The civic Internet of Things as a socio-technical object

Studies on community-based environmental monitoring,
sustained civic engagement and new opportunities in journalism.

Dissertation

zur Erlangung des Grades eines Doktors
„Doctor philosophiae“
(Dr. phil.)

am Fachbereich Politik- und Sozialwissenschaften
der Freien Universität Berlin

vorgelegt von Andrea Hamm, M. A.

Berlin, 2022

Erstgutachter:

Prof. Dr. Christoph Neuberger
Professor für Publizistik- und Kommunikationswissenschaft, Schwerpunkt „Digitalisierung und Partizipation“
Institut für Publizistik- und Kommunikationswissenschaft

Freie Universität Berlin
Garystraße 55
14195 Berlin
Deutschland

Zweitgutachter:

Prof. Dr. Christoph Raetzsch
Associate Professor in Journalism Studies and Digital Methods
Department of Media and Journalism Studies

Aarhus Universitet
Helsingforsgade 14
DK-8200 Aarhus N
Danmark

Tag der Disputation:

15. Dezember 2022

Selbstständigkeitserklärung
Hiermit erkläre ich, dass ich die vorliegende Arbeit selbstständig und ohne unerlaubte fremde Hilfe angefertigt, keine anderen als die angegebenen Quellen und Hilfsmittel verwendet und die den verwendeten Quellen und Hilfsmitteln wörtlich oder inhaltlich entnommenen Stellen als solche kenntlich gemacht habe.

Berlin, 1. September 2022

Andrea Hamm

- - - to my wonderful family - - -

„Das Internet ist ein großer Misthaufen, in dem man allerdings auch kleine Schätze und Perlen finden kann.“

Joseph Weizenbaum, 2001, Hamburg

Danksagung

Diese Arbeit ist meiner Familie gewidmet, insbesondere meinem Mann Maximilian Hamm, der mich über die Jahre meiner Dissertation unterstützt und motiviert hat. Unsere Tochter Ariane (*2020) ist inmitten meines Promotionsprojekt sowie kurz vor dem ersten pandemisch-bedingten Lock-Down in Deutschland geboren worden. Auch wenn es in den letzten zwei Jahren durch Home Office, Lock-Downs, Quarantäneregeln, Zoom-Meetings, Internetausfällen, etc. nicht immer stressfrei war, so schaffte Ariane es immer, mich nach vorne schauen zu lassen. Diese Dissertation ist eine echte Teamleistung meiner Familie, die viele Tage und Nächte zurückstecken mussten, wenn ich eine Manuskript-Deadline, Reviews und Proofs auf der To-Do-Liste hatte. Max, ich danke dir für deine unendliche Unterstützung! Ohne dich wäre diese Arbeit niemals möglich gewesen.

Ich danke auch von ganzem Herzen meinen Eltern, Hartmut und Petra Schindel für Ihre jahrelange Unterstützung meiner Studien- und Forschungszeiten und ihre vielen guten Zusprüche, wenn es einmal schwieriger wurde. Ich danke ebenfalls meinen Schwiegereltern, Alfons und Carmen Hamm, die mir in vielen akademischen und persönlichen Anliegen weitergeholfen haben.

Ich danke Christoph Neuberger für seine Bereitschaft, die Erstbetreuung meiner Promotionsarbeit übernommen zu haben und mich in sein Forschungscolloquium aufzunehmen. Christoph, ich danke dir für deine Ratschläge und deine thematische Offenheit. Ich möchte ebenfalls allen Mitarbeitenden deiner Forschungsgruppe an der FU Berlin danken, die meiner Dissertation mit vielen nützlichen Kommentaren und Fragen zum Abschluss verholfen haben.

Ich danke vielmals Stefan Ullrich und Ina Schieferdecker dafür, dass sie während meines Einstellungsgesprächs im Jahr 2018 das Potential in mir gesehen haben, als Quereinsteigerin aus der Kommunikationswissenschaft, in der Informatik arbeiten zu können. Stefan, ich danke dir vielmals für die wissenschaftliche Freiheit, die du mir in den letzten Jahren gewährt hast. Diese Freiheit hat es mir ermöglicht, meinen Platz in der „Bindestrich-Informatik“ zu finden und ein Thema zu entdecken, welches mich sowohl begeistert als auch herausgefordert hat. Ich danke dir, dass du stets an mich geglaubt hast und meinen Weg sogar über die Promotion hinaus unterstützt.

Als nächstes möchte ich mich bei meinen (ehemaligen) Kolleginnen und Kollegen von der TU Berlin bedanken: Hans-Christian Gräfe, Rainer Rehak, Jakob Kröger, Theo Vassiliou-Gioles, Martin Schüssler, Mila Miceli und Gunay Kazimzade. Wir haben gemeinsame Forschungsseminare geplant und durchgeführt, Research Days Programme vorbereitet und an Retreats teilgenommen. Mit euch habe ich über unzählige Weizenbaum-Themen philosophiert und ihr habt meine Promotionszeit geprägt. Ein besonderer Dank gilt Prof. Dr. Bettina Berendt, Principal Investigator der TU-Gruppen am Weizenbaum-Institut für ihre Unterstützung.

I am thankful to Prof. Hideyuki Tanaka (former Professor at the University of Tokyo, Japan). Yuki, we met when I was just about to finalize my master thesis and you invited me several times to your lab meetings in Tokyo where I had the chance to present my research to your group. Thank you so much for being so inclusive and open-minded. Thanks to you I learned how international collaborations could begin. Even if unfortunately an illness led to the fact that we had to terminate our cooperation prematurely, I am very grateful that through you, I could get to know your amazing colleague Yuya Shibuya.

Yuya Shibuya has accompanied me from afar over the last few years. Yuya, I thank you in so many ways! We have taken several field trips together in Japan and Germany and worked repeatedly on challenging scientific articles. Not all of these texts have found their way into this thesis, but they have always motivated me to continue researching. Thanks to you, I was able to maintain the connection to Japan during the difficult time of the initial supervision change, which always allowed me to look beyond the European horizon and to keep hopes for later stays abroad.

I thank Prof. Teresa Cerratto Pargman for her un-limited support. Tessy, I first “met” you when you were my reviewer for my first single author paper at LIMITS workshop 2020. You wrote such an inspiring review for my manuscript that we kept discussing and collaborating and we ended up with 2 published research articles! You are such an inspiring personality for me and without your support I would definitely not have been able to finalize my dissertation. Thank you so much!

Ich möchte den Mitarbeitenden und Ehemaligen am Weizenbaum-Institut danken, mit denen ich viele inspirierende Gespräche führen durfte. Bitte seht es mir nach, dass ich nicht alle von euch hier namentlich nennen kann. Ich möchte dennoch meine Zusammenarbeit mit den Doctoral Researchers‘ Representatives 2019-2021 hervorheben: Rainer, Sophie und Philipp, vielen Dank dass ich zwei Jahre lang mit euch zusammen als Doktorand*innensprecherin arbeiten durfte.

Als Letztes möchte ich noch der deutschen Steuerzahlergemeinschaft danken, die unabhängige Forschung ermöglicht und finanziert. Ich war mir des Privilegs, in der Forschung arbeiten zu dürfen, stets bewusst und habe es auch immer als Teil meiner Arbeit verstanden, meine Erkenntnisse an die breite Gesellschaft zu vermitteln. Vielen Dank, dass ich dieser Dissertation nachgehen durfte!

Abstract

In the presented work, Internet of Things (IoT) technologies, like sensors and their applications, have been investigated from a socio-technical perspective focusing on civic purposes of the technologies' use. The aim of the work is to gain a better understanding of civic IoT and its transformative potential for society. Therefore, the overarching research question is: What are the societal implications of the technological object *civic IoT*? Three application areas identified as highly relevant have been studied: community-based environmental monitoring, sustained engagement of civic tech initiatives, and the "Journalism of Things."

In the first study, the civic IoT initiative Luftdaten.info dedicated to the community-based monitoring of particulate matter in the air was examined. The initiative is organized within limits of technical equipment, resources, and academic knowledge. The case study comprises a media content analysis, a web application analysis, and two expert interviews. The data illustrates that the local air pollution topic is a discursive long-term process striving towards a more sustainable city and community. The findings show that the information provided by Luftdaten motivates certain people to become aware and engaged for their local environment, and some to change their behavior. I found that the initiative itself is managed in a sustainable way being inclusive and resource-saving. The media content analysis shows that events around the emergence of the Luftdaten initiative had a certain influence on the local media agenda. Finally, a data map comparison shows how easily misunderstandings in the representation of monitoring data can occur when taking different decisions during the data analysis and visualization of almost identical datasets.

In the second study, two long-lasting civic tech initiatives of global scale were investigated to understand what makes them sustain over time. We conducted two mixed-method case studies of the initiative Luftdaten.info from Germany and the initiative Safecast from Japan. We combined social network analysis and qualitative content analysis of Twitter data with insights from expert interviews. Drawing on our findings, we identified a set of key factors that help the studied civic tech initiatives to grow and last. Contributing to Digital Civics in HCI, we argue that the civic tech initiatives' scaling and sustaining are configured through the entanglement of (1) civic data both captured and owned by the citizens for the citizens, (2) the use of open and accessible technology, and (3) the initiatives' public narrative, giving them a voice on the environmental issue.

In the third study, Journalism of Things (JoT) as a new paradigm in digital journalism was investigated. Three case studies on recent award-winning journalism projects in Germany were conducted with the analytical lenses of boundary work and objects of journalism. The study comprises interviews with journalists, media content analyses, and observations of virtual public events. The findings suggest four typical phases in JoT projects: formation, data work, presentation, and ramification. Blurred boundaries of journalism towards science and activism become apparent when co-creative JoT teams apply scientific methods and technology design while mobilizing communities. Findings further show that things (or objects) of JoT have implications on the configuration for collaborative arrangements and audience relations. By creating and disseminating new local knowledge on matters of common concern, JoT is also contributing to empowering both journalism and citizens.

This dissertation is a cumulative work comprising three peer-reviewed scientific publications.

Zusammenfassung

In dieser Dissertation wurden Internet of Things (IoT) Technologien, wie Sensoren und ihre Anwendungen, aus einer soziotechnischen Perspektive mit Schwerpunkt auf zivilgesellschaftliche (engl. civic) Zwecke für die Verwendung der Technologien erforscht. Das Ziel der Arbeit ist es, ein tiefergehendes Verständnis vom Civic IoT und seinen gesellschaftlichen Transformationspotenzial zu erlangen. Die übergreifende Forschungsfrage lautet: Was sind die gesellschaftlichen Implikationen des technologischen Objekts *Civic IoT*? Drei Anwendungsbereiche, welche als hochrelevant eingestuft wurden, werden in dieser Arbeit studiert: gemeinschaftliche (engl. community-based) Umweltbeobachtung, nachhaltiges Engagement von Civic-Tech-Initiativen und der „Journalism of Things".

In der ersten Studie wurde die Civic-IoT-Initiative Luftdaten.info untersucht, welche sich mit der gemeinschaftlichen Umweltbeobachtung von Feinstaub in der Luft beschäftigt. Die Initiative ist innerhalb zahlreicher Begrenzungen bezüglich ihrer technischen Ausstattung, ihren Ressourcen und ihrem Zugang zu akademischem Wissen organisiert. Die Fallstudie umfasst eine Medieninhaltsanalyse, eine Webanwendungsanalyse und zwei Experteninterviews. Die Daten zeigen, dass das Luftverschmutzungsthema ein lokaler, diskursiver Langzeitprozess zu einer nachhaltigeren Stadt und Community ist. Die Ergebnisse legen nahe, dass die Informationen zu den Umweltdaten einige Leute dazu motiviert, sich ihre lokale Umwelt bewusster zu machen und sich für sie zu engagieren, manche verändern ihr Verhalten. Ich fand heraus, dass die Initiative selbst auf ökonomisch, ökologisch und sozial nachhaltige Weise arbeitet. Medieninhaltsanalysen zeigen außerdem, dass die Ereignisse rund um das Entstehen von der Luftdaten-Initiative einen gewissen Einfluss auf die Medienagenda hatten. Zuletzt zeigt ein Datenkartenvergleich wie schnell Missverständnisse bei der Darstellung von Umweltbeobachtungsdaten auftreten können, wenn unterschiedliche analytische und gestalterische Entscheidungen für fast identische Datensätze getroffen werden.

In der zweiten Studie wurden zwei langlebige Civic-Tech-Initiativen von globalem Umfang untersucht, um zu verstehen, was sie im Laufe der Zeit bestehen lässt. Wir haben zwei Fallstudien über die Initiative Luftdaten.info aus Deutschland und die Initiative Safecast aus Japan durchführt. Dabei verwendeten wir gemischte Methoden (engl. mixed methods) und kombinierten die Analyse sozialer Netzwerkdaten und die qualitative Inhaltsanalyse von Twitter-Inhalten mit Erkenntnissen aus Experteninterviews. Auf der Grundlage unserer Ergebnisse haben wir eine Reihe von Schlüsselfaktoren identifiziert, die den untersuchten Civic-Tech-Initiativen zu Wachstum und Beständigkeit verhelfen. Als Beitrag zum Gebiet *Digital Civics* im Feld *Human-Computer-Interaction* (HCI) argumentieren wir, dass die Skalierung und Nachhaltigkeit der Civic-Tech-Initiativen durch die Verflechtung von drei Faktoren konfiguriert wird: (1) zivilgesellschaftlichen Daten, die von Bürger*innen für Bürger*innen erfasst werden und sich in ihrem Besitz befinden, (2) die Verwendung offener und zugänglicher Technologie und (3) die öffentliche Narration der Initiativen, die ihnen eine Stimme in Umweltfragen verleiht.

In der dritten Studie wurde der „Journalism of Things" (JoT) als ein neues Paradigma im digitalen Journalismus erforscht. Unter den analytischen Blickwinkeln der *Grenzarbeit* (engl. boundary work) und der *Objekte des Journalismus* wurden drei Fallstudien über aktuelle preisgekrönte Journalismus-Projekte in Deutschland durchgeführt. Die Studie umfasst Interviews mit Journalistinnen und Journalisten, Medieninhaltsanalysen und Beobachtungen virtueller öffentlicher Veranstaltungen. Die Ergebnisse deuten auf vier typische Phasen in JoT-Projekten hin: Formation, Datenarbeit, Präsentation, und Auswirkungen (engl. ramifications). Verschwimmende Grenzen im Journalismus in Richtung Wissenschaft und Aktivismus werden ersichtlich, wenn ko-kreative Teams wissenschaftliche Methoden anwenden und Technologieentwicklung betreiben, während sie Leser*innen mobilisieren. Die Ergebnisse zeigen außerdem, dass die Dinge (oder Objekte) des JoT Implikationen auf die Konfiguration von Zusammenarbeit und Publikumsbeziehungen haben. Durch das Generieren und Verbreiten von neuem lokalem Wissen über Angelegenheiten gemeinsamen Interesses trägt JoT zum Empowerment Journalismus und Bürger*innen bei.

Diese Dissertation ist eine kumulative Arbeit und umfasst drei begutachtete wissenschaftliche Publikationen.

About this thesis

This dissertation has been written as a research fellow at Weizenbaum Institute for Research of the Networked Society and Technical University Berlin as part of the research group "Responsibility and the Internet of Things" led by Dr. Stefan Ullrich. The interdisciplinary Weizenbaum Institute in its continuous development provided a dynamic context for my work in which I adapted my research to changing context.

From summer 2018 to winter 2020/21, I started as PhD student in Computer Science at Technical University Berlin, with Prof. Dr. Ina Schieferdecker as supervisor. In spring 2021, the supervision changed to Prof. Dr. Christoph Neuberger and I changed my PhD studies to "Medieninformatik" (Digital Media and Technology) at Freie Universität Berlin which suited better the scope of this thesis.

Consequently, this dissertation is an interdisciplinary, cumulative work consisting of three peer-reviewed publications from the fields of Computer Science and Communication Studies.

Study 1 was subjected to a one-step non-blind peer review process and was published as full paper in the proceedings of 2022 ICT4Sustainability (ICT4S). Such proceedings are the common publication type in the field of Computer Science rather than journal publications. They comparable to journal publications in other field regarding scope, readership, and review process. The ICT4S described itself as:

> *"ICT4S is the premier international conference to bring together leading researchers in Information and Communications Technology (ICT) for Sustainability, with representatives from government, industry and the wider society. This includes decision-makers and end-users with an interest in using ICT for sustainability, researchers focusing on ICT effects on sustainability, and developers of sustainable ICT systems or applications. ICT4S encompasses all types of research, developments and applications of ICT to support sustainability, and the topic is receiving significant attention across the world." (https://www.bristol.ac.uk/cabot/events/2020/2020ict4sorg.html)*

Study 2 was published in the proceedings in the 2021 Conference on Human Factors in Computing Systems (CHI). This conference is ranked top-tier[1] in the field of Human-Computer Interaction. The published full paper was subjected to a three-step, double-blind peer review process prior to the acceptance for publication. The CHI 2021 described itself as:

> *"The 2021 ACM CHI Virtual Conference on Human Factors in Computing Systems is the premier international conference on Human-Computer Interaction. […] CHI – pronounced 'kai' – is a place where researchers and practitioners gather from across the world to discuss the latest in interactive technology. CHI is generally considered the most prestigious in the field of HCI and attracts thousands of international attendees annually." (https://chi2021.acm.org/)*

The proceedings of these two conferences are published by the largest association in Computer Science, the Association of the Computing Machinery (ACM), and both articles are available as Open Access Papers in the ACM Digital Library (please find the weblinks in the appendix of this work).

In communication studies, it is common to publish articles in scientific journals rather than conference proceedings. Study 3 was submitted to *Digital Journalism* published by Taylor&Francis. The journal is listed in the Social Science Citation Index.

Study 1 and 3 were prepared as single-author papers. Study 2 was prepared by a team of Co-authors. I was first author of the paper, and my contributions were: writing the full text, performing the largest

[1] http://www.conferenceranks.com/?searchall=Conference%20on%20Human%20Factors%20in%20Computing%20Systems#data

part of the literature analysis, performing the qualitative analysis of the English-language social media contests, and conflating the qualitative categories with the English-language interview data. Co-author Yuya Shibuya supported the analysis of the presented Japanese case study, contributed knowledge from Japanese-language social media contents and other web contents, and performed the network analysis. Co-author Teresa Cerratto Pargman supported the work with her knowledge and experience in the field of Sustainable HCI and Digital Civics. Co-author Stefan Ullrich provided important advice on the research in the Open Knowledge Community. All authors exchanged ideas about the interpretation of the data and contributed to the final editing of the text.

All three studies in this cumulative dissertation were published in English language.

Contents

List of Figures

Introduction

Internet of Things (IoT) technologies became ubiquitous in today's societies. They are integrated parts of smartphones, tablets, wearables, cars, bicycles, and numerous household devices; and they used to be understood from a marketing and consumer perspective only (Soro et al., 2018). However, IoT technology can also be applied for *civic* purposes. So far, research just started to address what "civic IoT" is and what kind of social aspects it inheres (C. Liu et al., 2019). For instance, IoT technologies can be leveraged for environmental monitoring in cities and communities (Bibri, 2018; Lambrechts & Sinha, 2016) and citizen-led civic tech initiatives leverage IoT technologies to collect data on matters of common concern (Brown et al., 2016; Gabrys et al., 2016). Journalists apply IoT technologies to create new kinds of stories with the help of self-collected data (D'Ignazio & Zuckerman, 2017; Schmitz Weiss, 2016). To gain a better understanding of civic IoT and its transformative potential, this dissertation seeks to answer the question: **What are the socio-technical implications of the *civic IoT*?**

This dissertation investigates civic IoT technology as an object of research in two disciplines: human-computer interaction and communication research. The goal of this dissertation is to provide new steps in the direction of a broader interdisciplinary groundwork between the two disciplines. To approach the overarching research question, I apply an advanced technical understanding of civic IoT to selected application areas that appear to be among the most relevant ones:

1. Civic IoT as a *technology with limited computing resources* that allows community-based environmental monitoring
2. Civic IoT as an *easy-to-use technology* that facilitates sustained engagement of civic tech initiatives
3. Civic IoT as an *enabling technology for the Journalism of Things* that transforms journalistic practices and generates further societal ramifications

In the following, I introduce important concepts and theories that form the basic conceptual framework of this dissertation in order to contribute knowledge to the application areas mentioned above. First, I present the concepts and principles of *civic technologies*, a term referring to all kinds of technologies designed for civic purposes–not just IoT technologies. Second, I introduce the research field of "Computing within Limits," which focuses on low-energy and low-material use of computers and critiques research that ignores the environmental impacts of computing technologies. As IoT technologies can contribute to both increasing and decreasing negative environmental effects, it is exciting to study civic IoT that inheres an inclusive and participatory design, provides new civic data, and might also have a positive effect on environmental matters. This dissertation provides insights about civic IoT's potential to achieve more sustainable local communities from a computing within limits perspective. Third, I describe the field of *digital civics*, which is a natural research field when studying civic tech, and hence also when studying civic IoT, being a part of civic tech. In digital civics, the key

question is how to design technologies with citizens for citizens–and not just for consumers. One important question that is covered in this dissertation is: how to design and organize civic tech to be long-lasting. Fourth and last, I explain recent theory and questions in *digital journalism* studies that are highly related to the use of civic IoT in journalism. Journalists applying civic IoT is a fascinating perspective that is so far scarcely studied. Journalism being a societal multiplier itself may highly increase potential implications of civic IoT technologies at the same time the technology is also having implications on journalism. For both reasons, digital journalism represents an important field to be considered when studying socio-technical implications of civic IoT.

Figure 0.1 shows the study model of the socio-technical object *civic IoT*. In the upper part, the model shows the co-creation process conducted by the selected actor groups, i.e. civic tech initiatives and journalists, who design the technology and data together with other stakeholders, such as domain experts, scientists and technologists. Civic IoT is produced with limited resources and used by engaging a citizen community to generate data and narratives. In the lower part of the figure, the three application areas of civic IoT studied in this work are shown: Community-based environmental monitoring, sustaining civic initiatives, and Journalism of Things. This study model provides an overview on the scope of this dissertation.

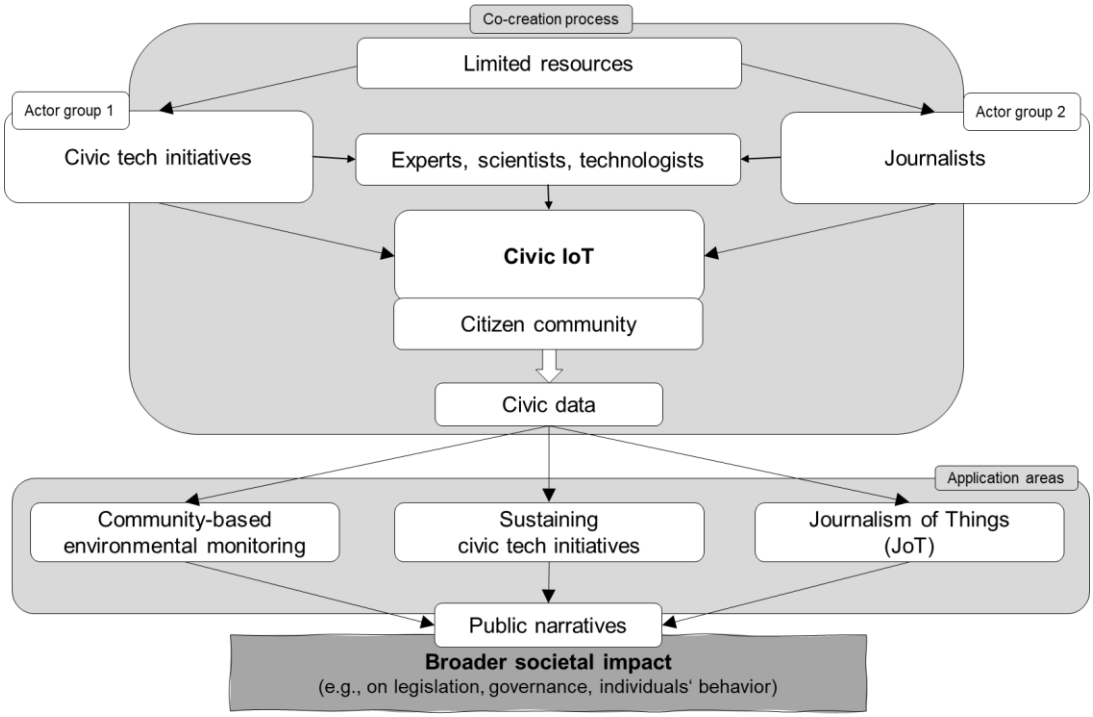

Figure 0.1: Study model of civic IoT. The model bases the socio-technical study of civic IoT on the technology's limited need of resources that allows the two studied actor groups, i.e., civic tech initiatives and journalists, to become engaged with it. The central co-creation process includes the design of particular civic IoT technologies together with other stakeholders, such as domain experts, scientists, and technologists. Civic IoT is then used and applied by a larger citizen community in a participatory and decentralized way. At the end of the co-creation process, civic data is generated and allows to create public narratives on matters of common concern. The civic data and its narratives have societal implications which are studied in three selected application areas: the citizen-led provision of public information, the longevity of civic initiatives, and transformations of journalism in the "journalism of things."

