Unravelling the Human Perspective and Considerations for Urban Data Visualization

Sarah Goodwin [*] Monash University
Sebastian Meier[†] HafenCity University
Lyn Bartram [‡] Simon Fraser University
Alex Godwin [§] American University
Till Nagel [¶] Mannheim University of Applied Sciences
Marian Dörk [‖] Potsdam University of Applied Sciences

Figure 1: CityVis Workshop (W1): a) Note Taking, b) Presentations, c) Group Brainstorming, d) Documenting Findings

Abstract

Effective use of data is an essential asset to modern cities. Visualization as a tool for analysis, exploration, and communication has become a driving force in the task of unravelling our complex urban fabrics. This paper outlines the findings from a series of three workshops from 2018-2020 bringing together experts in urban data visualization with the aim of exploring multidisciplinary perspectives from the human-centric lens. Based on the rich and detailed workshop discussions identifying challenges and opportunities for urban data visualization research, we outline major human-centric themes and considerations fundamental for CityVis design and introduce a framework for an urban visualization design space.

Index Terms: Human-centered computing—Interaction design—Interaction design process and methods; Human-centered computing—Visualization—Visualization design and evaluation methods

1 Introduction

The exponential growth of urban data brings opportunities for complex data analytics of integrated data sources, reveals new patterns in human behavior, and improves our understanding of urban environments (e.g., [15, 24]). Yet the capacity to manage, explore, form hypotheses, make sense of, and interpret patterns in the data presents a huge barrier for comprehensive analysis, communicating issues and policies, and engaging diverse stakeholders in decision making: all common goals of smart city strategies. There is a crucial need to bridge the gap between the flood of urban data, the capacity of decision makers to integrate that data into effective and informed decisions, and the ability for citizens, businesses, and other urban organizations to comprehend and contribute. This surge of urban data is driving new directions in visualization research pertaining to urban concerns. Akin to trans-disciplinary visualization research that intersects with other fields such as art (VISAP) or biology (BioVis), an urban data visualization research community is emerging under the umbrella term 'CityVis'. With connections to urban informatics, planning, architecture, and geography, CityVis focuses on the visualization of urban phenomena (see [36] for a detailed survey).

Table 1: CityVis workshop series details. *Virtual due to COVID19

ID	Year	Conference	Location	Workshop focus
W1	2018	IEEE VIS	Berlin, DE	CityVis Themes
W2	2019	IEEE VIS	Vancouver, CA	Role of Citizens
W3	2020	ACM e-Energy	Melbourne, AU*	Domain. Energy

The connection between visualization and cities is not new; in fact, the history of information visualization is tightly linked with urban development. John Snow's dot map of Cholera cases is a poster child for early urban data visualization. Another classic in visualization history is the ISOTYPE picture language devised to inform and educate citizens about economic and urban development [32]. The premise behind these efforts was that informing a citizenry would require the development of a visual system that conveys complex developments. This ethos reverberates in Wurman's plea to make cities observable, which "implies allowing the city to become an environment for learning" [35]. We now see a growing recognition of the need for visibility of complex urban issues to substantiate the political discourse about current challenges for cities such as climate change and urbanisation itself [8].

Data visualization offers rich opportunities to address urban issues, but techniques alone are insufficient. Different city perspectives —from governments and companies to citizens—can dramatically influence the design and adoption of CityVis solutions [9, 23, 27]. Building on feedback from the first CityVis competition in 2016 (exhibited at the UN Habitat conference in Quito, Ecuador), a series of CityVis workshops were initiated with the visualization community to explore the growing need for innovative methods, approaches, and perspectives within urban data visualiza-

[*]e-mail: sarah.goodwin@monash.edu
[†]e-mail: sebastian.meier@hcu-hamburg.de
[‡]e-mail: lyn_bartram@sfu.ca
[§]e-mail: godwin@american.edu
[¶]e-mail: t.nagel@hs-mannheim.de
[‖]e-mail: doerk@fh-potsdam.de

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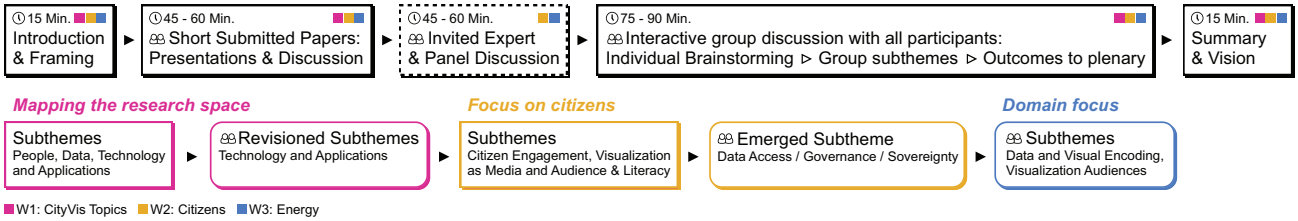

Figure 2: CityVis workshop flow. Panel discussions introduced for W2 (with practitioners) and W3 (energy experts) based on feedback from W1.

tion. The CityVis workshop series focuses explicitly on human-centric, rather than technological perspectives, seeking to acknowledge the profound role that social contexts play in the impact and adoption of urban data and technology.

