven nature of data collection, e.g., maps by the global Sensor.Community for tracking air pollution (sensor.community). In Japan, a community-developed COVID-19 dashboard visualized crowd-sourced, daily updated information about critical pandemic-related indicators (e.g., local COVID-19 testing of positive cases and hospital bed occupancy rates). In Taiwan, mask maps were developed by civic tech initiatives, allowing citizens to check on mask inventory levels in their

neighboring areas to mitigate mask panic-buying behaviors (Shibuya et al., 2022). Whether as a map, a dashboard, or a data repository, each output form enables and limits subsequent uses of data, shaping the impact of a project.

3.2.3 Interfaces embedding data standards

Civic tech projects tend to focus on the collection and communication of case-specific data rather than using established metadata frameworks, which would allow data from different cases to be comparable and fulfill scientific quality standards. Open-source repositories for software scripts (such as GitHub), the global civic tech field guide platform (https://civictech.guide), or open-data collections (such as Zenodo) need to be considered from a project design perspective to enable capacity-building and transferability of methods between use cases and projects. Standardizing data collection procedures (e.g., for monitoring uses of public spaces or environmental conditions) can be achieved by employing metadata standards formulated in Public Participation in Scientific Research (PPSR Core) by the Citizen Science Association (CSA) or employing FAIR principles to enhance the findability and reusability of data assets (Wilkinson et al., 2016). Researchers can help translate standards into the practice of citizen-oriented projects.

3.3 Impact pathways for mainstreaming civic tech and citizen sensing

Collaborations between civic tech activists, researchers, citizens, journalists, and policymakers signal new ways in which research contributes to tangible outcomes for society, especially in social sciences and humanities. From a research policy perspective, new collaborative arrangements between researchers and society are studied as "impact pathways" (Muhonen et al., 2019). In civic tech and citizen sensing projects, convergence and synergies arise between scientific, journalistic, and activist practices of knowledge production, enabling new kinds of data collection, fostering community-building, and creating new modalities of public engagement. Impact pathways and other multidimensional models of impact assessment (Passani et al., 2022) show how civic tech and citizen sensing approaches can be mainstreamed from niche innovations to contribute to changes in existing socio-technical regimes, e.g., in governance, education, or journalism (Geels, 2019).

Baack has argued that "civic technologies can be described as alternative ways of fulfilling functions traditionally described as "journalistic"" (Baack, 2015: 7), and differences between activist facilitator roles and journalistic gatekeeper roles often need to be negotiated in practice (Baack, 2018: 680). The close affinity between citizen-sensing projects and data journalism creates new impact pathways, although conservative interpretations of data journalism still prevail in practice (Beiler, Irmer, and Breda, 2020; Morini, 2023). For example, in the project "Unser Wasser" (Our Water), the German public broadcaster ARD collected citizen-sensed data about the decline of water bodies during the drought in Germany in 2022 and provided an interactive and informative data map co-developed with scientists. Journalistic routines remain focused on informing rather than engaging citizens (Appelgren and Jönsson, 2021). Online participatory journalism often remains under the control of journalists (Engelke, 2019), and new forms of crowdsourcing knowledge are still limited in scope (Aitamurto, 2016). Data journalists regard their work as contributing to public debates, e.g., by interpreting abstract data through visualizations (Boyles and Meyer, 2016; cf. Stalph and Heravi, 2021). When the sources of data journalism are based on civic data, new challenges emerge between the objectives of community empowerment and the commercial use of data by media outlets (Morini, Dörk, and Appelgren, 2022).

4 Outlook: mainstreaming citizen sensing

Civic tech and citizen sensing projects are often driven by engaged volunteers, community organizers, and/or researchers. The impact of such projects, though, often remains quite limited if they fail to contribute to local capacity-building or building institutional frameworks of participation that ensure their legacy (Cerratto Pargman et al., 2019). We suggest that a focus on co-creation methodologies, data interfaces throughout a project's lifecycle, and impact pathways are crucial elements and stages in such projects. The proposed research agenda seeks to facilitate knowledge exchange around such projects as well as offer an agenda for comparative, international research that addresses mechanisms and obstacles of mainstreaming citizen sensing. Lastly but crucially, we regard it as essential that questions of equity and inclusiveness of co-creation processes in civic tech and citizen sensing interventions (Paleco et al., 2021) will become much more central to such an agenda as niche innovations confront larger socio-technical regimes. Which actors contribute to such projects? How are marginalized groups addressed and engaged? Which issues of public concern lend themselves better to citizen sensing approaches than others? What organizational and occupational factors (e.g., in civic tech or journalism) can foster or impede the uptake of civic tech and citizen sensing approaches? These are some central questions this research agenda addresses for future research to pluralize inclusive understanding of knowledge creation, research impact, and civic empowerment.