Computing within Limits and the Civic IoT

The notion of the IoT is intermingled with the high increase in numbers of electronic devices, data centers, and cloud servers. Being related to several market developments, IoT technologies have led to reduced costs in various domains. Such market developments include the enormous augmentation of available processing power, storage capacities and networking capabilities, the miniaturization of chips and cameras, and the digitization and expansion of data repositories (Rose et al., 2015). Early work on the IoT concentrates on technical innovations mainly for business and industries, such as IoT for intelligent factories and "Industrie 4.0" (Hu et al., 2019; Chen et al., 2018; Lucke et al., 2008). A recent prognosis states that the number of connected IoT devices will triple between 2020 and 2030.[1]

This technological development goes hand in hand with a high increase of material consumption for producing electronic devices and a high energy consumption for creating, processing, and providing a large offer of applications, data, and software. The scientific community *Computing within Limits* criticizes computing visions that would be too strongly led by market principles and encouraging unrealistic perspectives of unlimited computing (Nardi et al., 2018). In short, they argue that computing is a part of human development that equally has to respect the planet's natural resources' boundaries. Limits' researchers and designers demand to consider three principles when developing computing tools and solutions: to question growth, to consider models of scarcity, and to reduce energy and material consumption (Nardi et al., 2018). Popular technologies such as cloud computing, video streaming, and social networking would highly increase growth and consumption, instead of decreasing them.

IoT technology has the potential contribute to energy efficiency and a reduction of resource consumption (L. Liu, 2018; Nižetić et al., 2020). To better understand this potential from a societal perspective, it is essential to broaden the understanding of how implications of IoT technologies can look like. Recent advances in IoT studies give first evidence that IoT technologies can be applied to support various political actions. Liu, Balestrini and Vilaza (2019) problematize economy-driven innovation of IoT technologies extending their services to people's personal lives, homes, and cities. Common practices of data properties, analytics, and advertisements are seen as questionable (C. Liu et al., 2019, p. 205). Therefore, they developed a vision of the *civic IoT*. Civic IoT would not only consider the IoT's impact on individual human beings, for example to manage one's room temperature at home or evaluate one's daily number of footsteps, but it considers the IoT's potentials for change on a community level. The civic IoT perspective underscores that innovation of networked sensor and related technologies can serve civic purposes. Such purposes are for example addressing matters of concern, building communities, inviting citizen participation, raising awareness, and triggering social interactions (C. Liu et al., 2019, p. 203). IoT systems can be designed with the aim to fulfilling community's needs. The

[1] https://www.statista.com/statistics/1183457/iot-connected-devices-worldwide/ (last access: 03/22/2022)

scaling of such technologies can possibly lead to social and political changes that are beneficial for communities' progress.

Multiple studies in the domain of sensor-based environmental monitoring and citizen science, i.e. scientific tasks conducted by non-scientists, showed how new sets of environmental data can contribute to a better understanding and a potentially better management of our changing environment (Bibri, 2018; Brown et al., 2016; Hemmi & Graham, 2014; H.-Y. Liu et al., 2017; Pargman et al., 2019). For instance, the civic tech initiative Safecast has collected local radioactivity data with self-developed, relatively low-cost IoT devices in the Fukushima region after the 2011 Great Eastern Japan Earthquake and Tsunami that have damaged the Fukushima Dai-ichi nuclear power plant (Brown et al., 2016). Safecast generated datasets that have not been existent previously and provided data-based knowledge through an online map for the local residents and the public.

When considering the interplay of IoT monitoring technologies, community progress, and engagement, it is so far not yet well understood how civic IoT design impacts societal processes. This dissertation provides findings to grasp how civic IoT and data contribute to local knowledge production and dissemination as well as to shaping the public discourse on matters of concern.

Digital Civics and Civic Technologies

When technologies and data are put at the service of citizens and communities, it is often referred to as civic technologies, or civic tech (Schrock, 2018). Civic tech relates to all kinds of technologies, not just IoT technologies, and addresses their use for civic purposes. Civic tech is often developed by civic initiatives which are groups of people from civil society becoming engaged with technologies. These civic tech initiatives represent socio-technical arrangements attempting to bring citizens (i.e., individuals, groups, communities, the general public) and authorities together to discuss matters of common concern (Latour, 2004; C. Liu et al., 2019). As a particular forms of community activism, they act outside formalized channels of political work and institutions (Asad & Le Dantec, 2015). Civic tech raises questions on how technologies can be leveraged to encourage civic participation, social change, and progress. Such questions are not easy to answer because they allude to many fields of research, for example participatory design (Asad & Le Dantec, 2015), digital civics (Vlachokyriakos et al., 2016), innovation and participation (Hsu et al., 2020; Wehn & Evers, 2014), democratic deliberation and western political processes (Habermas, 1991; Kreide, 2016). This dissertation provides some new theory in this multidisciplinary direction.

Civic IoT initiatives use the Internet of Things (IoT) and related sensing, information, and communication technologies to improve community services, civic engagement, and citizens' quality of life. Some of these initiatives became dedicated to social or environmental issues and contributed to society in terms of publishing data (Dunn, 2016; Earthwatch, 2020; Kim et al., 2011; National Audubon Society, 2020), building new communities (Le Dantec & DiSalvo, 2013; Pargman et al., 2019), and

raising awareness (Le Dantec et al., 2011; Wehn & Evers, 2014). It is critical to understand how technological innovations attract attention, are adopted, and used in practice (Couldry, 2012). The study of societal implications also includes to understand limitations of civic IoT initiatives, for example, in terms of disseminating public information, and impacting media coverage and local governance.

Though providing new applications and data to the public, civic technologies appear to be limited in time. Their sustained use and maintenance remains rather low (Harding et al., 2015) and civic tech initiatives are often only short-lived (Hansen et al., 2020; C. Liu et al., 2019, p. 197f.). For instance, the "Code For" project archive shows a large number of civic tech initiatives discontinued, seeking for volunteers, and ran out of budget.[2] This observation brings up the crucial question on how civic tech initiatives can last over time in the social, civic, and political ecologies in which they operate (Gordon & Lopez, 2019, p. 58). The initiatives' longevity is important to make sure that communities and technologies contribute to social progress in a sustained way and that their engagement leads to a manifested outcome. Research approaching this question is considering how civic technologies can be better designed (Schrock, 2018) and how infrastructures for civic participation can be designed to foster the formation of publics (Hansson et al., 2018; Le Dantec, 2016; Le Dantec & DiSalvo, 2013).

Such questions on socio-technical arrangements contribute to the growing research area "digital civics", which is dedicated to improving or creating "new modes of citizen participation" (Corbett & Le Dantec, 2018a, 2018b). Digital civics explores how dynamic relational models implanted in civic tech design might "reconfigure power relations between citizens, communities and the state" (Vlachokyriakos et al., 2016, p. 1096). Researchers and designers in digital civics seek to fostering democratic design models valuable for both citizens and local governments.

The scholarship of civic technologies in digital civics shows many interrelations to studies of citizen-led environmental monitoring (e.g., Duchon et al., 2012; Gabrys et al., 2016; Hemmi & Graham, 2014) and citizen science (e.g., Hecker et al., 2018; Kim et al., 2011; Preece, 2016). Though, the understanding of citizens and their role for the broader society is revised in digital civics. For instance, improving matters of common concern is a goal of many citizen-led projects in environmental monitoring, citizen science, and digital civics. Civic IoT for environmental monitoring produces local knowledge that can be used for negotiating matters affecting their communities. More specifically, citizen-supported projects generate data that incorporate a civic perspective that has been lacking before. From this particular perspective, the primary value of citizen-sensed data is the provision of unprecedented data on a particular socio-environmental issue in a particular geographical place (Gabrys et al., 2016). With the help of civic tech, citizens create new rational arguments through the new data captured and shared by the involved citizens. Without the intervention of civic IoT, there would be no data on local matters of common concern, making the data and associated narratives extremely relevant for journalistic use.

[2] https://codefor.de/projekte/archiv/ (last access: 03/22/2022)

For this reason, this dissertation also contributes to journalism studies, the particular area of journalism studies will be introduced in the following.

Digital Journalism

Journalism, in particular digital journalism, is a field that reproduces civic data (Shibuya et al., 2021) and communicative objects (Raetzsch & Bødker, 2016). With such increasingly complex constructions of social data in journalism, Lowrey and Hou (2021) see the risk that journalists' lacking of technical and statistical knowledge and skills could prevent them from fulfilling their institutional role. Also Usher (2018, p.355) has described how journalists lack skills in statistical and data literacy, which would be a major issue when journalism becomes more and more quantified. It is crucial for journalists today to understand complex data-driven decision-making and the constructions of officially collected data to remain independent from authorities' interpretations of data (Lowrey & Hou, 2021, p. 37).

With civic IoT technologies that are accessible, inexpensive, and distributable among people, journalists have the potential to generate their own datasets designed to address matters of public concern. A group of German journalists has founded the "Journalism of Things" (JoT) as a new paradigm for journalism in increasingly networked societies (Vicari, 2019). The community signed a manifesto[3] in 2019 based on which they regularly organize a JoT conference (www.jot-con.de). Several JoT projects won journalism awards. In this dissertation, the study of the JoT interlinks the study of journalistic practices around technological developments with the study of broader societal implications of such journalism innovations and brings the findings into scholarly discussions of digital journalism.

The Journalism of Things connects to existing streams in journalism studies such as participatory journalism (Singer, 2011) and open innovation practices (Aitamurto & Lewis, 2013). Journalists started to apply sensor technologies for new kinds of storytelling with self-collected datasets (D'Ignazio & Zuckerman, 2017; Schmitz Weiss, 2016). In particular, the datafication of previously non-traceable phenomena (Baack, 2018) and crowdsourcing for reporting and storytelling (Aitamurto, 2016) leads to novel practices and new boundaries of journalism demanding further inquiry (Carlson, 2018; Carlson & Lewis, 2019; Usher, 2016, 2018). Such advances have been grouped in the discussion of pioneer journalism which incorporates "imaginaries of new possibilities" (Hepp & Loosen, 2019, p. 5; Loosen, 2018) interlinked with technological knowledge and skills that make their way into journalistic production routines.

Journalism has a long history of seeking for factual knowledge and objective truth (Anderson, 2018). Over time numerous practices of design and technology application have been included in journalistic production routines. Since the last decades, technology-led and data practices become increasingly

[3] Journalism of Things Manifesto signed by the interviewed journalists https://github.com/journalismofthings/manifesto, (last access: 03/05/2022)

important in and for journalism and new questions need to be asked on transforming competences and new entrants in journalism (Usher, 2016). Object-oriented journalism studies describing a material turn in journalism focus on the role that technical artefacts play when journalists interact with these during their work (Steensen, 2018). One key question of this field is, for example, how objects entering and leaving newsrooms transform journalistic practice (Anderson & De Maeyer, 2015). For instance, Rodgers describes that journalistic thinking itself becomes more computational when journalists have to continuously deal with computational tools in their daily routine (Rodgers, 2015). Such an object orientation in journalism studies can provide a more nuanced study of power through revealing underlying power relations embedded in technological objects that journalists use for their work (Anderson & De Maeyer, 2015). Such a viewpoint offers more a relational understanding of technical artefacts as it seeks to "uncover the human decisions, cultural values, organizational imperatives, and material affordances" integrated in them (Anderson & De Maeyer, 2015, p. 4).

With regard to civic IoT, journalists need to conduct technology design and data collection and analysis. They are no longer relying on third party data sources but can capture exactly the kind of data they need for their story production, e.g., water quality and traffic noise measuring. Such datafication of social phenomena is often interrelated with activist practices (Baack, 2015, 2018). Because different from purely scientific data collection and analysis, journalists aim at telling a particular story from the data. Such blurring boundaries between scientific and activist practices and journalism need to be better understood and are addressed in this dissertation.

All in all, this dissertation investigates civic IoT technology as an object of research in multiple disciplines. I combine scholarship from the fields of computing within limits, civic tech/digital civics, and digital journalism to provide new steps in the direction of a broader interdisciplinary groundwork between human-computer interaction and media and communication studies.

References

Aitamurto, T. (2016). Crowdsourcing as a Knowledge-Search Method in Digital Journalism. *Digital Journalism*, *4*(2), 280–297. https://doi.org/10.1080/21670811.2015.1034807

Aitamurto, T., & Lewis, S. C. (2013). Open innovation in digital journalism: Examining the impact of Open APIs at four news organizations. *New Media & Society*, *15*(2), 314–331. https://doi.org/10.1177/1461444812450682

Anderson, C. W. (2018). *Apostles of certainty: Data journalism and the politics of doubt.* Oxford University Press.

Anderson, C. W., & De Maeyer, J. (2015). Objects of journalism and the news. *Journalism*, *16*(1), 3–9. https://doi.org/10.1177/1464884914545728

Asad, M., & Le Dantec, C. A. (2015). Illegitimate Civic Participation: Supporting Community Activists on the Ground. *Proceedings of the 18th ACM Conference on Computer Supported Cooperative Work & Social Computing*, 1694–1703. https://doi.org/10.1145/2675133.2675156

Baack, S. (2015). Datafication and empowerment: How the open data movement re-articulates notions of democracy, participation, and journalism. *Big Data & Society*, *2*(2), 2053951715594634. https://doi.org/10.1177/2053951715594634

Baack, S. (2018). Practically Engaged: The entanglements between data journalism and civic tech. *Digital Journalism*, *6*(6), 673–692. https://doi.org/10.1080/21670811.2017.1375382

Bibri, S. E. (2018). The IoT for smart sustainable cities of the future: An analytical framework for sensor-based big data applications for environmental sustainability. *Sustainable Cities and Society*, *38*, 230–253. https://doi.org/10.1016/j.scs.2017.12.034

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

Carlson, M. (2018). Boundary Work. In *The International Encyclopedia of Journalism Studies* (pp. 1–6). American Cancer Society. https://doi.org/10.1002/9781118841570.iejs0035

Carlson, M., & Lewis, S. C. (2019). Boundary Work. In *The Handbook of Journalism Studies* (2nd ed.). Routledge.

Chen, B., Wan, J., Shu, L., Li, P., Mukherjee, M., & Yin, B. (2018). Smart Factory of Industry 4.0: Key Technologies, Application Case, and Challenges. *IEEE Access*, *6*, 6505–6519. https://doi.org/10.1109/ACCESS.2017.2783682

Corbett, E., & Le Dantec, C. A. (2018a). Going the Distance: Trust Work for Citizen Participation. *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, 1–13. https://doi.org/10.1145/3173574.3173886

Corbett, E., & Le Dantec, C. A. (2018b). The Problem of Community Engagement: Disentangling the Practices of Municipal Government. *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, 1–13. https://doi.org/10.1145/3173574.3174148

Couldry, N. (2012). *Media, society, world: Social theory and digital media practice*. Polity Press. http://www.politybooks.com/

D'Ignazio, C., & Zuckerman, E. (2017). Are We Citizen Scientists, Citizen Sensors or Something Else Entirely? Popular Sensing and Citizenship for the Internet of Things. In B. S. De Abreu, P. Mihailidis, A. Y. L. Lee, J. Melki, & J. McDougall (Eds.), *International handbook of media literacy education*. Routledge, Taylor & Francis Group.

Duchon, M., Wiesner, K., Müller, A., & Linnhoff-Popien, C. (2012). Collaborative Sensing Platform for Eco Routing and Environmental Monitoring. In F. Martins, L. Lopes, & H. Paulino (Eds.), *Sensor Systems and Software* (pp. 89–104). Springer. https://doi.org/10.1007/978-3-642-32778-0_8

Dunn, P. (2016, September 5). *Open data: How access to public data is growing in Detroit*. Model D. https://www.modeldmedia.com/features/open-data-090516.aspx

Earthwatch. (2020). *FreshWater Watch*. Earthwatch FreshWater Watch. https://freshwaterwatch.thewaterhub.org/

Gabrys, J., Pritchard, H., & Barratt, B. (2016). Just good enough data: Figuring data citizenships through air pollution sensing and data stories. *Big Data & Society*, *3*(2), 205395171667967. https://doi.org/10.1177/2053951716679677

Gordon, E., & Lopez, R. A. (2019). The Practice of Civic Tech: Tensions in the Adoption and Use of New Technologies in Community Based Organizations. *Media and Communication*, *7*(3), 57–68. https://doi.org/10.17645/mac.v7i3.2180

Habermas, J. (1991). *The Structural Transformation of the Public Sphere: An Inquiry into a Category of Bourgeois Society*. MIT Press.

Hansen, N. B., Klerks, G., Menendez Blanco, M., Maye, L., Strohmayer, A., de Waal, M., & Schouten, B. (2020). Making Civic Initiatives Last: Ecosystems, Technologies, Approaches and Challenges. *Companion Publication of the 2020 ACM Designing Interactive Systems Conference*, 433–436. https://doi.org/10.1145/3393914.3395921

Hansson, K., Forlano, L., Choi, J. H., DiSalvo, C., Pargman, T. C., Bardzell, S., Lindtner, S., & Joshi, S. (2018). Provocation, Conflict, and Appropriation: The Role of the Designer in Making Publics. *Design Issues*, *34*(4), 3–7. https://doi.org/10.1162/desi_a_00506

Harding, M., Knowles, B., Davies, N., & Rouncefield, M. (2015). HCI, Civic Engagement & Trust. *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, 2833–2842. https://doi.org/10.1145/2702123.2702255

Hecker, S., Haklay, M., Bowser, A., Makuch, Z., Vogel, J., Bonn, A., Brenton, P., von Gavel, S., Vogel, E., & Lecoq, M.-E. (Eds.). (2018). Technology infrastructure for citizen science. In *Citizen*

Science: Innovation in Open Science, Society and Policy (pp. 63–80). UCL Press. https://doi.org/10.2307/j.ctv550cf2

Hemmi, A., & Graham, I. (2014). Hacker science versus closed science: Building environmental monitoring infrastructure. *Information, Communication & Society*, *17*(7), 830–842. https://doi.org/10.1080/1369118X.2013.848918

Hepp, A., & Loosen, W. (2019). Pioneer journalism: Conceptualizing the role of pioneer journalists and pioneer communities in the organizational re-figuration of journalism. *Journalism*, 146488491982927. https://doi.org/10.1177/1464884919829277

Hsu, Y.-C., Cross, J., Dille, P., Tasota, M., Dias, B., Sargent, R., Huang, T.-H. (Kenneth), & Nourbakhsh, I. (2020). Smell Pittsburgh: Engaging Community Citizen Science for Air Quality. *ACM Transactions on Interactive Intelligent Systems*, *10*(4), 1–49. https://doi.org/10.1145/3369397

Hu, L., Miao, Y., Wu, G., Hassan, M. M., & Humar, I. (2019). iRobot-Factory: An intelligent robot factory based on cognitive manufacturing and edge computing. *Future Generation Computer Systems*, *90*, 569–577.

Kim, S., Robson, C., Zimmerman, T., Pierce, J., & Haber, E. M. (2011). Creek watch: Pairing usefulness and usability for successful citizen science. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 2125. https://doi.org/10.1145/1978942.1979251

Kreide, R. (2016). Digital spaces, public places and communicative power: In defense of deliberative democracy. *Philosophy & Social Criticism*, *42*(4–5), 476–486. https://doi.org/10.1177/0191453715623831

Lambrechts, J., & Sinha, S. (2016). *Microsensing Networks for Sustainable Cities*. Springer.

Latour, B. (2004). Why Has Critique Run out of Steam? From Matters of Fact to Matters of Concern. *Critical Inquiry*, *30*, 24.

Le Dantec, C. A. (2016). *Designing publics*. MIT Press.

Le Dantec, C. A., & DiSalvo, C. (2013). Infrastructuring and the formation of publics in participatory design. *Social Studies of Science*, *43*(2), 241–264. https://doi.org/10.1177/0306312712471581

Le Dantec, C. A., Farrell, R. G., Christensen, J. E., Bailey, M., Ellis, J. B., Kellogg, W. A., & Edwards, W. K. (2011). Publics in practice: Ubiquitous computing at a shelter for homeless mothers. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 1687. https://doi.org/10.1145/1978942.1979189

Liu, C., Balestrini, M., & Vilaza, G. N. (2019). From Social to Civic: Public Engagement with IoT in Places and Communities. In A. Soro, M. Brereton, & P. Roe (Eds.), *Social Internet of Things* (pp. 185–210). Springer International Publishing. https://doi.org/10.1007/978-3-319-94659-7_10

Liu, H.-Y., Grossberndt, S., & Kobernus, M. (2017). Citizen Science and Citizens' Observatories: Trends, Roles, Challenges and Development Needs for Science and Environmental Governance. In G. Foody, L. See, S. Fritz, P. Mooney, A.-M. Olteanu-Raimond, C. C. Fonte, & V. Antoniou (Eds.), *Mapping and the Citizen Sensor* (pp. 351–376). Ubiquity Press. https://doi.org/10.5334/bbf.o

Liu, L. (2018). IoT and A Sustainable City. *Energy Procedia*, *153*, 342–346. https://doi.org/10.1016/j.egypro.2018.10.080

Loosen, W. (2018). Data-Driven Gold-Standards: What the Field Values as Award-Worthy Data Journalism and How Journalism Co-Evolves with the Datafication of Society. In L. Gray & J. Bounegru (Eds.), *The Data Journalism Handbook 2. Towards a Critical Data Practice.* European Journalism Centre and Google News Initiative. https://s3.eu-central-1.amazonaws.com/datajournalismcom/handbooks/The-Data-Journalism-Handbook-2.pdf

Lowrey, W., & Hou, J. (2021). All forest, no trees? Data journalism and the construction of abstract categories. *Journalism*, *22*(1), 35–51. https://doi.org/10.1177/1464884918767577

Lucke, D., Constantinescu, C., & Westkämper, E. (2008). Smart Factory—A Step towards the Next Generation of Manufacturing. In M. Mitsuishi, K. Ueda, & F. Kimura (Eds.), *Manufacturing Systems and Technologies for the New Frontier* (pp. 115–118). Springer London.

Nardi, B., Tomlinson, B., Patterson, D. J., Chen, J., Pargman, D., Raghavan, B., & Penzenstadler, B. (2018). Computing within limits. *Communications of the ACM*, *61*(10), 86–93. https://doi.org/10.1145/3183582

National Audubon Society. (2020). *Frontpage*. Audubon. https://www.audubon.org/frontpage

Nižetić, S., Šolić, P., López-de-Ipiña González-de-Artaza, D., & Patrono, L. (2020). Internet of Things (IoT): Opportunities, issues and challenges towards a smart and sustainable future. *Journal of Cleaner Production*, *274*, 122877. https://doi.org/10.1016/j.jclepro.2020.122877

Pargman, T. C., Joshi, S., & Wehn, U. (2019). Experimenting with Novel Forms of Computing: The case of the Swedish Citizen Observatory for Water Quality Conservation. *Proceedings of the Fifth Workshop on Computing within Limits - LIMITS '19*, 1–10. https://doi.org/10.1145/3338103.3338111

Preece, J. (2016). Citizen Science: New Research Challenges for Human–Computer Interaction. *International Journal of Human-Computer Interaction*, *32*(8), 585–612. https://doi.org/10.1080/10447318.2016.1194153

Raetzsch, C., & Bødker, H. (2016). Journalism and the Circulation of Communicative Objects. *TECNOSCIENZA: Italian Journal of Science & Technology Studies*, *7*(1), 129–148.

Rose, K., Eldridge, S., & Chapin, L. (2015). *The Internet of Things: An Overview* (p. 53). The Internet Society (ISOC).