This paper reports on three CityVis workshops run from 2018-2020 (see Table 1). This workshop series was designed and managed by an international organiser and program committee of researchers and practitioners that evolved and diversified as the series progressed (see `www.cityvis.io` for more details).

This paper contributes to the urban visualization discourse on two levels. On the one hand this paper is a documentation of workshop planning, methods, outcomes and insights. We hope this can inspire other academic workshop organisers to document and reflect on their processes. On the other hand, ensuring that the outputs of these rich workshop discussions reach a broader audience, this paper describes how the workshop's methodology has led to the emergent themes, challenges, and goals of urban data visualization. These outcomes contribute to the visualization community and beyond, to help guide, scope and frame future research activities in urban data visualization.

2 Evolving Workshop Theme

Each CityVis workshop was held in a different city, country, and continent with different, albeit complementary, focus areas, yielding a diversity of cultural and domain perspectives over the series.

2.1 Workshop Overview and Structure

The workshops were designed to include research papers, reports from the field, and collaborative brainstorming sessions. This ensured they were highly interactive and rich in discussions. Each were structured using a similar format (as documented in Fig. 2). This included a short introduction, presentations and discussions; then participants broke into subgroups to brainstorm issues, goals, and challenges in identified subtopics before coming together in a plenary session to cohere and identify emergent themes. As highlighted in Fig. 2, not only did the findings evolve, but the workshop design improved for each iteration. Following feedback at the end of W1, a practitioners panel was added in W2 and W3 that brought in expert perspectives beyond the core visualization community.

Papers were short in format and peer-reviewed[1]. Paper (W1: 9, W2: 8 and W3: 4) and panel talks (W2: 3 and W3: 4) were kept concise (approximate timings are provided in Fig. 2) to allow as much time as possible for discussions. The core outcomes of the workshops, however, arose from the collaborative explorations in the brainstorming sessions. Well-known design thinking techniques [18] were employed to foster an inclusive atmosphere while jointly seeking the definition of the field. In order to give everyone a chance to provide their perspectives on what 'urban data visualization' meant with respect to each workshop's focus, the interactive session began with individual brainstorming, where participants were encouraged to write their thoughts and ideas on post-it notes. Throughout the workshop different note colors were used to distinguish *goals* and *challenges* of the domain (see Fig. 1). These were arranged and clustered on sheets dedicated to a particular subtheme (described in Sec. 2.2). Smaller working groups were created around each subtheme where participants had more in-depth discussions, using different techniques like card sorting, affinity diagramming and content mapping to organize ideas (see Fig. 1). Finally, each working group presented their findings to the whole workshop, leading to an overall discussion.

2.2 Evolving Topics and Themes

Each of the workshops' call for papers included broad CityVis topics: Human visualization interaction and user-centric design; Urban data; Disruptive technologies; Visualization contexts; and Visualization challenges[2]. The workshop focus and subthemes differed:

W1: People, Data, Technology and Applications: For the first workshop, four subthemes were proposed for the brainstorming phase to link user-centered design, urban data scope, the use of emerging technologies, and the variety of urban applications: *People*, *Data*, *Technology* and *Applications*.

Whilst *Technology* and *Applications* had been envisaged to include emerging and disruptive technologies, as well as potential application domains and scenarios, the subtheme groups critically reflected that technologies are usually case-specific and difficult to generalize and applications on the other hand are too manifold. Interestingly, whilst each group generated valuable and distinct insights, all groups commented on how the subtheme goals and challenges related to data and citizens. The role of citizens was an important motif emerging in all four subgroups.

W2: The Role of the Citizen(s): While the human-centric aspects of CityVis had been a goal of the workshops from the beginning, in W2 the goal focused on the role of citizen stakeholders in urban data visualization and how this can impact visualization design. Three subthemes were chosen for the brainstorming phase, based on findings from W1: *Citizen Engagement*, *Visualization as Media*, and *Audience & Literacy*. A fourth subtheme of *Data Access / Governance / Sovereignty* emerged during the workshop. Some common themes arose across all groups related in particular to data literacy, diversity, and inclusivity.