Data availability statement

The original contributions presented in the study are included in the article; further inquiries can be directed to the corresponding author.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

Aitamurto, Tanja (2016). Crowdsourcing as a knowledge-search method in digital journalism. *Digit. Journal.* 4 (2), 280–297. doi:10.1080/21670811.2015.1034807

Appelgren, Ester, and Jönsson, Anna Maria (2021). Engaging citizens for climate change—challenges for journalism. *Digit. Journal.* 9 (6), 755–772. doi:10.1080/21670811.2020.1827965

Baack, Stefan (2018). Practically engaged: The entanglements between data journalism and civic tech. *Digit. Journal.* 6 (6), 673–692. doi:10.1080/21670811.2017.1375382

Baack, Stefan (2015). Datafication and empowerment: How the open data movement Re-articulates notions of democracy, participation, and journalism. *Big Data & Soc.* 2 (2), 205395171559463. doi:10.1177/2053951715594634

Beiler, Markus, Irmer, Felix, and Breda, Adrian (2020). Data journalism at German newspapers and public broadcasters: A quantitative survey of structures, contents and perceptions. *Journal. Stud.* 21 (11), 1571–1589. doi:10.1080/1461670x.2020.1772855

Bieber, Christoph (2018). "Smart City" und "Civic Tech": Urbane Bewegungen im Zeichen der Digitalisierung. *Die Mediatisierte Stadt: Kommunikative Figurationen des Urbanen Zusammenlebens*. Editor Hepp Andreas, Kubitschko Sebastian, and Marszolek Inge. Wiesbaden, Germany: Springer Fachmedien Wiesbaden, 177–194. doi:10.1007/978-3-658-20323-8_10

Bowe, Emily, Simmons, Erin, and Mattern, Shannon (2020). Learning from lines: Critical Covid data visualizations and the quarantine quotidian. *Big Data & Soc.* 7 (2), 205395172093923. doi:10.1177/2053951720939236

Boyles, Jan Lauren, and Meyer, Eric (2016). Letting the data speak. Role perceptions of data journalists in fostering democratic conversation. *Digit. Journal.* 4 (7), 944–954. doi:10.1080/21670811.2016.1166063

Brown, A., Franken, P., Bonner, S., Dolezal, N., and Moross, J. (2016). Safecast: Successful citizen-science for radiation measurement and communication after Fukushima. *J. Radiological Prot.* 36 (2), S82–S101. doi:10.1088/0952-4746/36/2/S82

Brynskov, Martin, Heijnen, Adriënne, Balestrini, Mara, and Raetzsch, Christoph (2018). Experimentation at scale: Challenges for making urban informatics work. *Smart Sustain. Built Environ.* 7 (1), 150–163. doi:10.1108/SASBE-10-2017-0054

Callaghan, C. T., Rowley, J. J. L., Cornwell, W. K., Poore, A. G. B., and Major, R. E. (2019). Improving big citizen science data: Moving beyond haphazard sampling. *PLOS Biol.* 17 (6), e3000357. doi:10.1371/journal.pbio.3000357

Cerratto Pargman, T., Joshi, S., and Wehn, U. "Experimenting with novel forms of computing: The case of the Swedish citizen observatory for water quality conservation," in Proceedings of the Fifth Workshop on Computing within Limits - LIMITS '19, Lappeenranta, Finland, June 2019, 1–10. doi:10.1145/3338103.3338111

Cervone, Guido, Sava, Elena, Huang, Qunying, Schnebele, Emily, Harrison, Jeff, and Waters, Nigel (2016). Using twitter for tasking remote-sensing data collection and damage assessment: 2013 boulder flood case study. *Int. J. Remote Sens.* 37 (1), 100–124. doi:10.1080/01431161.2015.1117684

Corbett, Eric, Le Dantecand Christopher, A. "Exploring trust in digital civics," in Proceedings of the 2018 Designing Interactive Systems Conference, New York, NY, USA, June 2018. doi:10.1145/3196709.3196715

Coulson, Saskia, Woods, Mel, and Making, Sense E. U. (2021). Citizen sensing: An action-orientated framework for citizen science. *Front. Commun.* 6. doi:10.3389/fcomm.2021.629700

de Lange, Michiel, and de Waal, Martijn (2019). *The hackable city. Digital media and collaborative city-making in the network society*. Singapore: Springer. doi:10.1007/978-981-13-2694-3

D'Ignazio, Catherine, and Zuckerman, Ethan (2017). "Are we citizen scientists, citizen sensors or something else entirely," in *International handbook of media literacy education*. Editors Belinha S. De Abreu, Mihailidis Paul, Y. Alice, and L. Lee (New York, NY, USA: Routledge), 193–210. doi:10.4324/9781315628110-17

DiSalvo, Carl (2022). *Design as democratic inquiry: Putting experimental civics into practice*. Cambridge, MA, USA: MIT Press.