Schmitz Weiss, A. (2016). Sensor Journalism: Pitfalls and Possibilities. *Palabra Clave - Revista de Comunicación*, *19*(4), 1048–1071. https://doi.org/10.5294/pacla.2016.19.4.5

Schrock, A. (2018). *Civic Tech: Making Technology Work for People* (1st ed.). Rogue Academic Press.

Shibuya, Y., Hamm, A., & Raetzsch, C. (2021, July 13). From Data to Discourse: How Communicating Civic Data Can Provide a Participatory Structure for Sustainable Cities and Communities. *Proceedings of the 27nd ISDRS '21*. International Sustainable Development Research Society Conference, Östersund. http://oxford-abstracts.s3.amazonaws.com/ed49028e-aa20-40f4-a6f4-90d463e1994f.pdf

Singer, J. B. (Ed.). (2011). *Participatory journalism: Guarding open gates at online newspapers*. Wiley-Blackwell.

Soro, A., Brereton, M., & Roe, P. (2018). *Social Internet of Things*. Springer.

Steensen, S. (2018). What is the matter with newsroom culture? A sociomaterial analysis of professional knowledge creation in the newsroom. *Journalism*, *19*(4), 464–480. https://doi.org/10.1177/1464884916657517

Usher, N. (2016). *Interactive Journalism: Hackers, Data, and Code*. University of Illinois Press. https://doi.org/10.5406/illinois/9780252040511.001.0001

Usher, N. (2018). Hacks, Hackers, and the Expansive Boundaries of Journalism. In S. A. Eldridge & B. Franklin (Eds.), *The Routledge Handbook of Developments in Digital Journalism Studies* (1st ed., pp. 348–359). Routledge. https://doi.org/10.4324/9781315270449

Vicari, J. J. E. (2019). *Journalismus der Dinge: Strategien für den Journalismus 4.0*. Herbert von Halem Verlag.

Vlachokyriakos, V., Crivellaro, C., Le Dantec, C. A., Gordon, E., Wright, P., & Olivier, P. (2016). Digital Civics: Citizen Empowerment With and Through Technology. *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*, 1096–1099. https://doi.org/10.1145/2851581.2886436

Wehn, U., & Evers, J. (2014). Citizen observatories of water: Social innovation via eParticipation. *ICT4S-14*, 1–10. https://doi.org/10.2991/ict4s-14.2014.1

Research Design and Outline of the Dissertation

On the context and research fields

Figure 0.2 summarizes the dissertations' conceptual overview and shows how the respective chapters on diverse aspects on civic IoT are interlinked to each other and surrounded by related academic fields. This interdisciplinary dissertation ranges from Human-Computer-Interaction studies to Media and Communication studies. It investigates civic IoT technologies from three subfields' perspectives: (1) computing within limits, (2) civic tech/digital civics, and (3) digital journalism. These three research perspectives are approached by empirical case study designs that follow in the next three chapters. In this chapter, I outline the design of each of the studies.

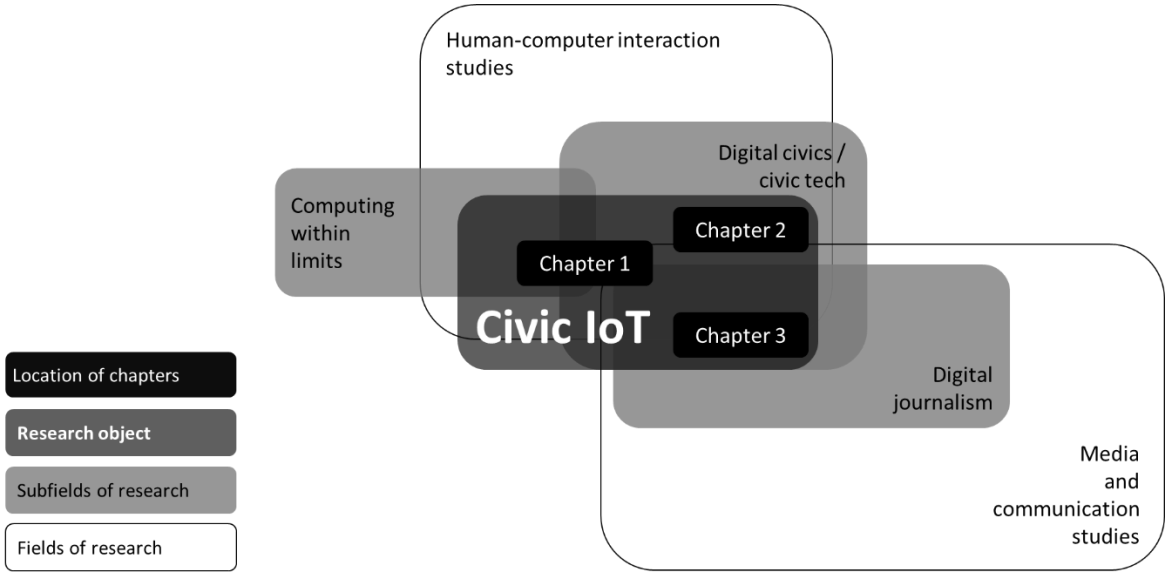

Figure 0.2: Conceptual overview. The figure shows the location of the chapters of this interdisciplinary dissertation and their related fields of study.

On Chapter 1: Civic IoT as a tool for community-based environmental monitoring

The goal of the first study is to better understand how a long-term civic IoT project can contribute to cities and communities becoming more sustainable. This question is posed multidimensionally. Sustainability is here not only understood in an ecological way, for example, in terms of using recycled IoT devices, rather it includes social and political perspectives on environmental monitoring.

The case study of the civic IoT initiative *Luftdaten.info* (in the following called *Luftdaten*, though it has recently been renamed to *Sensor.Community*) is designed at the intersection of IoT, communication, and sustainability research. The three areas, each being a separate research field, are connected to each other since civic IoT *technology* provides the basis for *communication* with the intention to foster a more

sustainable city and community. Luftdaten is an interesting case to study this intersection for three reasons: (1) Luftdaten innovated a relatively easy-to-use IoT device and an open data environment providing both to ordinary people (2) Luftdaten activates ordinary people for a sustainability-related issue while disseminating citizen-sourced data on this contested environmental issue, i.e., air pollution, and (3) Luftdaten's accessible open data has led to a new local media product *Feinstaubradar* disseminating air pollution data and interpretations to a broader audience with the potential to generate larger societal impact.

Analyzing this case allows to make interdisciplinary conclusions from a technology and communication perspective in a context of computing within limits. Air pollution as an environmental topic connects to sustainability questions like public health, clean traffic and production, and low-emission habitation. I explore the potential of technologies to have a greater impact on society while being limited by financial, professional, and material resources.

I applied an exploratory methodology, which means that the initial results led to the decision on the next methodological steps. Such a flexible multi-method design is well suited for young and interdisciplinary research objects, such as civic IoT and computing within limits. The study is divided in multiple sub-considerations addressing different levels of sustainable communities. I first present and discuss the sustainability management of the civic IoT initiative including the question how the project organizes itself, its community, and its technology design within limits of material consumption, energy resource, budget and initial knowledge. Second, I discuss the societal dimension of using civic tech for environmental monitoring of, here, air pollution with particulate matter. This discussion is related the citizens' active participation engagement in matters of common concern. Finally, I analyze and discuss the local media coverage on the air pollution topic as well as the different ways of data visualization for public information. More details on data collection, operationalization, and data analysis can be found in the respective chapter.

On Chapter 2: Civic IoT as an easy-to-use technology for sustained civic engagement

In chapter 2, research from chapter 1 has been extended and contributes to ongoing scientific discussion in the domain of digital civics being part of human-computer interaction studies. A recent research question in this domain is asking about how civic initiatives can be designed to be long-lasting (Balestrini et al., 2014; Hansen et al., 2020; Taylor et al., 2013). As the two cases exist since several years and manage to stay relevant for their communities and the public, they are suitable cases for an in-depth analysis of this question. The goal of this second study is to extract common key factors that have contributed to the longevity and continuous relevance of the two initiatives for their respective communities and the public.

Luftdaten and *Safecast* are suitable cases to approach the research question "What makes civic tech initiatives to last over time?" because both initiatives reached large international scale in terms of community members and measurement stations. Luftdaten was founded in 2015 and installed 13,000 with over 10 billion data points in 73 countries (Sensor.Community, 2020). Luftdaten mobilized thousands of people worldwide to be engaged against air pollution and emerged from a Code for Germany campaign by the Open Knowledge Foundation from which it became an independent organization. The Japan-based case Safecast is dedicated to radioactivity pollution and has been founded in the aftermath of the Great East Japan Earthquake in 2011 which caused the Fukushima Dai-ichi nuclear disaster turning large areas of living inhabitable. Safecast was founded in 2011 and installed 5,000 sensor stations with more than 150 million data points in 102 countries as of Dec, 2020 (Safecast, 2020). The cases were selected due to their long-term existence, both were already been recognized in academia (see for example Blon, 2017; A. Brown et al., 2016; D'Ignazio & Zuckerman, 2017). The two civic tech initiatives continuously managed to be part of public discourses to which they are contributing open data and interpretations on their respective environmental issue.

It is particularly interesting to complementing both cases with each other. They show several similarities, in particular, innovating civic IoT technology in the domain of environmental monitoring, relying on volunteers and engagement, and tackling a local matter of common concern. Though both being located in democratic OECD countries, the cases differ with regard to socio-cultural, geographic, and political contexts in Germany and Japan as well as the respective public discourses related to air pollution and radioactivity pollution. The study has been carried out by a German-Japanese team of researchers being able to qualitatively analyze the Germany- and Japan-based cases.

We have conducted two exploratory multi-method case studies on the civic tech initiatives to understand the particularities that have led to their longevity. We applied a mixed methods design to integrate qualitative and quantitative findings and leverage each method's strength while verifying and converging them (Greene et al., 1989; Schoonenboom & Johnson, 2017). We quantitatively mapped the cases' sustainability over time by conducting a social network analysis of Twitter data per year of unique hashtags and accounts.

In addition, we conducted several qualitative methods to understand better the activities, actions, motivations, expectations, identities, and transformations of the initiatives studied. We analyzed two transcribed expert interviews with core team members of Luftdaten and Safecast. We further reviewed snowball-sampled online materials, such as blog entries, media articles, project websites, research papers, that would help to illustrate the backgrounds and contexts of both initiatives. Finally, we conducted a structuring qualitative content analysis (QCA) of the initiatives historical Twitter communication dating back to 2011 and 2015 allows to understand the discussion topics and community interactions over time. We complemented results from the Twitter data with the core team interview data which allows to interpret today data captured in the past. In this way, we conduct a retrospective

longitudinal study which are recommended as research design for studying scaling systems (B. Brown et al., 2017, p. 30).

More details on data collection, operationalization, and data analysis can be found in the respective chapter.

On Chapter 3: Civic IoT as an enabling technology for the Journalism of Things

Chapter 3 comprises a multi-case study of three award-winning German journalism projects that emerged in the Journalism of Things (JoT) community. JoT strongly relates to the notion of civic IoT as it represents the use of IoT technology by journalists to carry out their journalistic profession in a new way and as a response to increasingly networked societies. A group of German journalists have founded the "Journalism of Things" (JoT) and signed a same-named manifesto in 2019. Several JoT projects conducted by these journalists won journalism awards and represent examples of establishing fields of pioneering journalism providing "imaginaries of new possibilities" (Hepp & Loosen, 2019, p. 5; Loosen, 2018).

The goal of this third and last study is to understand innovation practices in JoT and how objects in JoT, particularly IoT technologies, are entangled with new boundaries of journalism, knowledge, and power in journalism. I use a grounded theory approach to answer which new innovation practices emerge in JoT and what kind of phases and practices of boundary work can be observed. Further, the study connects to current debates in international journalism studies around broader implications of the IoT objects on journalism practice, audience and society, and power relations (Anderson & De Maeyer, 2015; Moran & Usher, 2021).

The selected cases are shortly named the air case, the bees case, and the cyclists case. All of them apply civic IoT technology, crowdsourcing, and co-creation practices aiming at producing new kinds of stories for matters of common concern, namely air pollution, insect mortality, and bicycle safety. The cases show elements of sensor journalism, data journalism, and participatory journalism.

The air case is the project Feinstaubradar (english: 'fine dust radar') by Stuttgarter Zeitung. This study on the air case connects to what has been researched in chapter 1. Here in chapter 3, I conceptualize the local air pollution data map and the application as tools for digital journalism intending to balance the public debate through more precise knowledge dissemination. The database for the digital journalistic products derives from the open data by Luftdaten, which is collecting air pollution values through a volunteer community of citizens. Feinstaubradar was implemented in 2017 to transparently share air pollution data and to inform about technical issues of sensors. Feinstaubradar enriched the available public information on air pollution by merging three different datasets, i.e., from Luftdaten, the local authorities, and private weather stations. The JoT project won the 2017 German Local Journalists Award in the category Data Journalism.

The bees case is the project *Bienenlive* (english: 'bees live') which aims at raising awareness for insect mortality through monitoring beehives. This experimental journalistic project started 2018 and was planned in context of increasing bee mortality in Germany. Journalists equipped beehives from volunteering beekeepers with multiple sensors and a 360° camera to collect unique data on the insects which they could leverage for new kinds of journalistic outputs. Next to being broadcasted in more traditional ways on *WDR* TV and radio programs, the data story was disseminated via an educational website including three blogs and journalists created WhatsApp conversations "with" three queen bees. Together with the IoT data, Bienenlive disseminated research articles on insects and service news on bee-friendly places and behaviors. The JoT project won the 2019 German Reporter Award in the category Multimedia.

The cyclists case is the project *Radmesser* (english: 'bike meter') that investigated traffic safety through crowdsourced data collection from local cyclists. The project affiliated with the Berlin-based national newspaper *Tagesspiegel* was conducted in 2018. Two temporarily employed scientists innovated together with journalists ultrasonic IoT devices. Attached to bicycles, these IoT devices measured the distance between bicycles and passing cars. Being passed too closely by cars on the road constitutes one of the biggest threats to cyclists (Raetzsch & Brynskov, 2018).The project involved 100 volunteers from the newspaper's to collect passing distance data while cycling through the city. The data was scientifically analyzed and journalistically prepared. The new data on bicycle safety was disseminated together with a more general data journalistic story on bicycle traffic in Berlin, a large survey on urban bicycle riding. The JoT project won the 2018 German Reporter Award for Data Journalism.

I applied an open, exploratory research design using grounded theory for analyzing the collected material (Strauss & Corbin, 1998, p. 12f.). I conducted semi-structured interviews with the journalists leading these three JoT projects, qualitative analyses of related media articles, web applications and non-public documents, and observations of public journalistic events. Such multiple-case study design is especially appropriate in new topic areas (Eisenhardt, 1989). The three cases provide a sufficient database to make empirically-based assumptions on implications of civic IoT on work and practices in journalism, in particular, digital journalism.

More details on data collection, operationalization, and data analysis can be found in the respective chapter.

On the concluding chapter

In the conclusion, I summarize the findings of this dissertation and discuss their implications in a broader context. Further, I consider the limitations and suggest ideas for future research within the interdisciplinary field of civic IoT.

All in all, this dissertation advances current understandings of the technological object *civic IoT* with regard to its societal implications. This knowledge can be abstracted when discussing digital technology's use for social change, digitalization, and sustainability transformation in more general. Each of the chapters contributes to a particular field of research, i.e. computing within limits, digital civics, and digital journalism, of which I believe they are key for understanding the role of civic IoT for society.

The first study is examining a large-scale civic IoT initiative seeking to disseminate new knowledge on air pollution by applying participatory design and reaching a large visibility via local media. This study opens usual foci of the computing within limits community on material and energy consumption of computing towards a more discursive perspective of using limited technologies for setting particular topics on the local public agenda potentially leading to regulatory and behavioral changes.

The second study extracts key factors for long-living and continuously relevant civic IoT initiatives by investigating insightful cases from Germany and Japan. The key factors show the importance of being engaged in diverse sectors and areas of actions. This study is innovative because it combines the technological study with the study of communicative strategies and outputs of the community. The revealed key factors particularly contribute to scientific discussions on sustained digital civics in the field of human-computer interaction.

The third study takes a look at projects in digital journalism leveraging civic IoT technology. I discuss how JoT leads to new boundaries of journalism and demands new collaborative arrangements. Further it is essential that to learn about the novel practices of journalists when they start capturing the data for their stories by themselves to evaluate their meaning and impact for the societal role of journalism.

Finally, it becomes apparent that the question how civic IoT impacts people and society cannot be answered in one field of research. The challenge for researchers is to approach such question from multiple directions to receive a sufficient understanding. Consequently, this dissertation provides further steps into this interdisciplinary groundwork.

References

Anderson, C. W., & De Maeyer, J. (2015). Objects of journalism and the news. *Journalism*, *16*(1), 3–9. https://doi.org/10.1177/1464884914545728

Balestrini, M., Bird, J., Marshall, P., Zaro, A., & Rogers, Y. (2014). Understanding sustained community engagement: A case study in heritage preservation in rural argentina. *Proceedings of the 2014 CHI Conference on Human Factors in Computing Systems*, 2675–2684. https://doi.org/10.1145/2556288.2557323

Blon, M. (2017). *Untersuchungen zur Messung von Feinstaub Das Citizen Science Projekt luftdaten.info* [Hochschule Esslingen]. https://www.bund-neckar-alb.de/fileadmin/neckaralb/MasterarbeitBlonFeinstaubmessungimVergleich2017.pdf

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

Brown, B., Bødker, S., & Höök, K. (2017). Does HCI scale?: Scale hacking and the relevance of HCI. *Interactions*, *24*(5), 28–33. https://doi.org/10.1145/3125387

D'Ignazio, C., & Zuckerman, E. (2017). Are We Citizen Scientists, Citizen Sensors or Something Else Entirely? Popular Sensing and Citizenship for the Internet of Things. In B. S. De Abreu, P. Mihailidis, A. Y. L. Lee, J. Melki, & J. McDougall (Eds.), *International handbook of media literacy education*. Routledge, Taylor & Francis Group.

Eisenhardt, K. M. (1989). Building theories from case study research. *Academy of Management Review*, *14*(4), 532–550.

Greene, J. C., Caracelli, V. J., & Graham, W. F. (1989). Toward a Conceptual Framework for Mixed-Method Evaluation Designs. *Educational Evaluation and Policy Analysis*, *11*(3), 255–272.

Hansen, N. B., Klerks, G., Menendez Blanco, M., Maye, L., Strohmayer, A., de Waal, M., & Schouten, B. (2020). Making Civic Initiatives Last: Ecosystems, Technologies, Approaches and Challenges. *Companion Publication of the 2020 ACM Designing Interactive Systems Conference*, 433–436. https://doi.org/10.1145/3393914.3395921

Hepp, A., & Loosen, W. (2019). Pioneer journalism: Conceptualizing the role of pioneer journalists and pioneer communities in the organizational re-figuration of journalism. *Journalism*, 146488491982927. https://doi.org/10.1177/1464884919829277

Loosen, W. (2018). Data-Driven Gold-Standards: What the Field Values as Award-Worthy Data Journalism and How Journalism Co-Evolves with the Datafication of Society. In L. Gray & J. Bounegru (Eds.), *The Data Journalism Handbook 2. Towards a Critical Data Practice*. European Journalism Centre and Google News Initiative. https://s3.eu-central-1.amazonaws.com/datajournalismcom/handbooks/The-Data-Journalism-Handbook-2.pdf

Moran, R. E., & Usher, N. (2021). Objects of journalism, revised: Rethinking materiality in journalism studies through emotion, culture and 'unexpected objects.' *Journalism*, *22*(5), 1155–1172. https://doi.org/10.1177/1464884920985730

Raetzsch, C., & Brynskov, M. (2018). *Challenging the Boundaries of Journalism through Communicative Objects: Berlin as a Bike-friendly City and #Radentscheid*. https://futuremaking.space/challenging-boundaries-journalism-communicative-objects-berlin-bike-friendly-city-radentscheid/

Safecast. (2020). *Safecast*. Safecast. https://safecast.org/

Schoonenboom, J., & Johnson, R. B. (2017). How to Construct a Mixed Methods Research Design. *KZfSS Kölner Zeitschrift Für Soziologie Und Sozialpsychologie*, *69*(S2), 107–131. https://doi.org/10.1007/s11577-017-0454-1

Sensor.Community. (2020). *Build your own sensor and join the worldwide civic tech network*. https://sensor.community/en/

Strauss, A. L., & Corbin, J. M. (1998). *Basics of qualitative research: Techniques and procedures for developing grounded theory* (2nd ed). Sage Publications.

Taylor, N., Cheverst, K., Wright, P., & Olivier, P. (2013). Leaving the wild: Lessons from community technology handovers. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 1549. https://doi.org/10.1145/2470654.2466206

Chapter 1: Civic IoT as a tool for community-based environmental monitoring

This chapter was published as:

Hamm, A. (2020). Particles Matter: A Case Study on How Civic IoT Can Contribute to Sustainable Communities. In: *Proceedings of the 7th International Conference on ICT for Sustainability* (ICT4S 2020), June 21 - 26, 2020, Bristol, UK. ACM, NY, USA. https://doi.org/10.1145/3401335.3401815 (peer-reviewed)

Chapter 2: Civic IoT as an easy-to-use technology for sustained civic engagement

This chapter was published as:

Hamm, A.; Shibuya, Y.; Ullrich, S., & Cerratto Pargman, T. (2021). What Makes Civic Tech Initiatives To Last Over Time? Dissecting Two Global Cases. In: Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI '21), May 8–13, 2021, Yokohama, Japan. ACM, New York, NY, USA. https://doi.org/10.1145/3411764.3445667 (double-blind reviewed)

What Makes Civic Tech Initiatives To Last Over Time? Dissecting Two Global Cases

Andrea Hamm
Weizenbaum Institute / Technical University Berlin
Berlin, Germany
andrea.hamm@tu-berlin.de

Yuya Shibuya
The University of Tokyo
Tokyo, Japan
yuya-shibuya@iii.u-tokyo.ac.jp

Stefan Ullrich
Weizenbaum Institute / Technical University Berlin
Berlin, Germany
stefan.ullrich@tu-berlin.de

Teresa Cerratto Pargman
Stockholm University
Stockholm, Sweden
tessy@dsv.su.se

ABSTRACT

Civic tech initiatives dedicated to environmental issues have become a worldwide phenomenon and made invaluable contributions to data, community building, and publics. However, many of them stop after a relatively short time. Therefore, we studied two long-lasting civic tech initiatives of global scale, to understand what makes them sustain over time. To this end, we conducted two mixed-method case studies, combining social network analysis and qualitative content analysis of Twitter data with insights from expert interviews. Drawing on our findings, we identified a set of key factors that help the studied civic tech initiatives to grow and last. Contributing to Digital Civics in HCI, we argue that the civic tech initiatives' scaling and sustaining are configured through the entanglement of (1) civic data both captured and owned by the citizens for the citizens, (2) the use of open and accessible technology, and (3) the initiatives' public narrative, giving them a voice on the environmental issue.

CCS CONCEPTS

• **Human-centered computing → Empirical studies in HCI**.

KEYWORDS

Civic Tech, Digital Civics, Civic IoT, Scaling, Citizen Science, Sustainability

ACM Reference Format:
Andrea Hamm, Yuya Shibuya, Stefan Ullrich, and Teresa Cerratto Pargman. 2021. What Makes Civic Tech Initiatives To Last Over Time? Dissecting Two Global Cases. In *CHI Conference on Human Factors in Computing Systems (CHI '21), May 8–13, 2021, Yokohama, Japan.* ACM, New York, NY, USA, 17 pages. https://doi.org/10.1145/3411764.3445667

CHI '21, May 8–13, 2021, Yokohama, Japan

ACM ISBN 978-1-4503-8096-6/21/05.
https://doi.org/10.1145/3411764.3445667

1 INTRODUCTION

This paper investigates the emergence and sustained development of civic initiatives that use the Internet of Things (IoT) (i.e., sensors and applications) and related sensing, information, and communication technologies to improve community services, civic engagement, and citizens' quality of life. Such initiatives, here called civic tech initiatives [78], dedicated to social or environmental issues have become a worldwide phenomenon and made various invaluable contributions in terms of data [31, 32, 52, 66], community building [23, 58], and outreach [59, 82]. Meijer and Potjer [64] and Lui et al. [61] illustrated prominent examples of such initiatives. Yet, despite implementing user-centered technologies and applications, such technologies' sustained use remains low [41], and civic initiatives are often only short-lived [39, 61]. Two streams of empirical research in HCI have focused on this issue: (1) studies about the design, development, and use of civic technologies for citizen engagement and participation via data [24–26, 28, 41, 56, 57] like citizen science initiatives [29, 37, 52, 71] and (2) studies investigating the evolution of civic tech initiatives [5, 80] like studies on scale and scaling of community engagement [11, 20].