W3: Visualizing Energy Resilient Cities: In W3, discussions were focused on the specific urban domain of energy and the workshop itself was conducted at an energy conference (see Table 1). This aimed to bring together scientists, researchers, and practitioners from the energy field to discuss their challenges and goals[3]. Rather than proposing subthemes prior to the workshop, these were allowed to evolve naturally from clustering the goals and challenges from the individual brainstorming exercise. Two subthemes appeared: the first linked to the technical aspects of *Data & Visual Encoding*, and the second the more human-centric perspective of *Visualization Audiences*. During the subsequent break-out discussion these merged as they were found to be heavily connected.

[1] Accepted papers are available as proceedings on `www.cityvis.io`

[2] See `www.cityvis.io` for each call for papers for W1-W3

[3] Whilst the virtual format allowed for leading international speakers to be involved, networking and bespoke discussions were more difficult.

3 CityVis Design Considerations

Data visualization offers rich opportunities to address urban issues, but techniques alone are insufficient. The workshop series has allowed us as a community to collectively reflect on goals and challenges within the emerging domain of urban data visualization. Ten overarching consideration themes (**C1**–**C10**) materialized and evolved throughout the three workshops (see 2.1). These considerations are described in Sec. 3.1. Through the continued analysis of the insights and findings of the workshop series, five-dimensions (**D1**–**D5**) are proposed as a preliminary human-centric CityVis design space, as described in Sec. 3.2.

3.1 10 Considerations for CityVis Designers

C1: Data Quality and Quantity: Data granularity, reliability, and quality are all important challenges to consider that heavily impact visual output. This includes how and why data is collected (i.e. what questions are asked?) and the use of proxy data (i.e. how representative is it?). It is affected by the lack of common architectures: without common systems to collect, collate, and present data about cities, comparison across time or location is nearly impossible. Furthermore, the complexity of cities is reflected in the complexity of the data, which has its own visualization challenges (e.g. How much detail is needed? Is there too much data? Or not enough of the right type of data?). Whilst new types of data sources such as social media are recognized as critical in the generation and exchange of knowledge [2, 4, 5, 36], the ability for citizens to directly input data through crowd-sourcing has implications on data ethics and has privacy concerns (e.g. [25]).

C2. Physical Context and Infrastructure: City visualizations need to critically reflect the circumstances of data collection and the implications of the design decisions [9]. Arguably, the physical and technical infrastructure of the city can be mapped, viewed, and analyzed as cultural artefacts [13], likewise we can consider visualizations of urban phenomena as specific cultural forms. One of the most prevalent visualization types, the visualization dashboard, has found many applications in the monitoring and control of urban infrastructure [14]. Understanding the implicit relationships of how the actual physical location of a city space and the user's 'sense of place' interact brings a greater challenge.

C3. Complexity and Interconnections: Urban data is increasingly characterized by complexity arising not only from its growth and heterogeneity but from the degree to which data and analytics can be interconnected. A critical technical goal is to ensure our tools and techniques allow flexible and coherent data sharing. Moreover, data serve as proxies for real-world phenomena and how we represent them may inadequately support the intended purpose. Currently, our data dictionaries and visual representations are not rich enough and often metrics are inappropriate for the intended purpose [23, 27].

C4. Availability and Accessibility: No longer is data analysis technology restricted to experts; citizens, businesses and economic stakeholders for example, are all generating and seeking to benefit from data-driven approaches. Their needs will only be met, if access to (open)data includes access to tools and techniques to understand, explore, and make use of the data. The explosion in citizen-centric apps (see [5] for a comprehensive review) highlights challenges in both supporting this proliferation of data tools and burgeoning new user groups related to variable literacy, goals, and patterns of use. These challenges relate both to the design of more accessible visualizations and to the contexts in which people use them.

C5. Standards for Tools and Tech: Research indicates, visualizations should enable interactions (e.g. filtering, selecting etc.) and should encourage analysis at different resolutions (multi-scale) [27]. Visualization tools should also be usable for people of different analytical experience and confidence. The democratization of urban data technologies means they need to be platform agnostic and in particular useful 'in the wild': most if not all citizen engagement is now delivered via mobile apps [4], but visualization design for mobile platforms is still in its infancy. Emerging technologies such as VR and AR may offer more realistic and engaging data experiences for both citizen and expert (e.g. [29]). Yet, there are limited common standards between tools, systems and technologies, which can result in conflict. It is currently unclear which technology is best adapted to which use case and what are the best interfaces.

C6. Appropriate Visualization and Data Choice: Working with and for the diverse groups that comprise urban stakeholders and citizens poses many challenges. It is often difficult to connect abstract data spaces to reality (see e.g. [16]). Standard visualization forms common to analytics tasks may not be meaningful or comprehensible [27]. Data metrics may not capture meaningful information. For example, public safety dashboards that focus on general data crime and traffic congestion can be enriched with specific factors—such as neighbourhood cohesion—that are harder to express in data quantification and visualization but help to explain data patterns [23]. Numerous researchers point to an impoverished visual language in capturing intangible concepts such as health or social quality [7, 10]. This challenges the practice of using "traditional" visualization.