Engelke, Katherine (2019). Online participatory journalism: A systematic literature review. *Media Commun.* 7 (4), 31–44. doi:10.17645/mac.v7i4.2250

Gabrys, Jennifer (2019). *How to do things with sensors*. Minneapolis, Minnesota, USA: University of Minnesota Press.

Gabrys, Jennifer (2014). Programming environments: Environmentality and citizen sensing in the smart city. *Environ. Plan. D Soc. Space* 32 (1), 30–48. doi:10.1068/d16812

Gabrys, Jennifer., Pritchard, Helen, and Barratt, Benjamin (2016). Just good enough data: Figuring data citizenships through air pollution sensing and data stories. *Big Data & Soc.* 3 (2), 205395171667967. doi:10.1177/2053951716679677

Geels, Frank W. (2004). From sectoral systems of innovation to socio-technical systems. *Res. Policy* 33 (6-7), 897–920. doi:10.1016/j.respol.2004.01.015

Geels, Frank W. (2019). Socio-technical transitions to sustainability: A review of criticisms and elaborations of the multi-level perspective. *Curr. Opin. Environ. Sustain.* 39, 187–201. doi:10.1016/j.cosust.2019.06.009

Goodchild, Michael F. (2007). Citizens as sensors: The world of volunteered geography. *GeoJournal* 69 (4), 211–221. doi:10.1007/s10708-007-9111-y

Goodwin, Sarah, Meier, Sebastian, Bartram, Lyn, Godwin, Alex, Nagel, Till, and Dörk, Marian "Unravelling the human perspective and considerations for urban data visualization," in Proceedings from 2021 IEEE 14th Pacific Visualization Symposium (PacificVis), Tianjin, China, April 2021. doi:10.1109/pacificvis52677.2021.00024

Haklay, M., Dörler, D., Heigl, F., Manzoni, M., Hecker, S., and Katrin (2021). "What is citizen science? The challenges of definition," in *The science of citizen science*. Editors Katrin Vohland, Anne Land-Zandstra, Luigi Ceccaroni, Rob Lemmens, Josep Perelló, Marisa Ponti, et al. (Berlin, Germany: Springer International Publishing), 13–33. doi:10.1007/978-3-030-58278-4_2

Hamm, Andrea (2022). New objects, new boundaries: How the "journalism of things" reconfigures collaborative arrangements, audience relations and knowledge-based empowerment. *Digit. Journal.*, 1–20. doi:10.1080/21670811.2022.2096088

Hamm, Andrea, Shibuya, Yuya, and Ullrich, StefanTeresa Cerratto Cerratto Pargman "What makes civic tech initiatives to last over time? Dissecting two global cases," in Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems, Yokohama Japan, May 2021, 1–17.

Harrell, Cyd (2020). *A civic technologist's practice guide*. San Francisco, CA, USA: Five Seven Five Books.

Hecker, Susanne, and Taddicken, Monika (2022). Deconstructing citizen science: A framework on communication and interaction using the concept of roles. *J. Sci. Commun.* 21 (1), A07. doi:10.22323/2.21010207

Le Dantec, Christopher A. (2016). *Designing publics*. Cambridge, MA, USA: MIT Press.

Le Dantec, Christopher A. (2019). "Infrastructures of digital civics: Transportation, advocacy, and mobile computing infrastructuring publics: Medien der Kooperation. Editor Korn Matthias, Reißmann Wolfgang, Röhl Tobias, and Sittler David (Wiesbaden, Germany: Springer Fachmedien Wiesbaden), 169–184. doi:10.1007/978-3-658-20725-0_8

Longo, Antonella, Zappatore, Marco, and Bochicchio, Mario A. (2020). Apollon: Towards a citizen science methodology for urban environmental monitoring. *Future Gener. Comput. Syst.* 112, 899–912. doi:10.1016/j.future.2020.06.041

Loukissas, Yanni Alexander (2019). *All data are local. Thinking critically in a data-driven society*. Cambridge, MA, USA: MIT Press.