Drawing on previous work on Digital Civics in HCI, this paper explores what makes globally active civic tech initiatives sustain over time [5, 61, 80] to identify factors that ensure the long-lasting use of civic technologies and the evolution of the initiative. Knowledge about such factors may lead to a deeper understanding of the challenging and dynamic design space of Digital Civics [56, 81].

We report on a Civic IoT research project consisting of two case studies: Luftdaten, an initiative dedicated to particulate matter, and Safecast, dedicated to radiation. We have chosen to investigate these initiatives as they emerged in 2011 and 2015, respectively. Both initiatives reached a global scale while being maintained in two cities in Europe and Asia. Luftdaten includes more than 8,000 volunteers from 73 countries [79] and counts over 13,000 sensors installed worldwide. Safecast has a community of 5,000 volunteers from 102 countries and more than 5,000 sensors installed worldwide [76] (all data as of Dec 2020).

These two initiatives are issue-specific and so-called bottom-up, i.e., non-governmental and community-based organizations driven by sensor technology use, participatory design, and open data visualization. Both initiatives have assembled their own sensing devices

and provide their community members with easy-to-use tools. Furthermore, they both have engaged and still continue to engage citizens to capture and provide large amounts of Open Data, which are shared and visualized in a publicly available, browser-based map. Both initiatives are grounded in the volunteer work of people passionate about the role that technologies can play in addressing matters of civic concern and bringing about change in society [49]. As such, the initiatives here studied have not been initiated or designed by HCI researchers/designers.

We investigated these two civic tech initiatives using interviews conducted with their core team members to get insights into the initiatives' emergence and growth. We also collected and analyzed historical Twitter data by performing social network analyses and qualitative content analysis to understand better the intricacies of the community members' interaction and communication with the general public. We completed the study with a review of online and public materials, e.g., media articles and blog posts, which help to identify challenges and changes illustrating the dynamic character of the initiatives investigated.

In contrast to previous works, e.g., [5, 45, 80], we did not conduct action research [42] as we were not engaged in the design of any part of the initiative's development. Our work firstly contributes an in-depth understanding of how the civic tech initiatives examined managed to remain relevant to the public while keeping their community activated and their technologies running. Secondly, from the quantitative and qualitative data collected, we identify a set of key factors contributing to the development of long-lasting civic tech initiatives. We finally discuss our findings regarding current HCI studies on civic data, open civic tech, public narratives, and critical HCI scholarship on empowerment and power structures.

2 RELATED WORK

2.1 Civic Tech, Digital Civics, and Citizen Science

The notion of civic tech [78] (short version of "civic technologies") describes the use of technologies for civic purposes and was initially proposed by the Knight Foundation [69]. Civic tech initiatives allude to socio-technical arrangements in which technologies such as the Internet of Things (IoT) and data are put at the service of citizens and communities. They attempt to bring citizens (i.e., groups, communities, the general public) and authorities together to discuss matters of common concern [54, 61]. Such socio-technical arrangements have lately caught the attention of the HCI research community, which has, over the past years, showed an increasing interest in the design of digital technologies [78], for infrastructuring civic participation [58], and the formation of publics [40, 56]. Particularly, studies contributing to unpack the design space of Digital Civics [25, 26] have enabled to address "the needs of both citizens and civic authorities and helps establish trusted relationships between these different stakeholders." [41] (p. 2833)

By fostering democratic design models valuable for both citizens and local governments, the field of Digital Civics investigates how dynamic relational models embedded in the design of civic technologies can potentially "reconfigure power relations between citizens, communities and the state." [81](p. 1096)

For instance, Corbett and Le Dantec [25, 26] focusing on community engagement, have insightfully pointed out that communication between citizen stakeholders can also be understood from a set of everyday practices and goals that go beyond rigid transactions of service delivery. In this sense, these authors contribute to show the broader terrain of day-to-day challenges and breath of practices that makes up community engagement and informs the design of supporting technologies that mediate such practices and enable community goals [26].

We see strong ties between the design and scholarship of civic tech in Digital Civics and studies on citizen-supported environmental monitoring and citizen science [29, 37, 52, 71]. Likewise, to the aim pursuit by digital civics research and design practice, the produced local knowledge contributed by citizen science projects can be used for negotiating matters affecting their communities [46, 72]. More specifically, citizen science projects involving citizen-sensed data resonate with the civic tech initiatives we have studied concerning the value given to the data captured and shared by the involved citizens. For instance, previous works discussed the importance of citizen science data in terms of re-using shared data [83], for policy formulation and implementation [65]. Although, "citizen science data" is often criticized concerning data quality and the value of citizen participation for science, e.g. [67], citizen-sensed data can be "just good enough" [34], when the data primarily serves a civic purpose, e.g., awareness-raising or effecting changes. From this particular perspective, the primary value of citizen sensed data is that previously there has not been any data on a particular socio-environmental issue in a particular geographical place [34]. On this note, recent conceptions of "good enough" [34] or "imperfect" data [4] that are leveraged for civic purposes emphasize the potentials of citizen sensing data for public information and discourse [38], raising public awareness [34], civic action [13], or social change [4].

By studying Luftdaten and Safecast, we are dissecting these broader contexts of actors, tools, resources, knowledge, and discourses in which civic tech initiatives can emerge and last. In particular, in this paper, we focus on issues concerning the evolution of civic tech initiatives and how they sustain over time as those are still under-researched questions for the field of Digital Civics [39, 56, 81]. In doing so, we engage in the following section with previous work discussing sustained use of civic tech in relation to issues of scale and scaling.

2.2 Sustained Use of Civic Tech

Works focused on the sustained use of technologies for civic participation and why civic tech initiatives last are not easy to find, although several HCI studies [5, 41, 48, 57, 62, 80] and recent efforts in HCI [39, 74] touch upon these issues.

Analyzing the design of technologies with the involvement of communities, Taylor et al. [80] examined what steps were taken to ensure the long term viability of the deployment and what happened during the technology handover. In this context, Taylor et al. [80] contribute knowledge about how to plan and execute technology handovers when researching with communities. In detail, these authors refer, for instance, to the role played by the expectation management, the tensions around experimental technology, the

importance of iterative development, creating skills, and reaching mutual agreement [80] (p.1555f.). These insights serve, among others, to draw attention to both civic design and research aspects that inevitably configure the long life of the technology-use in the communities involved [14]. In this respect, Johnson and colleagues discussed the importance of an inclusive civic discourse and how ownership and giving control to the community positively affect the project's evolution [48].

In this light, Manuel and Crivellaro emphasize the need for a new approach enabling "citizens to use existing open-source tools developed in HCI to create a more sustainable long-term impact" [62] (p. 10). As such, these authors argue for providing open tools and documentation, so designers can support citizens and civic actors to tackle their civic purposes by technology. From this perspective, Manuel and Crivellaro point to how openness can contribute to community ownership and sustainable civic tech [62].

Moreover, it is the community's ecosystem and its social context that seems crucial for the sustainability of civic tech initiatives [23]. Balestrini et al. [5] provide a broader view of civic initiatives that includes local governments, the media, and schools. These works [5, 62] are of particular importance to our study. They help to understand the various challenges that emerge when designing civic tech interventions with communities and for the communities. We draw upon this work to shed light on factors involved in the long-term impact and sustainability of socio-technical innovations [74].

2.3 Scale and Scaling

Issues of long-term impact and sustainability of civic tech initiatives are often discussed in terms of scale that points to "how technology is used in large networks of interconnected systems, with billions of users, across diverse contexts" [20] (p. 29). Moving on from "scale," recent work has emphasized "scaling" taking into account "the variety of practices, along with the role of human and non-human agents, that contribute to the ways local initiatives proliferate across contexts and over time" [74]. In this respect, a simple "growth" in terms of user numbers or copy-pasting of technologies to other contexts falls too short. Especially bottom-up initiatives would rather work towards lasting collaborations than towards high quantities [74]. Such a lens on scale requires addressing whole infrastructures and artifact ecologies to move beyond more superficial analyses of singular systems and designs [20] (p. 30).

In that connection, Biørn-Hansen and Håkansson's [11] study on scaling up change in community organizations identifies three stages of scaling up change by distinguishing: the "sustaining" stage that refers to a relatively fixed implementation of an initiative's working routine and practice; the "growing" stage, that alludes to setting up and upgrading the technological infrastructure for a volunteer community, and the "spreading" stage that points to generating and distributing new skills and knowledge [11]. In particular, this work contributes to understanding that ICTs can play a role in each of such respective phases by: infrastructuring generic designs by allowing a range of future services in a community; supporting the long-term knowledge generation and practices so people meet and learn together, and "accepting that scaling up is not always the point" [11] (p. 10).

2.4 Summary of the Related Work

In sum, there is a significant body of work in HCI investigating the design, development, and use of civic technologies for citizen engagement and participation via data, and an increasing interest in the long-lasting of civic tech initiatives. However, little is still known about the sustained use of technologies in civic tech initiatives that have managed to grow globally and remain relevant for the involved citizens for a long time (i.e., more than five years). We argue this knowledge gap is essential to address in HCI. Longitudinal analyses of long-lasting communities involving multiple networks of actors and technologies are central to deepen our current understanding of the role that open data and open technologies play in the scaling and sustaining of civic tech initiatives [20].

3 METHODOLOGY

3.1 Case Selection

This paper presents empirical findings collected on two long-living civic initiatives Safecast and Luftdaten. We aim to understand the particularities of Safecast and Luftdaten. We have selected the cases due to their longevity (9 years of Safecast and 5 years of Luftdaten) and their global dimension (Luftdaten.info installed 13,000 sensor stations with more than 10 billion data points in more than 73 countries and Safecast 5,000 with more than 150 million data points in over 102 countries; as of Dec, 2020 [76, 79]). An unsystematic media review has identified the cases because many media reported thoroughly about them. We chose these particular cases due to several apparent similarities like environmental monitoring, sensor technology usage, citizen science, and civic engagement.

We are not part of the cases' core teams or broader communities and conducted non-participatory, observatory, and descriptive research.

3.2 Methods

To reach a more comprehensive view of the cases, we apply mixed methods by complementing each qualitative and quantitative data and method's strength, verifying and converging each method's results [35, 77].

First, we quantitatively show evidence of their sustainability over time. In detail, by using the Python package NetworkX, we conducted a social network analysis of Twitter data per year of the hashtags: #luftdaten, #airrohr, #safecast, and of the Twitter accounts @luftdaten, @airrohr, @SafecastJapan and @safecast. "Airrohr" means in English "airpipe" and is the given name to the air pollution sensor kit. The data has been crawled via the Twitter API.

Next, we applied several qualitative methods to understand better the activities, actions, motivations, expectations, identities, and transformations of the studied initiatives. More specifically, we conducted the following analyses:

- a structuring qualitative content analysis (QCA) on the API-crawled Tweet data of Twitter accounts @luftdaten (3205 Tw.), @airrohr (1098 Tw.), @safecast (2805 Tw.), @safecastjapan (1065 Tw.).
- a theme analysis of two transcribed interviews with core team members, i.e.,

  - with a Luftdaten admin (1h25min) who is a founder of the initiative and manages the database and the network infrastructure
  - with a Safecast admin (1h) who is a founder of the initiative and manages the initiative's global activities
- a review of snowball-sampled online materials (e.g., blog entries, media articles, project websites, research papers) for additional details which are helping us to illustrate the backgrounds of Safecast and Luftdaten

We drew upon Kieslinger et al. [51] for the design of the interview questionnaire, which provided valuable information on how to assess citizen-based projects for societal usefulness. The questionnaire covered different sections, including outreach, facilitation, and communication, collaboration and synergies, citizen participation, long-term planning and adaptive project management, philosophies/policies (e.g., being a platform/ transparency/ de-stigmatization). Example questions from the core team interviews are:

- How would you describe your volunteer community? Has the community evolved over the years?
- How did/does your initiative cooperate with established institutions (i.e., local government, media)? Who approaches whom?
- What are the target societal outcomes of your initiative? Have they changed over time?
- Do you see your initiative as a political actor?

When surveying people today about events that happened several years ago, interviewees might forget or reframe things from the past. For this reason, we believe that it is essential to complement the interviews conducted today with the core team with data captured in the past. In this vein, we decided to analyze historical social media data since it portrays the temporal dimension of the initiatives. In other words, by gathering social media data via API, we were able to analyze data going back from today to 2011. In this way, we conduct a retrospective longitudinal study that was suggested as a research design for studying scaling systems [20] (p. 30).

Among all of the initiatives' social media accounts, we decided to analyze their communications on Twitter for the following three reasons:

First, a comparison of Luftdaten's and Safecast's social media accounts shows that they have the highest follower numbers on Twitter compared to Facebook, Instagram, Vimeo, or LinkedIn. We assumed that the higher the follower number, the more people are targeted and reached by the initiatives' communication, and also the larger is the part of the initiatives' community that can be found on this particular platform.

Second, when accessing their Twitter feeds, we noticed that both initiatives' extensively used Twitter for their communication with the community and also the broader public and particular actors. We observed more interactions in terms of comments, sharing, or liking on Twitter than on the other platforms. Further, we could trace here the broader ecosystem of the initiative that possibly contributes to its sustainability, e.g., we saw that Luftdaten is retweeting messages from the World Health Organization (WHO), or from CNN and BBC to connect to international public discourses on air pollution.

Third, the interviewed core team members highlighted the importance of the Twitter platform for Luftdaten's and Safecast's evolutions, in particular, to recruit members, openly communicate their technological developments, and grow their communities in later phases.

The Twitter platform has certain advantages as a communication tool for civic tech initiatives. It has a lower barrier comparatively with for example, Facebook, Instagram, or Pinterest platforms, which ask people to register to read the contents. When the initiatives were founded (i.e., 2015 and 2011), Twitter was already a popular platform while others such as Instagram were not yet so wide-used in 2011. In Japan, Twitter was an essential communication tool during the Fukushima disaster [3].

3.3 Data Analysis

The data analysis was carried out by two of the four authors collectively and recursively. First, we created social network graphs of the Tweet data from account creation until 2019-12-31. Nodes of each graph were colored based on the Louvain community detection algorithm, which extracts the community structure of large networks by evaluating how much more densely connected the nodes within a community are, compared to how connected they would be in a random network [12]. We visualized the Retweet networks per year and received nine network graphs for Safecast (founded in 2011) and five network graphs for Luftdaten (founded in 2015). By comparing the yearly network graphs, we observed how the initiatives have grown over time and became sustained in their social media communication and networking. Retweet networks helped understand how effectively the initiatives reached out to the public and their community. In particular, being retweeted by Twitter accounts that have more followers would increase the initiatives' visibility.

For the structuring QCA, we directly accessed the Twitter pages and analyzed the Tweets manually within the Twitter environment (from account creation until 2019-12-31); older Tweets have been collected via the Twitter API and analyzed within a spreadsheet. We built categories and subcategories inductively from these Tweets by a systematic interpretative structuring of the contents [63] (p.63f.). We focussed on the categories that would help to explain the initiatives' longevity and sustainability. The goal of the qualitative analysis was to gain a more profound knowledge of the two initiatives by reading through their Tweeting activities and better understanding their evolution and linkages to other societal actors. In this way, Twitter gives us access to the initiatives' long-term activities and practices and functions like a documentary tool. Non-English data was translated by this study's authors, whose native languages include German and Japanese. Other languages occurring in the analysis have been translated with the help of DeepL. A sufficient and thorough category system gained from the material was the criteria for closing-off the QCA.

Still, we are aware that the Twitter analysis conducted in our study may not include all voices of people contributing to the civic tech initiatives' development (see Limitations for details). Subsequently, the transcripts of the interviews have been analyzed by theme analysis [63](p.104ff.). Based on the category system that we have constituted in the previous analysis of the Tweet contents,

we have read the interview transcripts several times to select those details that elaborate on the categories identified.

Finally, we interpreted the data on a more abstract level. We extracted the factors to make both cases to last over time from the vast data we collected. Doing so, we first extracted factors from each case, then we contrasted them and discussed their similarities collectively until the material was saturated. From those similarities, a set of key factors emerged.

3.4 Research Ethics and Positionality

The study's authors' positionality is essential for understanding and contextualizing a research paper [7]. Our international team of authors, in terms of nationalities and cultures, includes researchers with backgrounds from the cases' respective countries. We all care deeply about the social and ecological environment of the planet and are particularly interested in understanding the role that technology and data can play in bringing about change in society.

We are also aware of the resourceful economic statuses of Germany and Japan that are most likely reproducing certain privileges on the here-emerged civic initiatives compared to initiatives emerging in less privileged countries. We will address this particularity in the Discussion section.

To address ethical concerns, we asked the operators of the Twitter accounts for permission to analyze their public contents for this study, which they granted us. The initiatives' core teams are aware of our non-participatory, observatory study on the initiatives and appreciate that we selected their initiatives as research objects. For this reason, we decided to deanonymize the civic tech initiatives' names. Another reason is that both initiatives are already largely covered by domestic and international media, which is also why we found the cases. However, the names of the core team, community members, Twitter users remain anonymized.

3.5 Organization of the Results

The following sections present the results obtained from the analysis of Luftdaten and Safecast. As presenting results from two cases is always a challenging task, we follow the structure suggested by Taylor et al. [80]: We present each case separately before summarizing the results from both cases. In particular, we first introduce the initiative's background based on the review of additional online materials, and afterward, we illustrate the empirical results. The quantitative results build on the social network analysis, while the qualitative results build on the content analyses of the interviews and all Tweet data from the Twitter accounts of Safecast and Luftdaten. We structure the qualitative results according to apparent phases similarly illustrated in Biørn-Hansen and Håkansson [11].

In particular, we organize the qualitative results into three phases we have identified as emergence, growth, and sustaining. The transition from emergence to growth and sustaining is clearly defined here by the point in time when established institutions apply the initiative's data. However, growth and sustaining phases appear to be more intermingled and partly parallel. Growth is somewhat related to the amount of data, the impact, the community size and activity, and sensors installed. Whereas, the sustaining phase refers to an established network of collaboration partners, continuous funding, and other achievements that facilitate the initiative to last. Nevertheless, there can be further growth after the sustaining phase is achieved, or the initiative can grow during the sustaining phase.

4 CASE STUDY 1: LUFTDATEN.INFO

4.1 Background

Luftdaten.info (https://luftdaten.info/) is a project founded within the Code for Germany Program of the Open Knowledge Foundation in 2015. Luftdaten.info is dedicated to measuring particulate matter (PM), i.e., particles of, e.g., rubber, liquids, and dust that remain suspended in the air. On their website, we read that they identify with Citizen Science and Open Data. The civic initiative created a do-it-yourself sensor kit for about 30 EUR and started to capture PM data first in Stuttgart, later in Germany and worldwide. To communicate their data, they set up the Luftdaten map, where PM values are displayed as colored hexagons (https://maps.sensor.community/ - Luftdaten has recently been renamed to "Sensor Community"). The initiative's creative head is a communication designer who, like other core team members, has a personal motivation for cleaner air in Stuttgart [33]. The initiative was highly covered by German media and even by international media (https://luftdaten.info/presse/). Luftdaten has emerged in an already heated public discussion on air pollution, culminating after a reprimand from the EU commission. The EU commission threatened Stuttgart's government with a lawsuit before the European Court of Justice if the Stuttgart citizens are not effectively protected from the too-high PM concentrations [84]. From the beginning, Luftdaten provides their PM data as Open Data in an open archive (at https://archive.sensor.community/). Since 2017, the local news medium Stuttgarter Zeitung implemented its own PM data map sourced by Luftdaten PM data (https://www.stuttgarter-zeitung.de/feinstaub) and makes the data directly available for their readership on the medium's website.

Luftdaten appears already within the academic literature, in terms of, e.g., testing the quality of the applied SDS011 fine dust sensor [21], using the openly available PM data as a database for a hackathon [53] and a data science challenge [36].

4.2 Evolution and Reach through Social Media Networks

Following the evolution of Luftdaten's Twitter communication networks over time (see Figure 1) we found that Luftdaten.info started in 2015 with only a few engaged Twitter accounts representing a homogeneous group. In 2016, the network became organized in four smaller groups. Significant growth can be observed in 2017 when the network became much more extensive, and numerous Twitter accounts interacted with the Luftdaten initiative. Until 2019, the network shows more complexity. One can distinguish multiple subgroups that interact with each other. From 2017 to 2019, there are single nodes scattered at the outer area of the network. The largeness and diversity of active Twitter accounts in Luftdaten.info's communication are notable, indicating that over the past five years, Luftdaten.info has been successful in terms of getting new and more participants in the community and engaged in conversations with diverse actors from different publics.

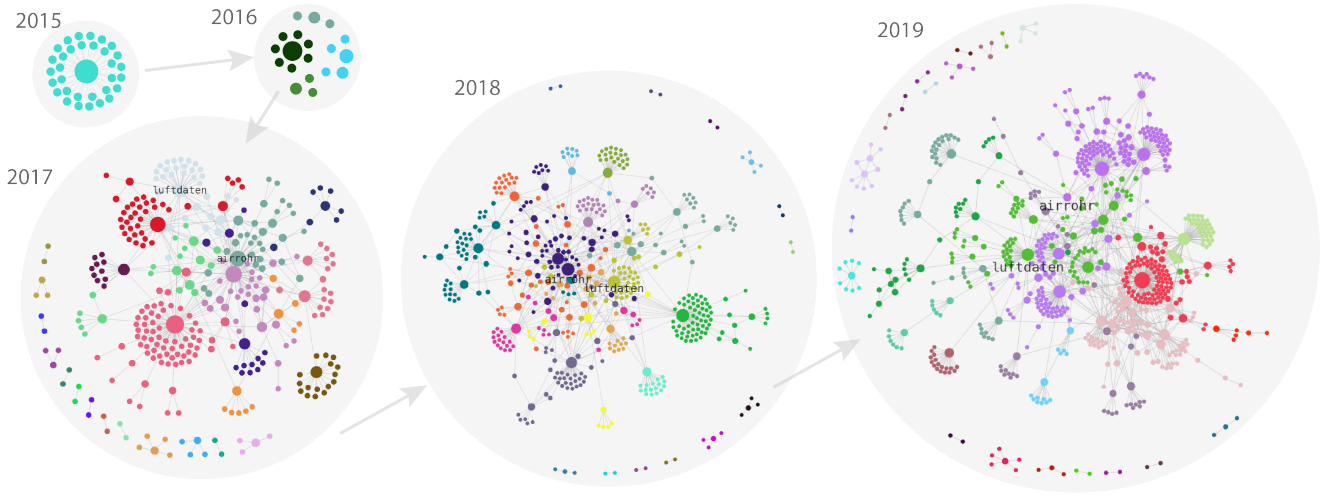

Figure 1: Luftdaten's Twitter communication network evolution. Starting with only a few people in the network in 2015 (33 nodes), year by year, the network grew significantly in 2017 (338 nodes) and became increasingly complex and more extensive until 2019 (744 nodes). As more diverse people and groups of people become involved, the visibility and reach of Luftdaten as an actor and as a topic is extended on the Twitter platform. About the network graphs: Each node in network graphs represents a Twitter account, and each edge represents a (re)tweet occurrence of the Twitter accounts related to @luftdaten and @airrohr. The node size indicates how many times this account has (re)tweeted to one of the Twitter accounts per year. The data basis for each figure is the retweet network per year. The graphs are created by the Python package NetworkX (for details see 3.3).

The combined network graphs of all years (see Figure 2) show the Twitter accounts' increment in Luftdaten's retweet network. The bigger the node, the more followers an account has. We found several accounts with more than 100K followers that are part of Luftdaten's Twitter communication network. These accounts include journalists and media, political parties, a domestic ministry, and international foundations.

4.3 Evolution Phases

In the following, the insights from the interview with a Luftdaten admin and the qualitative content analysis of the Twitter contents are combined and presented according to the initiative's three main evolution phases: emergence, growth, and sustaining.

4.3.1 Emergence. According to the Luftdaten admin, the initiative's main focus was a low-cost and easy-to-use technology to measure air pollution. "*Due to the low price, we can operate many more measuring points*" and in this way, the low-barrier technology is the basis for a potentially large community that operates the sensor kit independently. The Luftdaten admin explained their concern "*that it can always be the case in volunteer-based projects that someone [..] can no longer participate.*" For this reason, "*all the tools we develop should be as simple as possible, and they should be manageable or further developable by others.*" They decided from the beginning "*to run everything Open Source.*" As part of the Code for Germany program of the Open Knowledge Foundation, Luftdaten follows the principle of openness, i.e., Open Source and Open Data, with the intention that everybody can access the Luftdaten archive and download the data for further uses.

The first goal of Luftdaten.info was to install 300 fixed sensors to measure PM in Stuttgart. "*So we get an image of an entire area. And [...] I can make a statement [on this area] or at least check if I have a theory where the fine dust really comes from.*" Earlier, people would have relied on two official PM measurement stations in Stuttgart. However, from only two data points in a city, one could not say "*whether this is due to traffic, heating or industry. Because it is more or less arbitrarily determined where these two stations have been placed.*"

Another technology developed in the early phase is the Luftdaten map, "*which was developed relatively quickly over a weekend [...] as part of the NASA Space Apps Challenge.*" They brought their own data and used the event to work on the Luftdaten initiative. "*We said to ourselves, we already have data - we want to continue to make it available.*"

Within the emergence phase, Luftdaten did not use its Twitter account interactively and engagingly. Rather @Luftdaten communicated in one-way style as a PM info bot sharing the current air pollution values of various sensor stations in an automated way, e.g., "*2017-01-25 07:05 #finedust alert in 70186 Stuttgart! Sensor 286 = 218.63 µg/m³.*"

Nevertheless, Luftdaten started networking and reaching out to journalists very early, which led to the increasing presence of Lufdaten on public regional broadcaster SWR and national radio.

4.3.2 Growth and Sustaining. After the initial media reports, "*Stuttgarter Zeitung [a traditional local newspaper, A/N] became aware of us*" remembers the Luftdaten admin. "*They sent an editor to our meetings, about twice a month, who listened to us and asked if we could work together.*" They wrote regular reports on Luftdaten and started to experiment with Luftdaten's Open Data. From 2017, Stuttgarter Zeitung developed their own air pollution map, which shows aggregated PM data by city districts. After this, "*[w]e never had the problem that we had to go to the newspapers to report about*

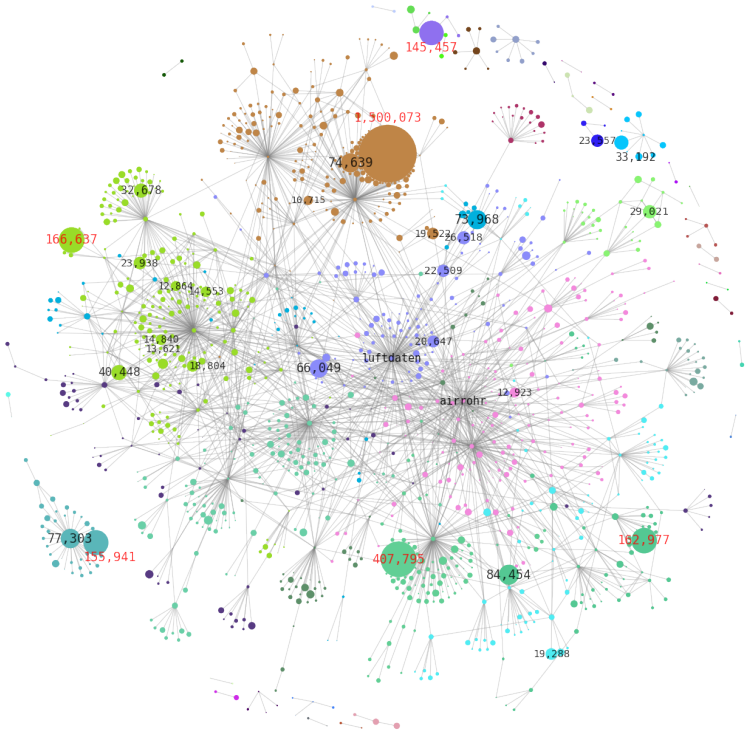

Figure 2: Network graph shows influential Twitter accounts involved in Luftdaten's retweet networks. In other words, it shows how far Luftdaten's online discourse reached. About the graph: Each node represents a Twitter account. Node sizes indicate follower numbers. If an account has more than 10k followers, the follower number is shown. The text is in red if the account has more than 100k followers. The graphs are created by the Python package NetworkX (for details see 3.3).

[us], but on the contrary [...] we sometimes had 2-3 newspapers or television teams sitting at [our] meetings."

Simultaneously, the Twitter account @airrohr was created in 2017, almost two years after the initiative began. "Airrohr" is an English-German neologism that translates to "air pipe" in English; it is the given name of the PM sensor kit that has been invented by Luftdaten. This account is dedicated to the "*most beautiful airrohr challenge*" where community members are invited to share photos of their self-made sensor kit with creative decorations under the #airrohr hashtag. This challenge seems to create a positive community feeling for the volunteers. Simultaneously, it helps increase the Luftdaten-related content on Twitter and probably the visibility of the air pollution topic.

From 2018, Luftdaten used its primary Twitter account @luftdaten for communication with the community and the public. The seemingly largest part of the Tweets is sharing content for public relations (PR) and community building. For example, they retweeted how community members set up a new sensor or posted photos from community workshops - such Tweets target the community and the public.

Luftdaten also shares media articles covering the Luftdaten initiative itself, e.g., from Stuttgarter Zeitung, The Guardian, Deutsche Welle. Also, community members share that they have seen media coverage on Luftdaten, e.g., "*video report on the #citizenScience project @luftdaten used to counter air pollution in Stuttgart.*"

Over the years, Luftdaten gained a large team of volunteer developers. If required, "*10-20 people spontaneously develop something.*" The community usually acts quickly because almost everything would be available on Github. Community members would do even translations to French, Russian, Polish, Spanish, Turkish, and other languages within a few days. On that score, the core team's workload is significantly reduced, and responsibilities are distributed among community members.

Besides the civic data collection and public visualization, Luftdaten themselves would not do much environmental simulations or modeling. For volunteers with their home computers, it would be challenging to process massive amounts of data. Preferably they search for academic collaboration. Since the beginning, Luftdaten has gathered several hundred gigabytes of data, "*we are happy if science helps out a little with data analysis.*" For example, in 2019, a German university hosted a data science challenge with the Luftdaten dataset as a basis.

Luftdaten is fully based on volunteers, also the core team works in their free time. For this reason, the regular costs would be relatively low ("*from 1.500 to 2.000 Euro for infrastructure*"). Via the

Betterplace platform, they organize donation campaigns that cover the costs regularly.

Today the core team based in Stuttgart consists of 8-10 active people responsible for different tasks. The admin states that the tasks are relatively flexible and shift from time to time: "*Well, I am actually an administrator, but I do a lot of programming in the meantime.*" People who know less about programming would try their hand at analysis, and other people would try to extend the sensor device. Nevertheless, their capacities are limited. "*So we always need people who know a little bit about it and bring in their knowledge.*"

We observed that Luftdaten uses Twitter as a tool for strategic networking and sharing information to raise awareness about a topic about which they care. They, for example, retweeted contents on air pollution by influential people that are not members of their community, e.g., from WHO officials writing, "*Women who breathe polluted air during the month right before or after they get pregnant are more likely to have babies with birth defects #AirPollution [...].*" Luftdaten retweeted not only media articles but air pollution information from internationally well-reputed institutions or projects like NASA or CopernicusEU. Further, Luftdaten shared air pollution-related contents from other local groups, e.g., in Brussels (Belgium), Münster (Germany), Bretagne (France), or Sheffield (UK). Other emergent topics were "civic tech" and "open data," or "smart city." These topics mainly appeared with events, panel discussions, or meetings dedicated to these developments, e.g., in the context of the event "Offene Stadt" (Engl. open city) in Hamburg (Germany), the organizer tweeted, "*On the road in Hamburg's #open city [...] Transparency, Open Data, Participation. With many great organizations and projects like [...] @Luftdaten [...] and many others.*" Luftdaten has several times been mentioned as a model for civic innovation in future-making smart city intentions of city planners, e.g., "*Best Practices, e.g., urban design Ulm with [...] or @luftdaten .info*"

Until 2020, Luftdaten achieved to install "*almost 400 sensors in Stuttgart,*" and it collects data from over 10K sensors installed worldwide. To extend their community, Luftdaten is networking towards other local groups interested in air pollution ("*If you know any local groups that are willing to help people with building and installing their #AirRohr [...]: we are building a "community map" so that interested people can find help nearby.*") In the future, Luftdaten would like to measure noise and nitrogen-dioxide because these topics would become more visible in public discussion.

The information provided by air pollution data from Luftdaten has a specific impact on some community members' daily lives. Luftdaten has "*several hundred if not thousands of users who have installed [the PM sensor, A/N] in their home automation systems.*" Such systems continuously analyze the sensor data, and if "*the air outside gets too dirty, please let me know or close all windows.*" According to the Luftdaten core team, members would look at the air pollution data of their balcony to decide on when to hang their laundry outside.

Luftdaten extended their activities towards student education. Together with IBM Germany, Luftdaten organized a workshop for more than 250 school students in Berlin in 2019. They showed how to acquire and assemble the sensor device, collect and upload the data to an open community portal.

5 CASE STUDY 2: SAFECAST

5.1 Background

The Safecast initiative emerged a few days after the 2011 Tohoku earthquake and the resulting Fukushima Daiichi nuclear disaster. The core team found together because they were worried about their families living in Japan, who, with the lack of radiation information, could not properly decide how to react to the disaster [75]. From this basis, they agreed on starting Safecast. It started with three people with backgrounds in programming, design, entrepreneurship, software development, and many other skills who assembled an improvised Geiger device. The device "bGeigie" was dedicated to measuring radiation in Japan in the aftermath of the disaster. Safecast visualizes the radiation data in a worldwide map that can be accessed via a browser (https://map.safecast.org/). A detailed description of the device and its updated versions, the datasets, and the map can be found in Brown et al. [19] (p. 84-89). The civic initiative has been driven by a quick mobilization of existing professional networks to set up the device, the data collection and visualization [75]. The role of academia has to be emphasized as a location that essentially facilitated the emergence and functionality of Safecast [75].

Safecast has been studied and portrayed in academic literature; these works helped us structure and make sense of the material we collected. For example, Brown et al. [19] describe the full volunteer and low-hierarchy structure as a crucial foundation of Safecast (p.89) as well as the vital outreach via social media and the public communication of their "message through many major media outlets in Japan and abroad" (p.91). Further, it is stated that "transparency and credibility are recognized as essential for the success of the Safecast project" (p.92). Another study looked at the societal impacts of Safecast. Abe [1] has contextualized Safecast as a "socio-technical system" pointing out that the collected data is not useful for knowledge production until people create narratives on the data. Further, it is the public communication of these narratives that would be necessary to reach the people. We build upon these works by examining Safecast's communication on social media and receiving insights from one of the founders.

5.2 Evolution and Reach through Social Media Networks

Safecast started with a relatively large range of actors in 2011 and has kept core parts of these networks for more than nine years (see Figure 3). Safecast began with diverse actors as an event-driven group after the Fukushima nuclear power plant incident in 2011. Over time, Safecast's communication has been mainly initiated by core members and sustained not only by core members but also by diverse international volunteers, organizations, journalists, and supporters.

We found several accounts with more than 100K followers that are part of Safecast's Twitter communication network (see Figure 4). These accounts include journalists and media, politicians, famous actors, famous academics, and worldwide-known museums.

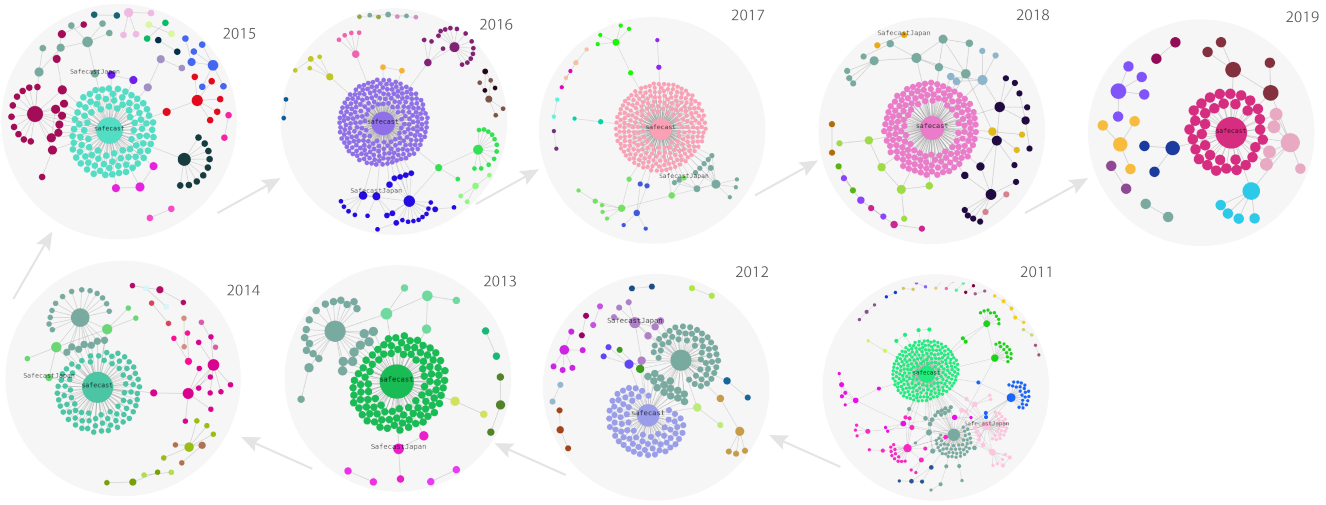

Figure 3: Safecast started with a relatively wide range of actors in 2011. From 2012 until 2019, the Twitter networks' size decreased continuously down to a stable core network. About the network graphs: Each node in network graphs represents a Twitter account, and each edge represents a (re)tweet occurrence of the Twitter accounts related to the civic initiative. The node size indicates how many times this account has (re)tweeted to one of the Twitter accounts per year. The data basis for each figure is the retweet network per year. The graphs are created by the Python package NetworkX (for details see 3.3).

5.3 Evolution Phases

In the following, the insights from the interview with Safecast and the qualitative content analysis of Safecast's Twitter accounts are combined and presented accordingly to initiative's evolution phases: emergence, growth and sustaining.

5.3.1 Emergence. Safecast's core team was using Twitter from the beginning as a tool for project management, i.e., directly contacting people via Twitter, sharing updates and technical news, and asking for donations and contributors. The communication here appears to be business-like and goal-oriented, e.g., Tweets like "*We're up and we need your help to gather up-to-date sourced information!*" or "*Thanks for the kind words. A Japanese version is in the works and will launch as soon as possible.*" They also reach out to find more contributors via Twitter in the initial phase to quickly set up their data collection, e.g., "*Looking for a technical contact who could provide an RSS/XML/JSON feed of their U.S. monitor data. Scraping HTML isn't fun.*" At the same time, Safecast acts from the beginning as a distributor of media activities and articles on the Fukushima Daiichi Nuclear Disaster, e.g., "*Press conference on NHK World: [LINK]*" or "*25 economies restrict food imports from Japan over radiation fears [LINK].*" After some time, Safecast emerged as a player within the disaster-caused radiation discourse in Japan.

Safecast adhered from the beginning to the value and principle of openness. "*We open every single thing up [...] so that we're not relying on us alone. Even if we don't have a lot of money if we publish the plans for the devices, other people out in the world can still make them and they can still start collecting data and publishing data.*" Safecast provided all resources for the volunteers, and this accessibility to the equipment and materials "*allows lots of things to happen even without our specific direction on it.*" With all materials open, Safecast believes that they are more trustworthy, which is useful to attract new community members, collaborators, and network partners. This decentralized form of running Safecast has helped them build resilience "*because our community is so strong, even if we have a lot of problems internally, the community keeps things moving.*"

In the early phase, Safecast's core team published on-the-ground reports. They visited disaster-stroke regions in Fukushima prefecture and shared their experiences, photos, and radiation values via their blog and Twitter. Quickly, local politicians in Fukushima were interested in the activities of Safecast, which helped them identify places for measurements, organize capacity-building workshops, communicate with residents in Fukushima, and connect them to other politicians and authorities. "*[V]ery early [...] the local governments became strong allies [...]*" and recognized that Safecast could collect the lacking information on what happened after the disaster.

The large parts of the initial funding came from the Knight Foundation [15], a foundation dedicated to quality journalism, media innovation, social responsibility, and the arts, to strengthen democracy. Later, we observed that Safecast's donation campaigns were extraordinarily successful at the beginning of the initiative, "*The Kickstarter we launched this morning was successfully funded in under 12 hours.*" or "*Only a few hours left for 200% donation matching. Please pass this on! Thank you!.*"

5.3.2 Growth and Sustaining. Civic authorities applying Safecast's data mark the transition from emergence to growth and sustaining phase. The authorities recognized Safecast's unique radiation data relatively early. Only about six months after the incident, the Fukushima Government has created a worldwide map of radiation measurements on their website, of which Safecast provided the

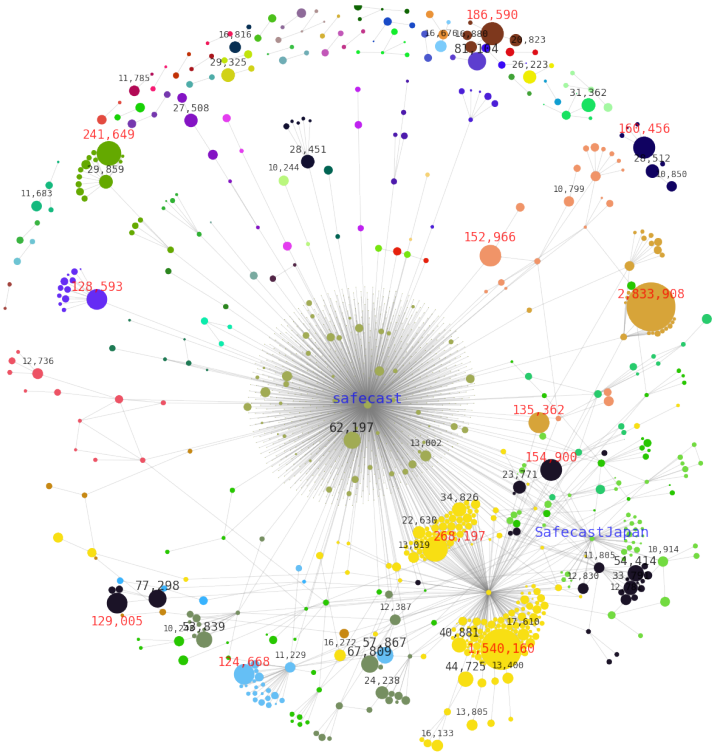

Figure 4: Network graphs show how influential twitter accounts have been involved in retweet networks. In other words, it shows how far Safecast's online discourse reached. Each node represents a Twitter account. Node sizes indicate follower numbers. If an account has more than 10k followers, the account name and the follower number are shown. The text is in red if the account has more than 100k followers. The graphs are created by the Python package NetworkX (for details see 3.3).

data. Also, Safecast has been invited since 2014 to The International Atomic Energy Agency (IAEA) to present their works [17, 18].

Safecast emphasized the importance of "*interaction with the community.*" Over more than nine years of Safecast history, they have held multi-scale events, from educational workshops for children to large international conferences. They organized numerous meetings and workshops in the Tokyo FabLab, the MIT Media Lab, different hackerspaces, and their Tokyo office. The symposiums and conferences aimed to have "*conversation in public*" with a broader online community in the background (i.e., more than 1,000 volunteers). The technological evolution of Safecast "*has always been based on feedback from the community.*"

From early on, Safecast saw talking to the media as one of the core tasks. They had an open policy to talk to anybody who approaches them regardless of their opinions or political positions, "*[...] hoping them to spread the word about our efforts and [...] what we are trying to promote: Openness and sharing the information and community self-alliance.*" Besides, they have leveraged various tools (e.g., blogs, medium, Twitter, Facebook, Linkedin) to diffuse their efforts and be visible, which may have helped them to be reachable.

Safecast is equally confident and open about their self understanding as they write on Twitter "*We're not a political organization, we collect & publish data. We've done more of that than all other orgs in Japan combined.*" Such an attitude would allow them to contribute arguments, i.e., radiation data, to the public discourse, but not acting as a political stakeholder around the socio-environmental issue. Referring to the lack of data, Safecast writes clearly on Twitter that "*The only way most people have data is because of us. Our data is open and transparent on every level [...].*"

To ensure long-term funding, Safecast used its Twitter networks to mobilize donors. Safecast managed their regular donation campaigns on the Kickstarter donation platform and advertised these campaigns on Twitter, e.g., "*We're at 92 backers on Kickstarter. Who will be #100???.*" Finally, Safecast received many donations from people outside Japan.

To remain relevant to the public and keep the initiative vivid, Safecast has widened its initial concerns about the environment over the years by adapting the current public discourse. From their Twitter data, we find that they became engaged in air pollution in Los Angeles and they carried out student education events. According to the interview data, Safecast has not expanded their purposes randomly. Instead, they evolve by adjusting with citizens' concerns or the community needs. Also, they expand purposes based on keeping their core ideas. e.g., Safecast provides all their data and information openly, so people could use it to make their own informed decisions. For example, we learned that residents in the

Fukushima Prefecture had used Safecast data to make decisions on their daily life, i.e., they decided where to move based on lower radiation values in a location [47].

In the next section, we summarize a set of key factors identified from the activities described in each of the phases observed. The quantitative analysis of the Twitter networks allowed us to take a temporal perspective on the cases, most often missing in the HCI literature. And, through the analysis of the qualitative data, our work provides an in-depth understanding of the multiple and diverse actors, technologies, and activities characterizing the emergence, growth, and sustaining phases of Safecast and Luftdaten.info. Building on these results, we developed a nuanced understanding of their evolutions, which can inform the study and design of scaling and sustaining civic tech initiatives.

6 SUMMARY OF KEY FACTORS FOR THE CIVIC TECH INITIATIVES' SCALING AND SUSTAINING

In the following, we explain the key factors identified from our retrospective longitudinal mixed-methods analysis of the scaling and sustaining phases of Luftdaten and Safecast.

With the set of key factors here identified, we do not intend to provide a checklist, implying that any civic initiative will be sustainable once all points are checked [5]. Instead, we stress that civic tech initiatives are complex and dynamic socio-technical arrangements embedded in specific cultural, geographical, and political ecologies, as well as structures of power [27]. As it is usual for case studies, the findings represent specific and situated cases.

Issue of public concern. Both cases had started their initiative when the tackled issues (Fukushima Daiichi disaster, air pollution, and emission scandals in Stuttgart) were part of the current media agenda and public discussion. There was a lack of data on this specific, critical issue potentially affecting people's health; the public needed this information in both cases. The social value given to both civic initiatives was associated with the central role they played in providing tools, capacity building, and communication space to discuss pressing issues regarding the city residents' wellbeing.

Competent core team. The human basis of the civic initiatives is a small team of well-organized, tech-savvy, and personally motivated people, i.e., freelancers, designers, entrepreneurs, and engineers. The core teams of both cases are geographically connected and have an emotional affective motivation towards the issue, their care about their cities, families, and future generations. Furthermore, they share values on transparency and openness, providing information and data to the public discourse. In both cases, most of the core team members who started the initiatives are still actively involved with the initiative; only a few people dropped out. The core teams carried out the necessary tasks and achieved the first milestones, on which the initiative grew. They set up community meetings and the community's infrastructure, assembled the prototypes, provided information materials, communicated the initiative's goals, and contacted potential collaborators.

Initial background network and further networking. Safecast and Luftdaten did not occur spontaneously. Both cases show that the initial background network, i.e., the foundations and academic networks supporting the initiatives, played a role in gathering expertise and spreading the word. Further networking - especially with established institutions and stakeholders - was a key factor related to trustworthiness and has led to external application of the collected data, which ensures a continuous relevance of a civic initiative. Besides, improving the quality of the data, the data analysis, the data visualization, and the devices involved was advantageous to connect to science and research institutions.

Access to material resources and openness. The core members of both initiatives relied on material resources such as available meeting rooms or labs from universities or foundations being part of their initial network. Openness here means that newly created resources have been made accessible. Sharing values regarding transparency in terms of Open Data, Open Source, or Open Knowledge, i.e., providing all data, plans, materials, and devices, allowed the initiatives a way to evolve, while not relying on being managed in a top-down manner.