Marx, Vivien (2013). Data visualization: Ambiguity as a fellow traveler. *Nat. Methods* 10 (7), 613–615. doi:10.1038/nmeth.2530

Morini, Francesca (2023). Data journalism as "terra incognita": Newcomers' tensions in shifting towards data journalism epistemology. *Journal. Pract.*, 1–17. doi:10.1080/17512786.2023.2185656

Morini, Francesca, Dörk, Marian, and Appelgren, Ester (2022). Sensing what's new: Considering ethics when using sensor data in journalistic practices. *Digit. Journal.* 11, 465–483. doi:10.1080/21670811.2022.2134161

Muhonen, Reetta, Benneworth, Paul, Olmos-Peñuelaand Julia (2019). From productive interactions to impact pathways: Understanding the key dimensions in developing SSH research societal impact. *Res. Eval.* 29. doi:10.1093/reseval/rvz003

Paleco, Carole, Peter, García, SabinaSeoane, Salas, NoraKaufmann, Julia, et al. (2021). "Inclusiveness and diversity in citizen science," in *The science of citizen science*. Editor Katrin Vohland (Cham, Germany: Springer International Publishing), 261–281. doi:10.1007/978-3-030-58278-4_14

Passani, Antonella, T6, Ecosystems S. r. l., Janssen, Annelli, Hölscher, Katharina, and Di Lisio and Giulia (2022). A participatory, multidimensional and modular impact assessment methodology for citizen science projects. *fteval J. Res. Technol. Policy Eval.* 54, 33–42. doi:10.22163/fteval.2022.569

Przeybilovicz, Erico, Cunha, Maria Alexandra, Geertman, Stan, Leleux, Charles, Michels, Ank, Tomor, Zsuzsanna, et al. (2022). Citizen participation in the smart city: Findings from an international comparative study. *Local Gov. Stud.* 48 (1), 23–47. doi:10.1080/03003930.2020.1851204

Raddick, M. J., Bracey, G., Gay, P. L., Lintott, C. J., Cardamone, C., Murray, P., et al. (2013). Galaxy zoo: Motivations of citizen scientists. http://arxiv.org/abs/1303.6886.

Sadowski, Jathan (2021). *Anyway, the dashboard is dead': On trying to build urban informatics*. United Kingdom: New Media & Society. doi:10.1177/14614448211058455

Schrock, Andrew R. (2019). "What is civic tech? Defining a practice of technical pluralism," in *The Right to the Smart City*. Editors Cardullo Paolo, Feliciantonio Cesare Di, and Kitchin Rob (Bingley, England: Emerald), 125–133.

Shibuya, Yuya, Hamm, Andrea, and Raetzsch, Christoph "From data to discourse: How communicating civic data can provide a participatory structure for sustainable cities and communities," in Proceedings from 27nd International Sustainable Development Research Society Conference, Östersund, Sweden, 2021.

Shibuya, Yuya, Lai, Chun-Ming, Hamm, Andrea, Takagi, Soichiro, and Sekimoto, Yoshihide (2022). Do open data impact citizens' behavior? Assessing face mask panic buying behaviors during the covid-19 pandemic. *Sci. Rep.* 12 (1), 17607. doi:10.1038/s41598-022-22471-y

Stalph, Florian, and Heravi, Bahareh (2021). Exploring data visualisations: An analytical framework based on dimensional components of data artefacts in journalism. *Digit. Journal.*, 1–23. doi:10.1080/21670811.2021.1957965

Strobl, B., Etter, S., Van Meerveld, H. J. I., and Seibert, J. (2019). Training citizen scientists through an online game developed for data quality control. *Geosci. education/Community Engagem.*, doi:10.5194/gc-2019-26

Stylinski, C. D., Peterman, K., Phillips, T., Linhart, J., and Becker-Klein, R. (2020). Assessing science inquiry skills of citizen science volunteers: A snapshot of the field. *Int. J. Sci. Educ. Part B* 10 (1), 77–92. doi:10.1080/21548455.2020.1719288

Suman, Berti, and Anna (2018). The smart transition: An opportunity for a sensor-based public-health risk governance. *Int. Rev. Law, Comput. Technol.* 32 (2-3), 257–274. doi:10.1080/13600869.2018.1463961

Vlachokyriakos, V., Crivellaro, C., Le DantecChristopher, A., Gordon, E., Wright, P., et al. "Digital civics. Citizen empowerment with and through technology," in Proceedings of the International Conference on Human Factors in Computing Systems, New York, NY, USA, May 2016. doi:10.1145/2851581.2886436

Vornhagen, Heike, Zarrouk, Manel, Davis, Brian, and Young, Karen "Do city dashboards make sense? Conceptualising user experiences and challenges in using city dashboards. A case study," in Proceedings of the 22nd Annual International Conference on Digital Government Research, New York, NY, USA, 2021. doi:10.1145/3463677.3463695

Wilkinson, M. D., Dumontier, M., Aalbersberg, I. J., Appleton, G., Axton, M., Baak, A., et al. (2016). The fair guiding principles for scientific data management and stewardship. *Sci. Data* 3, 160018. doi:10.1038/sdata.2016.18

Williams, Sarah (2020). *Data action: Using data for public good*. Cambridge, MA, USA: MIT Press.

Young, Gareth W., Kitchin, Rob, and Naji, Jeneen (2021). Building city dashboards for different types of users. *J. Urban Technol.* 28 (1-2), 289–309. doi:10.1080/10630732.2020.1759994