Low-barrier technology. The core teams of both initiatives developed the actual IoT and communication technologies, which combined with commercial components, formed an ecology of artifacts that enabled the initiative to capture data, coordinate itself, and become publicly visible. Such technologies are in particular: (1) a do-it-yourself, easy-to-use, relatively low-cost sensing device, (2) the underneath network architecture and an open database, (3) an intuitively understandable and publicly available data map, (4) communication technologies, which is mainly social media-based communication. The low-barrier technology was vital to find participants and attract a large community (also less tech-savvy people). If the technologies needed too much expert knowledge to use them, it would have been hard to spark people. Despite being do-it-yourself and easy-to-use, the technologies need to be "good enough" [34], so the data can be used for informing the public and serve as arguments in public discourse.

Data applied by established institutions. Both initiatives have successfully captured, shared, and communicated citizen data reused by other established institutions. In the case of Luftdaten, the air pollution data is applied by a traditional local news medium in Stuttgart. In the case of Safecast, it is the local government in Fukushima Prefecture that applied the radiation data. These institutions show and distribute the initiative's data via their websites until today. This continuous use and re-use of the data implies a certain trust towards these civic initiatives. At the same time, we see how the initiatives' data reaches out to the general public and ensures their societal relevance.

Attracting new community members. Finding new participants while keeping the community active is probably the primary key factor for making a civic initiative growing and scaling. We found out that organizing events for students, participating in networking social or cultural events, or business-like meetings helped to attract new people and potential new community members. We also find other practices that represent openness and help to attract new members, such as retweeting, establishing a partnership in terms of co-ownership, and translating into different languages.

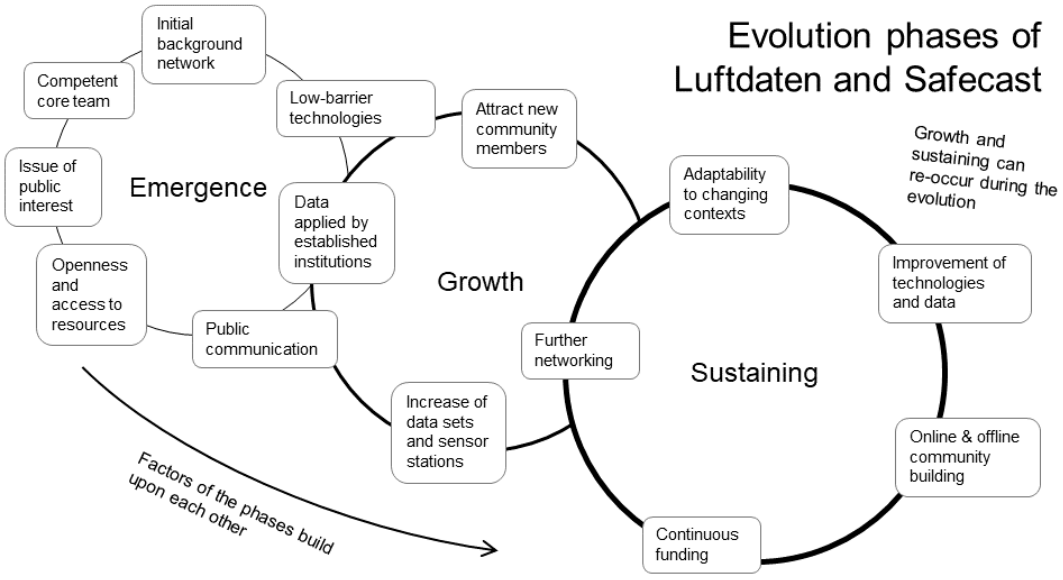

Figure 5: Evolution of Safecast and Luftdaten cases. The factors that are key for a sustainable initiative are placed around the evolution phases emergence, growth, and sustaining.

Increasing data sets and sensor stations. The increase of data sets and sensors stations is interconnected with attracting new community members. Simultaneously, few community members have been very engaged and set up many sensors just by themselves.

Continuous funding. One of the basic needs of sustaining is funding. We assume that the public willingness to donate money is relatively high as long as the issue, e.g., air pollution or radiation, is part of the public discourse. These initial donations collected by the platforms Kickstarter and Betterplace allowed the initiatives to grow a lot initially. Later the initiatives took efforts to remain in public discourse and to reach people that would be potential donors.

Public communication. Public communication is crucial to become a part of the public discourse on environmental issues and reach people by sharing their own data-driven narrative. It includes the continuous and interactive use of social media and working with traditional media, i.e., inviting journalists or giving interviews. Both cases also maintained two-way dialogue on Twitter with the community and the public that led to attracting new volunteers or distributing the core team's workload. The social media accounts likewise contributed to keeping the issue-related public discussion ongoing, e.g., by addressing famous people or officials of large organizations like the World Health Organization (WHO). Also, giving comments to issue-related media articles contributed to increasing public communication on the initiative.

Online and offline community building. A civic initiative lives from its community and vice versa. The communities brought many inspirations into their initiatives. For example, we observed how the communities were involved in photo challenges on social media, organizing meetings, workshops, and events, identification with citizen science and open data communities, sharing experiences, telling on-the-ground stories, and playing with data visualizations. Further, the community used Twitter to discuss their measurements or inform the public and the community if they recognized exceptional high values in their neighborhood.

Adaptability to changing contexts. Both cases have evolved from their initial purposes. They have worked with other sensors or evolved towards the educational sector or health communication. These extensions did not happen randomly, but they were reactions to community members' demands or towards the current public discourse. Reacting such demands by transforming the initiative helped the initiatives remain relevant for people and attractive for media coverage. Likewise, it helped to gain new donors and network partners.

Figure 5 summarizes the set of factors that are key for the civic tech initiatives examined. The bubbles' overlaps refer to the fact that the phases are not easily separable, and the factors are interlinked and building on each other.

7 DISCUSSION

From dissecting the emergence, growth, and sustaining of Luftdaten and Safecast over time (i.e., from 2011 and 2015), we discuss in this section how the factors identified have contributed to the Luftdaten and Safecast scaling and sustaining. In doing so, we draw particular attention to the role played by the initiatives' civic data, the use of open civic tech, and the involved citizens' public narratives on the environment for the long-lasting of both civic tech initiatives. We end this section with a note on pre-existing inequities and power structures embedded in the civic tech initiatives here studied.

7.1 Civic Data and Impact

Gathering data about air pollution and radiation has an impact on local people's daily lives. We learned about such influencing effects in relation to the captured sensor data, and what kinds of decisions are made based on this data, e.g. where people move, when they ventilate, or hang their laundry outside.

We, therefore, emphasize the term "civic data" to draw attention that such data is both captured and owned by the citizens for the citizens. More specifically, civic data is different from, for example, citizen science data as they are not primarily aiming at generating data for scientists concerned by contributing scientific knowledge. Instead, civic data aims at providing citizens means and knowledge to act upon the local pressing environmental issues affecting them and future generations.

While for civic data, scientific quality is not the first priority, enabling public discourse and social action rather are. The civic attribute of data echoes the social value of "imperfect data" underscored by Alvarado Garcia and colleagues [4] regarding the power of data in informing citizens, requesting action, and building capacity.

Although Safecast's and Luftdaten's data is not free from errors (e.g., [30]), it is definitely "just good enough" [34] for the emergence, growth, and sustaining of civic tech communities aiming at bringing about societal change via own's public narratives about the environment. Such imperfect, good enough civic data data is instrumental in creating high media attention, bringing established institutions to become involved and apply the citizen-collected data for their public information services, and engaging people worldwide.

7.2 Open Civic Tech

Because people need access to become involved in civic data, the civic tech initiatives required accessibility. The key factors "openness and access to materials" and "low-barrier technology" describe the open technology that includes principles of open source and open data. In this way, Luftdaten and Safecast are based on the ability to transmit not only within their respective communities but also to a globally networked data community. This ability depends on the existence of methods for interoperability [22, 83] like application programming interfaces (API) to open and machine-readable data [73]. Using APIs, Github, and other tools, civic initiatives can provide many materials, i.e., technologies, codes, data, and plans, openly and accessible for people with necessary technical skills. The sensor kits are relatively inexpensive compared to professional devices. It is a strength of Luftdaten and Safecast, that they make their materials and resources not only available but also accessible for people with basic technical knowledge [50, 62] and limited financial resources. We learned that they are even translating their materials in various languages, which allows them to attract and include non-English speaking people. Through their toolkits, extensive documentation, and regular workshops and educational events, the civic tech initiatives provide capacity building for their communities and interested people.

Apart from this, we understand that the shared value of openness is an essential condition for the initiative's rapid growth and scaling. The open design of the technologies, codes, and data is a fundamental decision that ensured that the initiatives' evolution was (and is) not dependent on specific individuals. Both initiatives' core teams have in common that they are less a managing team that gives top-down commands to the community, but they rely on the community's input and skills to evolve. Skills and capacities are built in the way of self-management and self-education by the community members. People can join Safecast or Luftdaten independently from the core team and bring in their own skills. This decentralized nature helps keep the community ongoing and stable, and the initiative flexible [43], which relates to the key factor "Adaptability to changing contexts". We learned that Luftdaten and Safecast became more professionalized and more visible over time as the core teams participated in strategic events around topics like Civic Tech, Open Data, Nuclear Energy, or Smart City. Doing so, they not only adapted their activities and communication to other contexts, e.g., urban planning, innovations, energy technology, or digital markets, but also met potential network partners, like IT companies, living labs, or hackerspaces.

Factors such as "Online and offline community building", "Attract new community members" and "Increase of data sets and sensor stations" illustrate that the low-barrier sensor kits have been assembled in participatory and joyful events. For example, with school students and community members who proudly share photos of their running sensor station in their homes or gardens. At the same time, these people become aware of the environmental issue they measure while oscillating from playfulness to seriousness and vice-versa [68] (pp.1-11). In this respect, the use of low-barrier and low-cost technologies by networks of actors in the community can allow overcoming digital exclusion that is still identified as a shortcoming in data-enhanced city scenarios [28, 62].

7.3 Public Narratives on Environmental Issues

Luftdaten's and Safecast's scaling and sustaining are not only about the role played by the open sensor technology, the civic data, and the communities built around them; but also about the public narrative contributed by the citizens (i.e., individuals, the academic institutions, the press media, the authorities, etc.) involved in the initiatives (i.e., gathering environmental data, analyzing it, programming tech, running educational workshops data, etc.). As Abe [1] has argued, Safecast is a "socio-technical system" whose collected data is not useful for knowledge production until people create narratives based on such data. In the case of Luftdaten, we observed the same. Citizens' narrative about the data captured and the sensors' use is an essential part of reaching out, networking, and generating attention within and outside the communities. Based on our findings, such a public narrative is particularly linked with the key factors "Public communication", "Attract new community members," "Data applied by established institutions," and "Further networking." From early on, the use of social media, by both initiatives, especially via strategic retweeting, helped them to initiate and maintain a two-way dialogue on air pollution and radiation while constructing community identity and agency vis-à-vis the general public. Such a dialogue led to attracting people, donors, and networking partners that led to public visibility and community engagement, and further key collaboration (e.g., with journalists, scientists, local politicians).

We see similarities to "data stories" previously conceptualized by Gabrys and colleagues [34]. Public narratives on the respective environmental issues are mediated via the initiatives' public communication with the media, their consistent use of blogs, and social media interactions. By sharing their respective angles on civic data and open tech, the various actors constituting Luftdaten's and Safecast's public narratives contributed "their stories" enabling them to have a say on public discourses on the Fukushima disaster and air pollution in urban areas.

Building on the communities' captured civic data and their use of open tech such civic techs' public narratives facilitated civic engagement and raising awareness of the environmental issue tackled by Luftdaten and Safecast. Moreover, the public narratives fell on a fruitful ground because when Luftdaten and Safecast joined the public discourses, the media had already reported on these environmental issues and people already discussed these issues on social media. In this regard, we learned from these cases that the public narrative facilitated by social media and close cooperation with traditional media (i.e., journalists) is part and parcel of the socio-technical arrangement embedded in these civic tech initiatives. Such a narrative (contributed in different languages) helped Luftdaten and Safecast scale-up and endured by having a voice in the public (i.e., local and international) environmental discourse.

Finally, through the citizens' participation in the public discourse, diverse actors become interested and engaged with the initiatives, and in doing so, infrastructuring that new issue-based publics can be designed [55] from a local to a global scale.

7.4 A Note on Empowerment and Embedded Pre-existing Power Structures

Luftdaten and Safecast have been founded on the premise that they would not accept the non-existence of data regarding particulate matter in the air and radioactively contaminated areas. For this reason, they started collecting the data by themselves in an activist way. They shared their knowledge with the broader public. They attempted to design technologies and analyses of civic data fully transparent and open to potential contributors (i.e., individuals, universities, the press, organizations, local authorities). As already pointed out by [81], such social and technical configurations can have democratic value. Ordinary citizens could empower themselves by joining the data collection and, in doing so, tackling issues of their concern [6, 44] to make informed decisions for their everyday lives.

However, while conducting this study, we noticed certain particularities linked to power imbalance or inequities (re)producing influence and power. Such particularities are recently discussed in critical scholarship on civic technologies e.g. [9, 10]. From such a socio-critical perspective, we are cognizant of Luftdaten's and Safecast's specific "socio-political and economic landscapes" [8] that have structurally helped to make them grow and sustain. In this context, we argue that we cannot fully understand the identified factors without linking them to their landscapes' economic power and socio-political influence. Coupled with pre-existing power and influence are especially early key factors "Competent core team", "Initial background network," "Access to material resources and openness," as well as later factors "Further networking," "Continuous funding" and "Data applied by established institutions." The technical skills and competencies of Luftdaten's and Safecast's core teams and the communities' high education status play an important role in the scaling and sustaining of the initiatives located in resource-rich Germany and Japan. We also observed the reproduction of existing gender imbalances in IT (e.g., [2]) in the full male founding teams of Luftdaten and Safecast.

Furthermore, the initiatives' positionalities are shaped by their initial background networks, including prestigious research institutions (in the case of Safecast) and global activists' networks (in the case of Luftdaten). These networks enabled them to quickly grow globally while bringing their message to an international public but also facilitated attracting highly skilled people to join the initiative and contribute to their activities and actions. In turn, such partnerships allowed more convenient access to technical knowledge, equipment, and other materials and resources. In this regard, we are aware of the role played by powerful local institutions for sustaining the initiatives (i.e., their data being applied by local government or news media). For instance, social media campaigning and social networking are not equally advantageous for every civic tech initiative since such communication strategies are deeply interlinked with the initiatives' positionality.

Compared to less resourceful civic initiatives (e.g., [9, 70], we presume that Luftdaten and Safecast can be viewed as part of something like a civic tech elite that benefits from the social capitals [16] of established actors in their networks in highly developed countries. Such pre-existing capital, prestige, and power can configure the initiatives' digital space, which further shapes the social field [60]. In that connection, we understand that civic tech initiatives emerging in less resourceful environments ([9, 70] where background networks are less powerful, education standards and access to technology are less developed; it is much harder to reach endurance and sustainability over time.

8 LIMITATIONS

As we build this paper on case studies, one cannot take the key factors and apply them to other cases. The reason is that the respective ecosystems (e.g., geography, culture, politics, economy) that the studied civic tech initiatives inhabit have strongly shaped the analyzed cases. For example, Safecast has emerged because of the tragic Fukushima Daiichi nuclear disaster in Japan. Only after this, the interplay of its privileged ecosystem and Safecast's own strategic decisions have led to their sustainable and robust initiative. The same applies to Luftdaten.info, which is tightly embedded in the German city Stuttgart's comparatively rich economic context and specific cultural and geographical features.

Another limitation of our work is that we are approaching the research question by primarily using the lenses of the initiatives' core teams. As such, we are aware that the choice of analyzing the core team and their Twitter accounts entails that other voices from the community are missing. Particularly, the Twitter analysis is missing members of the community who are not on Twitter and consequently, other social aspects that while contributing to the evolutions of the civic tech initiative, have not left any traces on Twitter.

There might be some important voices that are not uncovered during our analysis. We only have studied the initiatives through the founders and core team members and official social media and online contents. But there might be other actors or residents who know about the public issues at hand and have a different or even critical take on Safecast and Luftdaten (e.g., [30]).

In this respect, we might have missed additional key factors that cannot be identified by our pragmatically methodological choices. Possibly, some key factors could have been different if we would have selected cases from other socio-political and economic landscapes.

9 CONCLUSION

Drawing on previous HCI works in Digital Civics [81], we have studied two civic tech initiatives in Germany and Japan that reached a global scale and that include several thousands of volunteers and sensor stations, and millions of data points. We were able to identify the initiatives' evolution phases (emergence, growth, sustaining) and a set of key factors that helps them endure (see all key factors in Fig. 5). We could generate these findings by combining the core teams' lenses with a retrospectively designed longitudinal study of historical Twitter contents. Such a pragmatically developed mixed-method design can inform HCI research on scaling [20]. Finally, replying to what makes civic tech initiatives last over time, we argue that, in these cases, the entanglement of civic data, open tech, and the initiatives' public narrative plays a central role in the scaling up and sustaining of such socio-technical arrangements. Notwithstanding, we acknowledge issues of power [27] and inequities since the here-studied cases could take advantage of their resourceful environments and pre-existing privileges.

ACKNOWLEDGMENTS

We would like to thank Prof Ina Schieferdecker and Prof Hideyuki Tanaka who made this collaboration possible. We are also grateful to Gopinaath Kannabiran from the IT University of Copenhagen, and the anonymous reviewers who provided us with helpful comments on our work.

This work has been partially funded by the Federal Ministry of Education and Research of Germany (BMBF) under grant no. 16DII111 ("Deutsches Internet-Institut").

REFERENCES

[1] Yasuhito Abe. 2013. Why Safecast matters: A case study in collective risk assessment.

[2] Michael Ahmadi, Anne Weibert, Corinna Ogonowski, Konstantin Aal, Kristian Gäckle, Nicola Marsden, and Volker Wulf. 2018. Challenges and lessons learned by applying living labs in gender and IT contexts. In *Proceedings of the 4th Conference on Gender & IT (GenderIT '18)*. Association for Computing Machinery, New York, NY, USA, 239–249. https://doi.org/10.1145/3196839.3196878

[3] Akky Akimoto. 2011. Japan, the Twitter nation. https://www.japantimes.co.jp/life/2011/05/18/digital/japan-the-twitter-nation/#.Wadv47JJbIU

[4] Adriana Alvarado Garcia, Alyson L. Young, and Lynn Dombrowski. 2017. On Making Data Actionable: How Activists Use Imperfect Data to Foster Social Change for Human Rights Violations in Mexico. *Proceedings of the ACM on Human-Computer Interaction* 1, CSCW (Dec. 2017), 1–19. https://doi.org/10.1145/3134654

[5] Mara Balestrini, Jon Bird, Paul Marshall, Alberto Zaro, and Yvonne Rogers. 2014. Understanding sustained community engagement: a case study in heritage preservation in rural argentina. In *Proceedings of the 2014 CHI Conference on Human Factors in Computing Systems (CHI '14)*. Association for Computing Machinery, Toronto, Ontario, Canada, 2675–2684. https://doi.org/10.1145/2556288.2557323

[6] Mara Balestrini, Yvonne Rogers, Carolyn Hassan, Javi Creus, Martha King, and Paul Marshall. 2017. A City in Common: A Framework to Orchestrate Large-scale Citizen Engagement around Urban Issues. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems (CHI '17)*. Association for Computing Machinery, Denver Colorado USA, 2282–2294. https://doi.org/10.1145/3025453.3025915

[7] Jeffrey Bardzell and Shaowen Bardzell. 2016. Humanistic HCI. *Interactions* 23, 2 (Feb. 2016), 20–29. https://doi.org/10.1145/2888576 Place: New York, NY, USA Publisher: Association for Computing Machinery.

[8] Rosanna Bellini, Angelika Strohmayer, Patrick Olivier, and Clara Crivellaro. 2019. Mapping the Margins: Navigating the Ecologies of Domestic Violence Service Provision. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (CHI '19)*. Association for Computing Machinery, Glasgow Scotland Uk, 1–13. https://doi.org/10.1145/3290605.3300352

[9] Nicola J Bidwell. 2020. Wireless in the Weather-world and Community Networks Made to Last. In *Proceedings of the 16th Participatory Design Conference 2020 - Participation(s) Otherwise - Volume 1*. Association for Computing Machinery, Manizales Colombia, 126–136. https://doi.org/10.1145/3385010.3385014

[10] Nicola J. Bidwell. 2020. Women and the Sustainability of Rural Community Networks in the Global South. In *Proceedings of the 2020 International Conference on Information and Communication Technologies and Development*. Association for Computing Machinery, Guayaquil Ecuador, 1–13. https://doi.org/10.1145/3392561.3394649 tex.ids: bidwellWomenSustainabilityRural2020a.

[11] Aksel Biørn-Hansen and Maria Håkansson. 2018. Building Momentum: Scaling up Change in Community Organizations. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18)*. Association for Computing Machinery, Montreal QC, Canada, 1–13. https://doi.org/10.1145/3173574.3173984

[12] Vincent D Blondel, Jean-Loup Guillaume, Renaud Lambiotte, and Etienne Lefebvre. 2008. Fast unfolding of communities in large networks. *Journal of Statistical Mechanics: Theory and Experiment* 2008, 10 (Oct 2008), P10008. https://doi.org/10.1088/1742-5468/2008/10/p10008

[13] Kirsten Boehner and Carl DiSalvo. 2016. Data, Design and Civics: An Exploratory Study of Civic Tech. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16)*. Association for Computing Machinery, San Jose California USA, 2970–2981. https://doi.org/10.1145/2858036.2858326

[14] Cristian Bogdan and Teresa Cerratto Pargman. 2002. Reconsidering support for the members of specialized online communities. In *The 34th Congress of the Nordic Ergonomics Society, NES*. CID, Stockholm, Sweden, 121–126.

[15] Sean Bonner. 2011. Safecast + Knight Foundation. https://safecast.org/2011/10/safecast-knight-foundation/

[16] Pierre Bourdieu. 1985. The Social Space and the Genesis of Groups. *Theory & Society* 14, 6 (1985), 723–744.

[17] Azby Brown. 2014. Safecasting the IAEA. https://safecast.org/2014/02/safecasting-the-iaea/

[18] Azby Brown. 2018. Safecasting the IAEA. https://safecast.org/2018/10/safecast-at-the-iaea/

[19] Azby Brown, Pieter Franken, Sean Bonner, Nick Dolezal, and Joe Moross. 2016. Safecast: successful citizen-science for radiation measurement and communication after Fukushima. *Journal of Radiological Protection* 36, 2 (June 2016), S82–S101. https://doi.org/10.1088/0952-4746/36/2/S82

[20] Barry Brown, Susanne Bødker, and Kristina Höök. 2017. Does HCI scale?: scale hacking and the relevance of HCI. *Interactions* 24, 5 (Aug. 2017), 28–33. https://doi.org/10.1145/3125387

[21] Matthias Budde, Thomas Müller, Bernd Laquai, Norbert Streibl, Almuth D Schwarz, Gregor Schindler, Till Riedel, Michael Beigl, and Achim Dittler. 2018. *Suitability of the Low-Cost SDS011 Particle Sensor for Urban PM Monitoring*. Technical Report. Scientific Research Abstracts. 11 pages.

[22] Manuel Castells (Ed.). 2004. *The Network Society*. Edward Elgar Publishing, Cheltenham, UK. https://doi.org/10.4337/9781845421663

[23] Teresa Cerratto Pargman, Somya Joshi, and Uta Wehn. 2019. 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*. ACM Press, Lappeenranta, Finland, 1–10. https://doi.org/10.1145/3338103.3338111

[24] Eric Corbett. 2018. Trust and Community Engagement in Digital Civics: Exploring Opportunities for Design. In *Proceedings of the 2018 ACM Conference Companion Publication on Designing Interactive Systems (DIS '18 Companion)*. Association for Computing Machinery, Hong Kong, China, 367–370. https://doi.org/10.1145/3197391.3205384

[25] Eric Corbett and Christopher A. Le Dantec. 2018. Going the Distance: Trust Work for Citizen Participation. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18)*. Association for Computing Machinery, Montreal QC, Canada, 1–13. https://doi.org/10.1145/3173574.3173886

[26] Eric Corbett and Christopher A. Le Dantec. 2018. The Problem of Community Engagement: Disentangling the Practices of Municipal Government. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*

(CHI '18). Association for Computing Machinery, New York, NY, USA, 1–13. https://doi.org/10.1145/3173574.3174148

[27] Sasha Costanza-Chock. 2020. *Design Justice: Community-Led Practices to Build the Worlds We Need*. MIT Press, Cambridge, Massachusetts. Google-Books-ID: m4LPDwAAQBAJ.

[28] Jessa Dickinson, Mark Díaz, Christopher A. Le Dantec, and Sheena Erete. 2019. "The cavalry ain't coming in to save us": Supporting Capacities and Relationships through Civic Tech. *Proceedings of the ACM on Human-Computer Interaction* 3, CSCW (Nov. 2019), 123:1–123:21. https://doi.org/10.1145/3359225

[29] Janis L. Dickinson and Rick Bonney (Eds.). 2012. *Citizen Science: Public Participation in Environmental Research*. Cornell University Press, Ithaca, N.Y. https://doi.org/10.7591/cornell/9780801449116.001.0001

[30] Achim Dittler. 2017. Stuttgarter Zeitung verunsichert Bürger mit fehlerhaften PM10-Messwerten und fragwürdigen Grenzwertvergleichen. https://de.linkedin.com/pulse/stuttgarter-zeitung-verunsichert-b%C3%BCrger-mit-und-achim-dittler

[31] Patrick Dunn. 2016. Open data: How access to public data is growing in Detroit. https://www.modeldmedia.com/features/open-data-090516.aspx

[32] Earthwatch. 2020. FreshWater Watch. https://freshwaterwatch.thewaterhub.org/

[33] Jean-Pierre Fellmer. 2019. Beim Projekt Luftdaten.info bauen Bürger Feinstaubsensoren. https://www.weser-kurier.de/deutschland-welt/deutschland-welt-vermischtes_artikel,-beim-projekt-luftdateninfo-bauen-buerger-feinstaubsensoren-_arid,1847617.html

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

[35] Jennifer C Greene, Valerie J Caracelli, and Wendy F Graham. 1989. Toward a Conceptual Framework for Mixed-Method Evaluation Designs. *Educational Evaluation and Policy Analysis* 11, 3 (1989), 255–272. https://journals.sagepub.com/doi/pdf/10.3102/01623737011003255

[36] Hannes Grunert and Holger Meyer. 2019. Die Data Science Challenge auf der BTW 2019 in Rostock. In *BTW 2019 - Workshopband*. Lectures Notes in Informatics (LNI), Gesellschaft für Informatik, Bonn, 281–284. https://doi.org/10.18420/BTW2019-WS-30 Publisher: Gesellschaft für Informatik, Bonn.

[37] Trisha Gura. 2013. Citizen science: Amateur experts. *Nature* 496, 7444 (April 2013), 259–261. https://doi.org/10.1038/nj7444-259a Number: 7444 Publisher: Nature Publishing Group.

[38] Andrea Hamm. 2020. Particles Matter: A Case Study on How Civic IoT Can Contribute to Sustainable Communities. In *Proceedings of the 7th International Conference on ICT for Sustainability*. ACM, Bristol United Kingdom, 305–313. https://doi.org/10.1145/3401335.3401815

[39] Nicolai Brodersen Hansen, Gwen Klerks, Maria Menendez Blanco, Laura Maye, Angelika Strohmayer, Martijn de Waal, and Ben Schouten. 2020. Making Civic Initiatives Last: Ecosystems, Technologies, Approaches and Challenges. In *Companion Publication of the 2020 ACM Designing Interactive Systems Conference*. ACM, Eindhoven Netherlands, 433–436. https://doi.org/10.1145/3393914.3395921

[40] Karin Hansson, Laura Forlano, Jaz Hee-jeong Choi, Carl DiSalvo, Teresa Cerratto Pargman, Shaowen Bardzell, Silvia Lindtner, and Somya Joshi. 2018. Provocation, conflict, and appropriation: the role of the designer in making publics. *Design Issues* 34, 4 (2018), 3–7.

[41] Mike Harding, Bran Knowles, Nigel Davies, and Mark Rouncefield. 2015. HCI, Civic Engagement & Trust. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems (CHI '15)*. Association for Computing Machinery, New York, NY, USA, 2833–2842. https://doi.org/10.1145/2702123.2702255

[42] Gillian R. Hayes. 2011. The relationship of action research to human-computer interaction. *ACM Transactions on Computer-Human Interaction* 18, 3 (July 2011), 1–20. https://doi.org/10.1145/1993060.1993065

[43] Claude P. R. Heath, Clara Crivellaro, and Lizzie Coles-Kemp. 2019. Relations are more than bytes: Re-thinking the benefits of smart services through people and things. In *Proceedings of the 2019 CHI conference on human factors in computing systems (CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–12. https://doi.org/10.1145/3290605.3300538

[44] Sara Heitlinger, Nick Bryan-Kinns, and Rob Comber. 2019. The Right to the Sustainable Smart City. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (CHI '19)*. Association for Computing Machinery, Glasgow, Scotland Uk, 1–13. https://doi.org/10.1145/3290605.3300517

[45] Yen-Chia Hsu, Jennifer Cross, Paul Dille, Michael Tasota, Beatrice Dias, Randy Sargent, Ting-Hao (Kenneth) Huang, and Illah Nourbakhsh. 2020. Smell Pittsburgh: Engaging Community Citizen Science for Air Quality. *ACM Transactions on Interactive Intelligent Systems* 10, 4 (Nov. 2020), 1–49. https://doi.org/10.1145/3369397

[46] Yen-Chia Hsu and Illah Nourbakhsh. 2020. When human-computer interaction meets community citizen science. *Commun. ACM* 63, 2 (Jan. 2020), 31–34. https://doi.org/10.1145/3376892

[47] Sara Hussein. 2018. 'Citizen scientists' track radiation seven years after Fukushima. https://phys.org/news/2018-03-citizen-scientists-track-years-fukushima.html

[48] Ian G. Johnson, Dalya Al-Shahrabi, and John Vines. 2020. From Creating Spaces for Civic Discourse to Creating Resources for Action. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems (CHI '20)*. Association for Computing Machinery, Honolulu HI USA, 1–14. https://doi.org/10.1145/3313831.3376464

[49] Somya Joshi and Teresa Cerratto Pargman. 2017. Every Little Bit Makes Little Difference: The Paradox within SHCI. In *Digital Technology and Sustainability: Engaging the Paradox*, Mike Hazas and Lisa Nathan (Eds.). Routledge, Cambridge, MA.

[50] Rushil Khurana and Steve Hodges. 2020. Beyond the Prototype: Understanding the Challenge of Scaling Hardware Device Production. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*. ACM, Honolulu HI USA, 1–11. https://doi.org/10.1145/3313831.3376761

[51] Barbara Kieslinger, Teresa Schäfer, Florian Heigl, Daniel Dörler, Anett Richter, and Aletta Bonn. 2018. Evaluating citizen science. Towards an open framework. In *Citizen science innovation in open science, society and policy*, Susanne Hecker, Mordechai Haklay, Anne Bowser, Zen Makuch, Johannes Vogel, and Aletta Bonn (Eds.). UCL Press, London, 81–95. http://www.jstor.org/stable/10.2307/j.ctv550cf2 OCLC: 1105395270.

[52] Sunyoung Kim, Christine Robson, Thomas Zimmerman, Jeffrey Pierce, and Eben M. Haber. 2011. Creek watch: pairing usefulness and usability for successful citizen science. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '11)*. ACM Press, Vancouver, BC, Canada, 2125. https://doi.org/10.1145/1978942.1979251

[53] Evangelos Kosmidis, Panagiota Syropoulou, Stavros Tekes, Philipp Schneider, Eleftherios Spyromitros-Xioufis, Marina Riga, Polychronis Charitidis, Anastasia Moumtzidou, Symeon Papadopoulos, Stefanos Vrochidis, Ioannis Kompatsiaris, Ilias Stavrakas, George Hloupis, Andronikos Loukidis, Konstantinos Kourtidis, Aristeidis K. Georgoulias, and Georgia Alexandri. 2018. hackAIR: Towards Raising Awareness about Air Quality in Europe by Developing a Collective Online Platform. *ISPRS International Journal of Geo-Information* 7, 5 (May 2018), 187. https://doi.org/10.3390/ijgi7050187 Number: 5 Publisher: Multidisciplinary Digital Publishing Institute.

[54] Bruno Latour. 2004. Why Has Critique Run out of Steam? From Matters of Fact to Matters of Concern. *Critical Inquiry* 30 (2004), 24.

[55] Christopher A. Le Dantec. 2016. Design through collective action / collective action through design. *interactions* 24, 1 (Dec. 2016), 24–30. https://doi.org/10.1145/3018005

[56] Christopher A. Le Dantec. 2016. *Designing publics*. The MIT Press, Cambridge, Massachusetts.

[57] Christopher A. Le Dantec, Mariam Asad, Aditi Misra, and Kari E. Watkins. 2015. Planning with Crowdsourced Data: Rhetoric and Representation in Transportation Planning. In *Proceedings of the 18th ACM Conference on Computer Supported Cooperative Work & Social Computing - CSCW '15*. ACM Press, Vancouver, BC, Canada, 1717–1727. https://doi.org/10.1145/2675133.2675212

[58] Christopher A. Le Dantec and Carl DiSalvo. 2013. Infrastructuring and the formation of publics in participatory design. *Social Studies of Science* 43, 2 (April 2013), 241–264. https://doi.org/10.1177/0306312712471581

[59] Christopher A. Le Dantec, Robert G. Farrell, Jim E. Christensen, Mark Bailey, Jason B. Ellis, Wendy A. Kellogg, and W. Keith Edwards. 2011. Publics in practice: ubiquitous computing at a shelter for homeless mothers. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '11)*. Association for Computing Machinery, Vancouver, BC, Canada, 1687. https://doi.org/10.1145/1978942.1979189

[60] Zihao Lin, Andrea Hamm, and Susanne Reinhardt. 2018. Political Communication Chinese Style: The Elite Network in State-Regulated Sina Weibo. In *Digital Media and the Politics of Transformation in the Arab World and Asia*, Carola Richter, Anna Antonakis, and Cilja Harders (Eds.). Springer Fachmedien Wiesbaden, Wiesbaden, 85–111. https://doi.org/10.1007/978-3-658-20700-7_5

[61] Can Liu, Mara Balestrini, and Giovanna Nunes Vilaza. 2019. From Social to Civic: Public Engagement with IoT in Places and Communities. In *Social Internet of Things*, Alessandro Soro, Margot Brereton, and Paul Roe (Eds.). Springer International Publishing, Cham, 185–210. https://doi.org/10.1007/978-3-319-94659-7_10

[62] Jennifer Manuel and Clara Crivellaro. 2020. Place-Based Policymaking and HCI: Opportunities and Challenges for Technology Design. In *Proceedings of the 2020 CHI conference on human factors in computing systems (CHI '20)*. Association for Computing Machinery, Honolulu HI USA, 1–16. https://doi.org/10.1145/3313831.3376158

[63] Philipp Mayring. 2014. *Qualitative Content Analysis: theoretical foundation, basic procedures and software solution*. SSOAR, Klagenfurt. http://nbn-resolving.de/urn:nbn:de:0168-ssoar-395173

[64] Albert Meijer and Suzanne Potjer. 2018. Citizen-generated open data: An explorative analysis of 25 cases. *Government Information Quarterly* 35, 4 (Oct. 2018), 613–621. https://doi.org/10.1016/j.giq.2018.10.004

[65] Susana Nascimento, Jose Miguel Rubio Iglesias, Roger Owen, Sven Schade, and Lea Shanley. 2018. Citizen science for policy formulation and implementation. In *Citizen Science: Innovation in Open Science, Society and Policy*, Susanne Hecker, Muki Haklay, Anne Bowser, Zen Makuch, Johannes Vogel, and Aletta Bonn (Eds.).

UCL Press, London, 219–240. https://doi.org/10.2307/j.ctv550cf2

[66] National Audubon Society. 2020. Frontpage. https://www.audubon.org/frontpage

[67] Nature Editorial. 2015. Rise of the citizen scientist. *Nature News* 524, 7565 (Aug. 2015), 265. https://doi.org/10.1038/524265a Section: Editorial.

[68] S. Papert, I. Harel, and I. Harel. 1991. Situating Constructionism. In *Constructionism*. Ablex Publishing, NJ, 1–11.

[69] Mayur Pateland, Jon Sotsky, Sean Gourley, and Daniel Houghton. 2013. *The emergence of civic tech: Investments in a growing field.* Technical Report. Knight Foundation. https://knightfoundation.org/wp-content/uploads/2019/06/knight-civic-tech.pdf

[70] Tiago Peixoto and Micah L. Sifry. 2017. *Civic Tech in the Global South : Assessing Technology for the Public Good.* World Bank and Personal Democracy Press, Washington, DC.

[71] Jennifer Preece. 2016. Citizen Science: New Research Challenges for Human–Computer Interaction. *International Journal of Human-Computer Interaction* 32, 8 (Aug. 2016), 585–612. https://doi.org/10.1080/10447318.2016.1194153

[72] Danial Qaurooni, Ali Ghazinejad, Inna Kouper, and Hamid Ekbia. 2016. Citizens for Science and Science for Citizens: The View from Participatory Design. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16)*. Association for Computing Machinery, San Jose California USA, 1822–1826. https://doi.org/10.1145/2858036.2858575

[73] Christoph Raetzsch, Gabriel Pereira, Lasse S Vestergaard, and Martin Brynskov. 2019. Weaving seams with data: Conceptualizing City APIs as elements of infrastructures. *Big Data & Society* 6, 1 (Jan. 2019), 205395171982761. https://doi.org/10.1177/2053951719827619

[74] Chiara Rossitto, Airi Lampinen, Susanne Bødker, Ann Light, Ketie Berns, and Julie Hui. 2020. Reconsidering Scale and Scaling in CSCW Research. In *Conference Companion Publication of the 2020 on Computer Supported Cooperative Work and Social Computing*. ACM, Virtual Event USA, 493–501. https://doi.org/10.1145/3406865.3419409

[75] Safecast. 2011. Safecast Talk by Joi Ito at MIT Media Lab autumn event. https://vimeo.com/30461917

[76] Safecast. 2020. Safecast. https://safecast.org/

[77] Judith Schoonenboom and R. Burke Johnson. 2017. How to Construct a Mixed Methods Research Design. *KZfSS Kölner Zeitschrift für Soziologie und Sozialpsychologie* 69, S2 (Oct. 2017), 107–131. https://doi.org/10.1007/s11577-017-0454-1

[78] Andrew Schrock. 2018. *Civic Tech: Making Technology Work for People* (1 ed.). Rogue Academic Press, Long Beach, CA. OCLC: 1101075474.

[79] Sensor.Community. 2020. Build your own sensor and join the worldwide civic tech network. https://sensor.community/en/

[80] Nick Taylor, Keith Cheverst, Peter Wright, and Patrick Olivier. 2013. Leaving the wild: lessons from community technology handovers. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '13)*. Association for Computing Machinery, Paris, France, 1549. https://doi.org/10.1145/2470654.2466206

[81] Vasillis Vlachokyriakos, Clara Crivellaro, Christopher A. Le Dantec, Eric Gordon, Pete Wright, and Patrick Olivier. 2016. Digital Civics: Citizen Empowerment With and Through Technology. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems (CHI EA '16)*. Association for Computing Machinery, San Jose, California, USA, 1096–1099. https://doi.org/10.1145/2851581.2886436

[82] Uta Wehn and Jaap Evers. 2014. Citizen observatories of water: Social innovation via eParticipation. In *ICT4S-14*. Atlantis Press, Stockholm, 1–10. https://doi.org/10.2991/ict4s-14.2014.1 ISSN: 2352-538X.

[83] Jamie Williams, Colin Chapman, Didier Guy Leibovici, Grégoire Loïs, Andreas Matheus, Alessandro Oggioni, Sven Schade, Linda See, and Paul Pieter Lodewijk van Genuchten. 2018. Maximising the impact and reuse of citizen science data. In *Citizen Science: Innovation in Open Science, Society and Policy*, Susanne Hecker, Muki Haklay, Anne Bowser, Zen Makuch, Johannes Vogel, and Aletta Bonn (Eds.). UCL Press, London, 321–336. https://doi.org/10.2307/j.ctv550cf2

[84] Wolfgang Schulz-Braunschmidt. 2014. Luftverschmutzung in Stuttgart: Blauer Feinstaub-Brief aus Brüssel. https://www.stuttgarter-zeitung.de/inhalt.luftverschmutzung-in-stuttgart-blauer-feinstaub-brief-aus-bruessel.1e264aac-69d6-4e92-9fd8-d9f9157a5180.html

Chapter 3: Civic IoT as an enabling technology for the Journalism of Things

This chapter was published as:

Andrea Hamm (2022) New Objects, New Boundaries: How the "Journalism of Things" Reconfigures Collaborative Arrangements, Audience Relations and Knowledge-Based Empowerment, Digital Journalism, https://doi.org/10.1080/21670811.2022.2096088.

Conclusion

This dissertation explores civic IoT as a socio-technical object from three different research perspectives, i.e., computing within limits, digital civics/civic tech, and digital journalism. It comprises three empirical multi-case studies to better understand the potentials of civic IoT. In this section, I will summarize the findings of the three studies and elaborate on the key conclusions and implications of the results of these studies. In the last parts of this dissertation, I address its limitations and provide suggestions for future research.

Chapter 1: Civic IoT as a tool for community-based environmental monitoring

The first study examines a large-scale civic IoT initiative seeking to disseminate new knowledge on air pollution by applying participatory design and reaching large visibility via local media. The aim of this study is to understand how, civic IoT might contribute to cities and communities becoming more sustainable related to a specific topic, i.e. air pollution, and in a specific geographical area, in this case the Stuttgart region.

Civic IoT contributes in multiple ways to cities and communities becoming more sustainable. I found that Luftdaten is complying with demands of the computing within limits field and broader conceptualizations of sustainable design. In particular, Luftdaten takes measures to minimize its resource consumption and emissions, while seeking to maximize its public output, openness of technologies, and its community's diversity. Luftdaten also aims at an independent and durable project funding. In this way, the initiative could serve as an example for responsible civic innovation.

This study indicates that civic IoT devices can have a minimum of embodied energy costs while having a comparatively large output, i.e., a worldwide locally-based community working on the monitoring of particulate matter and creating local implications on the public sphere and potential impacts on governance towards a more sustainable future.

The transparent open data and citizen-inclusive nature of civic IoT technology encourages people to engage in data monitoring, learning about the complexity of the measured issue. For example, open data provided by the civic IoT initiative Luftdaten has led a local news medium to generate a second data map on air pollution for the local area, named Feinstaubradar (engl. fine dust radar). Such a finding shows a particular importance of the air pollution topic for the broader public in this region.

Data from civic IoT can facilitate public understanding of an environmental matter that is based on empirical data and which hence could present potential evidence for future regulations. It also advances a heated public debate as it provides an empirical bases for people to argue rather than exchanging opinions, interests, and emotions. Furthermore, the design of civic IoT and data is crucial

for interpretating the provided information. Multiple methodological decisions, in particular, the quality of the sensors, the decision where to install them, the motivations of people to become engaged with the initiative, and decisions of the data visualization, will have an effect on the meaningfulness of civic IoT data for public information. The comparison of the two data maps *Luftdaten Karte* and *Feinstaubradar* illustrates how different visualization techniques of an almost identical dataset could cause misunderstandings on the recipients' side. In particular, such misunderstandings can be caused by design decisions in respect to coloration of data values and to the degree of data aggregation, which can be accurate to single houses (hyperlocal) or aggregated on a district level.

The findings also indicate how data from civic IoT technology can have an impact on individuals' behavior and engagement for a healthier lifestyle and for a more sustainable city. However, such impact depends on people's commitment to become engaged for air pollution and their pre-existing motivations and demand further research. From a broader societal perspective, one can conclude that civic IoT might be one of many particles that matter towards making cities and communities more sustainable.

Chapter 2: Civic IoT as the core technology for sustained civic engagement

In the second study, we have investigated internationally scaling civic IoT initiatives with regard to what makes them long-lasting. We interviewed their core team members, analyzed their Twitter communication and their online public materials. The two selected cases for this multi-case study came from Germany and Japan, namely Luftdaten and Safecast. Through this study design which includes two socio-culturally and geo-locational different cases, we were able to receive a certain generalizability on the long-lastingness of civic IoT initiatives.

We composed a non-exhaustive list of key factors for sustaining civic tech initiatives. These key factors were assigned three development phases that describe the evolution of the initiatives: Emergence, Growth, and Sustaining phases (see Figure 5 in Chapter 2, p. 44). The key factors are described in detail in chapter 2 and include the following points:

- Issue of public concern, i.e., environmental issues having impacts on residents' lives
- Competent core team, i.e., engaged citizens with competences in design and technology development
- Initial background network and further networking, i.e., existing relations to universities and supporting non-governmental organizations
- Access to material resources and openness, i.e., accessibility of technical equipment and principles of *open data* and *open source*
- Low-barrier technology, i.e., easy-to-use sensor kits, public documentation, and use of social media technologies

- Data applied by established institutions, i.e., citizen data successfully reused by other established institutions
- Attracting new community members, i.e., increasing visibility by, e.g., translating materials to other languages and conducting transfer events to reach broader publicity
- Increasing data sets and sensor stations, i.e., scaling the technical infrastructure and increasing available data on the issues of public concern
- Continuous funding, i.e., efforts taken to keep donors active
- Public communication, i.e., sharing their own data-driven environmental narrative
- Online and offline community building, i.e., create and enable spaces for community members to further develop the civic initiative
- Adaptability to changing contexts, i.e., reaching out towards other societal sectors

While the list of individual key factors is primarily informative for designers and core team members of civic IoT initiatives, researchers' interests might rather be met by discussing the key factors on a more abstract level. Therefore, we structured the discussion of our findings along four topics of scientific debate: (1) civic data and impact, (2) open civic tech, (3) public narratives on environmental issues, and (4) power structures. These four discussion topics will be summarized in the following four paragraphs.

In this study, we promote the term *civic data* that describes data that is both captured and owned by the citizens for the citizens. We learned about influencing effects in relation to civic data that have an effect on people's behaviors and decisions. For civic data, scientific precision is not the priority. Citizen-sensed data can be "just good enough" (Gabrys et al., 2016), when the data primarily serves a civic purpose. Such purposes can be awareness-raising on pollution issues and the pursuit of effecting change: Citizen-sensed data becomes "civic data", which can be re-used within further societal processes (Williams et al., 2018), for example for policy formulation and implementation (Nascimento et al., 2018). On this note, studies on "good enough data" (Gabrys et al., 2016) and "imperfect data" (Alvarado Garcia et al., 2017) emphasize the potentials of civic data for public information and discourse (Hecker, Luckas, et al., 2018), creating publicity (Gabrys et al., 2016), civic action (Boehner & DiSalvo, 2016), and social change (Alvarado Garcia et al., 2017). This means that civic data aims at providing citizens information to act upon the local matters of concern affecting them and future generations. Such imperfect, good-enough data (Alvarado Garcia et al., 2017; Gabrys et al., 2016) appears to be instrumental in creating high media attention, bringing established institutions to become involved and apply the citizen-collected data for their public information services, and engaging people worldwide.

When displayed in public space, civic data can represent a democratic participatory structure that increases the visibility of local groups and issues (Shibuya et al., 2021). For instance, IoT-based bicycle counter data increases the visibility of cyclists in cities and communities in the city and in the

digital spaces related to the city (Shibuya et al., 2021). Such public screens can become communicative objects circulating in digital media spheres, and information and meanings are reproduced in other public contexts (Raetzsch & Bødker, 2016).

To become involved in civic data, it is crucial that people have access to it. The investigated civic tech initiatives therefore constructed accessibility by following principles of open source and open data, providing *open civic tech*. The key factors "access to material resources and openness" and "low-barrier technology" account for this use of openly accessible technologies. The initiatives Luftdaten and Safecast are able to transmit not only within their respective local communities but also to a globally networked community. This ability depends on the existence of methods for interoperability (Castells, 2004; Williams et al., 2018) like application programming interfaces (API) to open and machine-readable data (Raetzsch et al., 2019). We learned that the shared value of openness is an essential condition for the initiative's rapid growth and scaling. For instance, both initiatives' core teams have in common that they are not giving top-down commands to the community but rely on the community's input and skills to evolve. People can join Safecast or Luftdaten without depending on the core team and contribute their own knowledge and skills. This decentralized nature helps keeping the community active and stable, and the initiative flexible (Heath et al., 2019), which relates to the key factor "Adaptability to changing contexts".

We also found that Luftdaten's and Safecast's scaling and sustaining is also linked to *public narratives on environmental issues* contributed by people involved in the initiatives. These "people" can be citizens, academics, media professionals, and employees of public institutions who are involved in the initiatives' activities such as gathering environmental data, analyzing it, programming technology, and running educational workshops. Luftdaten and Safecast are "socio-technical systems" meaning that their collected data is scarcely useful for knowledge production until people create narratives based on such data (Abe, 2013). Creating public narratives about data captured and sensors' use is an essential part of transferring knowledge, networking, and generating attention within and outside the communities. Such narratives are particularly linked with the key factors "public communication", "attract new community members," "data applied by established institutions," and "further networking."

The study includes a note on empowerment and pre-existing *power structures*. Luftdaten and Safecast were initially founded because local people would not accept the non-existence of data regarding particulate matter in the air and radioactively contaminated areas. They started collecting data by themselves to provide the lacking information for themselves and the public. Such social and technical configurations can have further democratic value (Vlachokyriakos et al., 2016). Citizens gain the ability to empower themselves and simultaneously tackling issues of common concern through using and designing technology by themselves (Balestrini et al., 2017; Heitlinger et al., 2019). Nevertheless, certain particularities of the initiatives are linked to imbalances of power or inequities (re)producing

influence and power structures which are recently discussed in critical scholarship on civic technologies (Bidwell, 2020a, 2020b). The key factors "competent core team", "initial background network and further networking," "access to material resources and openness," "continuous funding," and "data applied by established institutions" are all relating to such pre-existing power structures. Last but not least, we also recognized the full male founding teams of Luftdaten and Safecast that are probably caused by but also reproducing gender imbalances in the technological domain (see for example Ahmadi et al., 2018).

The findings of chapter 2 particularly contribute to scientific discussions on sustained digital civics in the field of human-computer interaction. The study has been published as a double-blind reviewed proceedings article of the top-tier computer science conference ACM Human Factors in Computing Systems (CHI'21).

Chapter 3: Civic IoT as an enabling technology for the Journalism of Things

The third study takes a look at recent German projects in digital journalism leveraging IoT technology. Civic IoT is introduced as a new object of journalism that leads to new boundaries of journalistic work around the new paradigm of a Journalism of Things (JoT), in which particular civic IoT technologies are used for journalistic work.

In this study, I have investigated three cases of JoT. The study included interviews with journalists in JoT, observations of their public events, and reviews of related public articles and internal documents. This article translates the JoT paradigm to the scholarly discussion and offers the following extended definition as a major outcome of the study: *Journalism of Things (JoT) is a new paradigm in digital journalism where journalists co-create sensor technologies with citizens, scientists, and designers generating new kinds of data-based and community-driven insights to provide a novel perspective on matters of common concern. JoT is characterized by various technological objects confronting journalists with boundary work. It can be studied by considering four phases of journalistic production: formation, data work, presentation, and ramification. The phases include collaborative arrangements on different levels and result in newly created knowledge and empowerment. Practices in JoT show elements of social activism, science, and design. JoT addresses the needs of locally concerned people while borrowing methods and revenue models from science*.

The study reveals phases of JoT project that allow a better understanding of the journalistic production process in JoT and a more profound analysis of boundary work practices and further implications of *things* in journalism. The four phases observed in JoT projects are: Formation, data work, presentation, and ramification. In the *formation phase*, the journalistic idea is developed, IoT technology design and use is planned, and the story is imagined data. In the *data work phase*, the actual IoT data on matters of common concern is generated by using scientific methods. This phase also includes mobilize a local

community while co-creating with experts from science and design. In the *presentation phase*, the IoT data story is prepared and published in multimodal forms, such as online and print articles, web apps, maps, and automated texts. Finally, the *ramification phase* is subsequent to the core journalistic production process, it broadly describes behavioral changes and technology-based civic influence (Aragon et al., 2020), which may include policy changes, new regulations, and broader societal and civic awareness. Ramifications can be understood as outcomes of circulations when journalistic texts are re-activated and re-contextualized after publication through digital circulation (Raetzsch & Bødker, 2016).

Along the four phases, JoT shows journalistic boundary work increasingly blurred (Usher, 2018). The study revealed on the one hand practices and approaches that resemble research activities and scientific work, and on the other hand community mobilization practices and engagement for matters of common concern that are more closely related to constructive activism. Journalists in JoT seek to provide a new perspective on local contested matters, such as bicycle safety, insect mortality, and air pollution. Journalist adopt scientific approaches together with researchers. In particular, they design devices, the data collection process, and analysis methods, build prototypes, and interpret the data for a journalistic story. Simultaneously, the journalists' motivation is to raise awareness and facilitate change and improvement similar to intentions of constructive activism. The journalists identify themselves with a matter of common concern and aim at advancing the debates which are often stuck. The Figure 1 in Chapter 3 shows how the four phases of JoT are characterized by boundary work towards activist, scientific and design practices (see p. 63). Drawing on these observations, I found that JoT has primarily three implications which are elaborated on in more detail in the following three paragraphs on: (1) collaborative arrangements, (2) audience relationships, (3) empowerment, and (4) knowledge generation.

The study suggests that JoT is reconfiguring collaborative arrangements in journalism. Journalists have to learn about scientific and design practices. Scientists and designers need to understand journalistic production. Both groups depend on each other and are equally responsible for mobilizing the community and surveilling the participatory data gathering. Such co-creation leads to a lengthy process that poses a challenge when facing journalistic publishing schedules. Sensor projects are more time-intensive than usual journalistic projects. High efforts can lead to a clash of working routines (D'Ignazio & Zuckerman, 2017). Simultaneously, the co-creation of three stakeholder groups (i.e., journalists, technical experts, and citizens) with multiple backgrounds seeking to achieve a common goal can provide more meaningful outputs for society (Ruoslahti, 2020).

JoT is transforming traditional audience relationships and represents a reply to relational journalism's demands that "puts *the building and maintaining of relationships with publics it normatively serves* at the center of its work" (Lewis, 2020, p. 347 emphasis original). Feedback and crowdsourcing elements of JoT allow audiences to partially shape the story from their view, similar to reciprocal journalism

(Gutsche et al., 2017). Journalists appear as people sharing the interests with their readers and become engaged in bringing matters of common concern to public attention through new modalities of digital technologies.

The study of objects in journalism is related to questions of power and promotes a more relational understanding of technologies in and for journalism (Anderson & De Maeyer, 2015). Technological objects often lead to journalists' dependence pre-structured "black box data categories" (Lowrey & Hou, 2021). However, in JoT journalists empower themselves to control the technology and fully understand the data output. Journalists in JoT professionally decide on the topic to cover, which strengthens journalistic independence in a democratic society while supporting the needs of local communities. Technology empowers journalists and citizens because, in JoT, citizens' interests are covered more intensively. The independent production of devices and data products with support from scientists and domain experts ensures that JoT journalists thoroughly understand the data gathered and dutifully create suitable categories. Such locally self-collected data can update journalism's institutional role in society because JoT can unleash ramifications. The case studies suggested that court decisions have been rectified with the help of JoT data and that readers changed their behavior due to JoT messenger communication. Such ramifications underline how JoT can impact society and foster behavioral and regulatory change while strengthening the societal representation of less-represented groups and species.

Finally, this study adds a new perspective on the scholarly discussion on journalistic evidence, because observations of this study suggest that the distinction between technology-based knowledge and testimony-based knowledge in journalism (Godler et al., 2020) becomes partly dissolved in JoT. Technologies and data are co-created by a journalistic-scientific team who is designing, prototyping, and testing the IoT until it delivers the data in sufficient quality. The data becomes journalistic evidence (Godler & Reich, 2017). Journalists co-create such evidence by asking researchers and domain experts to evaluate the devices and the data. Communities take an active part in journalistic sourcing as they are the ones to whom the sensor devices are distributed for collecting the data. As crowdsourcing subjects, citizens have certain freedoms in using the sensor device to generate knowledge, such as choosing particularly dangerous routes for cycling. Citizens can add their own slight bias to the overall dataset and hence infuse the data with their perspective.

The findings in chapter 3 particularly contribute to scientific discussions on implications of objects on digital journalism in the field of journalism studies. It is accepted for publication in the Taylor & Francis journal Digital Journalism.

Key conclusion and implications: Civic IoT as a socio-technical object

How civic IoT impacts people and society cannot be answered within one scientific discipline. The challenge for researchers is to approach such a question from multiple directions for sufficient understanding. Consequently, this dissertation takes further steps toward this interdisciplinary groundwork.

In this dissertation, I describe impacts of civic technology on citizen and local publics that can go further than previous work described. For instance, the scholarly discussion on civic technology potentials is already advanced in terms of raising awareness (Balestrini et al., 2017; Liu et al., 2019a), telling data stories (Gabrys et al., 2016), and disseminating environmental information for public purposes (Bibri, 2018; Pargman et al., 2019; Tavmen, 2020). A new aspect to the discussion is that civic IoT technologies provide new knowledge and information for the public with modest but significant political intentions which are consequently translated into citizen participation and journalism. These activities are less relying on opinions and political views, but more on empirical data collected, though such information is not free of diverging interpretations (see for example data map comparison in Figure 3 in Chapter 1 on p. 27).

Civic IoT is observed as helpful for social change and societal progress, including a transition towards sustainable cities and communities in terms of limited use of resources, sustaining participatory design by default, and potentials for an improved institutional role of journalism. This dissertation reveals three important implications that civic IoT yields in the context of an increasingly digitalized world:

(1) Empowerment of people to make their own decisions and to stay informed about their environment and its transformation,
(2) Importance of communication and communities to mediate transformation processes and enabling participation, and
(3) Need of new collaborative arrangements towards new terrains of activity in community engagement and journalism.

(1) Civic IoT empowers citizens who would usually rely on authorities' information and services to understand complex socio-environmental phenomena. Civic IoT is characterized by principles of open data, open knowledge, an accessible software environment, and low-cost materials. Such characteristics allow a broad participation of diverse groups of people in generating knowledge of public importance. Volunteer data collectors contribute to societal debates and potentially to regulatory changes and decision-making. Civic data is data that is collected by citizens and for citizens to provide them guidance in making decisions in their daily lives. Such decisions can be which cycling route to choose through the city, when to hang the laundry outside, and where to move to be in a less radioactively polluted place. Civic data help people to make their own decisions and to stay informed about their environment and its transformation.

(2) Communication and media are important to produce public visibility for matters of common concern and to create common meaning from the technology and data. In a democratic society, change and progress cannot be installed in a top-down manner, the societies have to agree with them. Legitimacy of such a process has to grow over time. Civic IoT enables journalists to cover topics of societal importance through generating and providing previously non-existent data and evidence. Accessible technology empowers journalists who step out of the daily journalistic production routine and dive into boundary work. The technology provides the instrumental basis for a multifaceted communication on environmental issues by enabling democratic participation. Engaged people, designers, media workers and journalists join to generate unprecedented data that allows to promote topics of common concern. Civic IoT helps people to take a new perspective on such topics like air pollution, insect mortality, and bicycle safety. The vision of a "journalism of things" enables journalists to create journalistic incentives by themselves. The technology design, the collaboration with scientists and citizens, and the collection and interpretation of previously non-existent data generates sufficient news value for topics to be of interest for a broader audience.

(3) The use of technologies demands a substantial amount of skill, time, and knowledge from citizens and journalists. Civic IoT technologies are transforming community engagement and journalism towards boundary work and new terrains of activity. The data obtained exerts certain meaning on the engagement which is reproduced in community building and public narratives. Still, the complexity of socio-environmental matters translates into the less decisive attitude and a rather professional behavior of the initiatives towards the public, the government, and the administration. Civic tech initiatives and journalism seems to have a similar ideology when it comes to informing people and seeking for knowledge on contentious issues. They intend to provide new knowledge resources and improve information quality and meaningfulness for people.

Limitations

As this dissertation consists of multiple case studies, the findings have limited representativity. Such a limitation is not unusual in the field of civic technologies in which studies always rely on specific communities and technologies as an object of research. As explicated in chapter 2, cases are embedded in their respective ecosystems (e.g., geography, culture, politics, economy) which complicates to make conclusions from one case to another.

What further limits this dissertation is the studies' approach via the lenses of the civic IoT core teams, in particular the lead designers, administrators, and journalists. This limitation is partially caused by the restrictions in context of the covid19 pandemic which interdicted traveling to conduct fieldwork but which was also the reason why community meetings were cancelled. Furthermore, the choice to analyze the core teams entails that those other voices from the community are missing. Particularly, I

would like to mention that the Twitter analysis in chapter 2 is missing members of the civic tech community who are not on Twitter.

In chapter 3, another limitation is that due to data protection regulations the journalists could not allow me to contact any of the citizen participants of the Journalism of Things projects. Some important voices might not be included due to this circumstance.

Finally, I would like to add that the exploratory designed multi-case studies presented in this dissertation are a step towards an interdisciplinary terrain. I might have missed additional effects, factors, and boundaries that are of relevance to this field which motivates future studies in these directions.

Outlook

Current technological fields strongly led by marketing campaigns and prone to hypes. As a researcher, it is difficult to access the field and to accurately focus on the research object, as there is a diversity of claims, expectations, and buzz words existing in the field. The term IoT itself is a marketing term which is not often used by civic initiatives themselves. Originally, the term is related to industrial applications such as smart factories and the Industrie 4.0. But several researchers worked on reframing the IoT term (Atzori et al., 2012; Liu et al., 2019b; Soro et al., 2018) and contributed to make it more useful for societal debates. It important to show how basic technical solutions are very similar no matter if they are deployed for civic or industrial purposes. Such a "mainstreaming" of scientific terms also helps scholars from different disciplines to collaborate better in future.

I would like to encourage more interdisciplinary work on technological phenomena and objects. Future work may take a look at multiple academic disciplines to select for the ones that are most suitable to conduct research on a technological object. Though it presents a particular challenge to overcome differences in scientific languages, terms, and concepts in each domain, it leads to a broader understanding on how the technology is framed and understood. Sometimes numerous terms appear in the literature, all naming the same phenomenon. For instance in this dissertation, such terms have been civic tech, civic IoT, citizen science, citizen technology, smart citizen, open data, and environmental monitoring. It is useful to connect multiple academic fields to each other in order to receive more meaningful findings on a technological object. Finally, it might also allow to advance not just one but several fields at a time.

Future work on civic IoT may address issues that call for further consideration and research which would have gone beyond the scope of this dissertation. These issues are in particular relating to:

- Citizen science and questions on data quality, sensor device testing and improvements, and a contemporary understanding of knowledge production with the help of distributable IoT technology and ubiquitous measuring.
- Civic IoT as a counter to disinformation campaigns and actors, particularly considering trust relations towards organizations, technologies, and data. It would be interesting to investigate if people's trust in data and science would increase when they learn about civic IoT initiatives working on matters of common concern.
- Legitimization of civic initiatives with regard to collaborating with or contributing knowledge to the work of governments, authorities, and administration. Such a research perspective includes roles of journalism in a society and also highlights the importance of independent bodies providing guidance in ubiquitous digital innovation such as journalism awards.
- Observation of outsourcing of public tasks to engaged people and volunteer groups. Administration and governments could employ civic actor groups dedicated to issues of common concern to become part of official urban/rural development processes. It would be interesting to design multistakeholder collaborations and to compare the outcomes of such experiments with existing models of urban/rural development.

References

Abe, Y. (2013). *Why Safecast matters: A case study in collective risk assessment*. STS Forum on the East Japan Disaster.

Ahmadi, M., Weibert, A., Ogonowski, C., Aal, K., Gäckle, K., Marsden, N., & Wulf, V. (2018). Challenges and lessons learned by applying living labs in gender and IT contexts. *Proceedings of the 4th Conference on Gender & IT*, 239–249. https://doi.org/10.1145/3196839.3196878

Alvarado Garcia, A., Young, A. L., & Dombrowski, L. (2017). On Making Data Actionable: How Activists Use Imperfect Data to Foster Social Change for Human Rights Violations in Mexico. *Proceedings of the ACM on Human-Computer Interaction, CSCW*, *1*, 1–19. https://doi.org/10.1145/3134654

Anderson, C. W., & De Maeyer, J. (2015). Objects of journalism and the news. *Journalism*, *16*(1), 3–9. https://doi.org/10.1177/1464884914545728

Aragon, P., Alvarado Garcia, A., Le Dantec, C. A., Flores-Saviaga, C., & Saldivar, J. (2020). Civic Technologies: Research, Practice and Open Challenges. *Conference Companion Publication of the 2020 on Computer Supported Cooperative Work and Social Computing*, 537–545. https://doi.org/10.1145/3406865.3430888

Atzori, L., Iera, A., Morabito, G., & Nitti, M. (2012). The Social Internet of Things (SIoT) - When social networks meet the Internet of Things: Concept, architecture and network characterization. *Computer Networks: The International Journal of Computer and Telecommunications Networking*, *56*(16), 3594–3608. https://doi.org/10.1016/j.comnet.2012.07.010

Balestrini, M., Rogers, Y., Hassan, C., Creus, J., King, M., & Marshall, P. (2017). A City in Common: A Framework to Orchestrate Large-scale Citizen Engagement around Urban Issues. *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*, 2282–2294. https://doi.org/10.1145/3025453.3025915

Bibri, S. E. (2018). The IoT for smart sustainable cities of the future: An analytical framework for sensor-based big data applications for environmental sustainability. *Sustainable Cities and Society*, *38*, 230–253. https://doi.org/10.1016/j.scs.2017.12.034

Bidwell, N. J. (2020a). Wireless in the Weather-world and Community Networks Made to Last. *Proceedings of the 16th Participatory Design Conference 2020 - Participation(s) Otherwise - Volume 1*, 126–136. https://doi.org/10.1145/3385010.3385014

Bidwell, N. J. (2020b). Women and the Sustainability of Rural Community Networks in the Global South. *Proceedings of the 2020 International Conference on Information and Communication Technologies and Development*, 1–13. https://doi.org/10.1145/3392561.3394649

Castells, M. (Ed.). (2004). *The Network Society*. Edward Elgar Publishing. https://doi.org/10.4337/9781845421663

D'Ignazio, C., & Zuckerman, E. (2017). Are We Citizen Scientists, Citizen Sensors or Something Else Entirely? Popular Sensing and Citizenship for the Internet of Things. In B. S. De Abreu, P. Mihailidis, A. Y. L. Lee, J. Melki, & J. McDougall (Eds.), *International handbook of media literacy education*. Routledge, Taylor & Francis Group.

Gabrys, J., Pritchard, H., & Barratt, B. (2016). Just good enough data: Figuring data citizenships through air pollution sensing and data stories. *Big Data & Society*, *3*(2), 205395171667967. https://doi.org/10.1177/2053951716679677

Godler, Y., & Reich, Z. (2017). Journalistic evidence: Cross-verification as a constituent of mediated knowledge. *Journalism*, *18*(5), 558–574. https://doi.org/10.1177/1464884915620268

Godler, Y., Reich, Z., & Miller, B. (2020). Social epistemology as a new paradigm for journalism and media studies. *New Media & Society*, *22*(2), 213–229. https://doi.org/10.1177/1461444819856922

Gutsche, R. E., Jacobson, S., Pinto, J., & Michel, C. (2017). Reciprocal (and Reductionist?) Newswork: An examination of youth involvement in creating local participatory environmental news. *Journalism Practice*, *11*(1), 62–79. https://doi.org/10.1080/17512786.2015.1111159

Heath, C. P. R., Crivellaro, C., & Coles-Kemp, L. (2019). Relations are more than bytes: Re-thinking the benefits of smart services through people and things. *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*, 1–12. https://doi.org/10.1145/3290605.3300538

Heitlinger, S., Bryan-Kinns, N., & Comber, R. (2019). The Right to the Sustainable Smart City. *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*, 1–13. https://doi.org/10.1145/3290605.3300517

Lewis, S. C. (2020). Lack of trust in the news media, institutional weakness, and relational journalism as a potential way forward. *Journalism*, *21*(3), 345–348. https://doi.org/10.1177/1464884918807597

Liu, C., Balestrini, M., & Vilaza, G. N. (2019a). From Social to Civic: Public Engagement with IoT in Places and Communities. In A. Soro, M. Brereton, & P. Roe (Eds.), *Social Internet of Things* (pp. 185–210). Springer International Publishing. https://doi.org/10.1007/978-3-319-94659-7_10

Liu, C., Balestrini, M., & Vilaza, G. N. (2019b). From Social to Civic: Public Engagement with IoT in Places and Communities. In A. Soro, M. Brereton, & P. Roe (Eds.), *Social Internet of Things* (pp. 185–210). Springer International Publishing. https://doi.org/10.1007/978-3-319-94659-7_10

Lowrey, W., & Hou, J. (2021). All forest, no trees? Data journalism and the construction of abstract categories. *Journalism*, *22*(1), 35–51. https://doi.org/10.1177/1464884918767577

Pargman, T. C., Joshi, S., & Wehn, U. (2019). Experimenting with Novel Forms of Computing: The case of the Swedish Citizen Observatory for Water Quality Conservation. *Proceedings of the Fifth Workshop on Computing within Limits - LIMITS '19*, 1–10. https://doi.org/10.1145/3338103.3338111

Raetzsch, C., & Bødker, H. (2016). Journalism and the Circulation of Communicative Objects. *TECNOSCIENZA: Italian Journal of Science & Technology Studies*, *7*(1), 129–148.

Raetzsch, C., Pereira, G., Vestergaard, L. S., & Brynskov, M. (2019). Weaving seams with data: Conceptualizing City APIs as elements of infrastructures. *Big Data & Society*, *6*(1), 205395171982761. https://doi.org/10.1177/2053951719827619

Ruoslahti, H. (2020). Complexity in project co-creation of knowledge for innovation. *Journal of Innovation & Knowledge*, *5*(4), 228–235. https://doi.org/10.1016/j.jik.2019.12.004

Soro, A., Brereton, M., & Roe, P. (2018). *Social Internet of Things*. Springer.

Tavmen, G. (2020). Data/infrastructure in the smart city: Understanding the infrastructural power of Citymapper app through technicity of data. *Big Data & Society*, *7*(2), 205395172096561. https://doi.org/10.1177/2053951720965618

Usher, N. (2018). Hacks, Hackers, and the Expansive Boundaries of Journalism. In S. A. Eldridge & B. Franklin (Eds.), *The Routledge Handbook of Developments in Digital Journalism Studies* (1st ed., pp. 348–359). Routledge. https://doi.org/10.4324/9781315270449

Vlachokyriakos, V., Crivellaro, C., Le Dantec, C. A., Gordon, E., Wright, P., & Olivier, P. (2016). Digital Civics: Citizen Empowerment With and Through Technology. *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*, 1096–1099. https://doi.org/10.1145/2851581.2886436

Williams, J., Chapman, C., Leibovici, D. G., Loïs, G., Matheus, A., Oggioni, A., Schade, S., See, L., & van Genuchten, P. P. L. (2018). Maximising the impact and reuse of citizen science data. In S. Hecker, M. Haklay, A. Bowser, Z. Makuch, J. Vogel, & A. Bonn (Eds.), *Citizen Science: Innovation in Open Science, Society and Policy* (pp. 321–336). UCL Press. https://doi.org/10.2307/j.ctv550cf2

Appendix

List of previous publications resulting from this dissertation:

(1) **Hamm, A.** (accepted). New Objects, New Boundaries: How the "journalism of things" reconfigures collaborative arrangements, audience relations, and knowledge-based empowerment. In: *Digital Journalism*. https://doi.org/10.1080/21670811.2022.2096088 (double-blind reviewed)

(2) **Hamm, A.**; Shibuya, Y.; Ullrich, S., & Cerratto Pargman, T. (2021). What Makes Civic Tech Initiatives To Last Over Time? Dissecting Two Global Cases. In: *Proceedings of the ACM Conference on Human Factors in Computing Systems* (CHI '21), May 8–13, 2021, Yokohama, Japan. ACM, New York, NY, USA. https://doi.org/10.1145/3411764.3445667 (double-blind reviewed)

(3) **Hamm, A.** (2020). Particles Matter: A Case Study on How Civic IoT Can Contribute to Sustainable Communities. In: *Proceedings of the 7th International Conference on ICT for Sustainability* (ICT4S 2020), June 21 - 26, 2020, Bristol, UK. ACM, NY, USA. https://doi.org/10.1145/3401335.3401815 (peer-reviewed)