C7. Outreach and Engagement: Outreach includes getting the public interested, getting information to those who need it, reaching targeted users or making the information accessible to them. Engagement is a reciprocal component of outreach, in which we try to encourage citizens to collect and contribute data about themselves or improve civic engagement for collaborative analysis (see e.g. [1, 3, 30]). Key challenges in this space include sustaining attention over longer periods of time, incorporating feedback from a diverse audience, and dealing with subjective data. Data cannot provide the total picture. There is limited capacity to process information and bias towards technocratic solutions and public mobilization. We need to embed transparency and responsibility in our processes and our representations. Finally, we must make the data accessible. This connects to the research on the design space of situated and embedded visualizations [33]: from placing them into the public space, where they can blend with the physical objects at hand and citizens can encounter them in everyday situations [31], to visualizations on interactive surfaces or large displays in exhibition spaces, which have great potential to trigger interest in public data and smart cities [20, 21]. There is a striking balance between popularity vs sensational and the truth of capturing nuances of data. We also need to keep in mind the approach when evaluating visualizations e.g., the evaluation criteria of an outreach-themed effort should not be the same as an engagement-themed effort.

C8. Inclusivity and Diversity: Inclusive visualization crossing all sectors and socio-economic factors brings diverse lenses. We question, how might diversity translate to more inclusive analytical perspectives? In visualization, we need to seek representation and engagement of broader audiences, by making tools, techniques and data more widely available and ensuring they are personally meaningful through appropriate data choice and representations. This includes giving a voice to under-represented citizens and understanding biases, yet taking care to not misunderstand social norms. Exemplary projects from this line of research include participatory planning of refugee shelters in Hamburg [22], participatory maps and visualizations on the housing crisis in the San Francisco Bay Area to document and "render visible the landscapes, lives, and sites of resistance and dispossession" [12]. The relationship of CityVis to public behavior is two-fold; visualizations can be used to better understand and model citizen behavior but can, at times, be used to explicitly influence behavior or nudge habits, both of which should be undertaken with due consideration of ethics and privacy. Finally, it is essential to foster trust and buy-in from all diverse groups by showing provenance and allowing authorship; challenging the power to create and what values this embeds.

C9. Data and Visual Literacy: Data and visual literacy are not

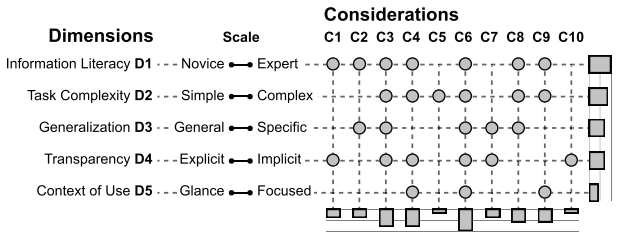

Figure 3: Relations between CityVis Considerations and Dimensions, with marginal histograms showing their cardinalities.

just about reading, but developing comfort with data-enabled thinking and its technological support. Closing the gap between designer and user will entail making data more comprehensible (determining relevant data representations for desired outcomes, finding the appropriate data to frame conversations and to set context); scaffolding learning; and allowing authorship and exploration of data alternatives. There is still a disconnect between the visualization research community's concept of data literacy and the broader needs for better data communication identified in urban informatics [27]: we need a richer understanding of how to support these needs. In education we are beginning to embed data literacy into curricula [34]. Data literacy workshops and education for urban communities may help citizens to acquire proficiency and criticality with regard to urban data [6].

C10. Citizen Trust: All the previous human-focused themes are vulnerable to issues of civic trust: who produces, owns, manages, frames and/or distributes the data? We have a digital footprint but what happens to it? Where does it go? Do we know where our data is actually being used? There is also much debate, especially for urban data on data ownership, stakeholders and rights holders with questions such as: What is truth?, What can I trust?, Who can I trust? [26]. This continues the discussion of how bringing data agency to the data creators can be embedded in our practices. Can we collaborate with citizens to ensure citizens take agency of their data? [27]. Examples in this area include the DECODE system and MyData Global[4] that allow individuals to control the sharing of their personal data. Moreover, a closer consideration of data practices at the local level (e.g. [28]) can help dispel the myth of a totalizing views [11]. There is need for CityVis to facilitate this context and help to build agency and trust, without leaving out crucial perspectives [17].

3.2 Towards a CityVis Design Space

CityVis designers must be familiar with the needs of a wide range of urban data users. We argue that better understanding of these users, as the audience of the visualization, is central to the design space. To help designers consider their diverse perspectives, we propose a design space for urban visualization applications with five interweaving dimensions (**D1–D5**) that connects to all 10 considerations (see Fig. 3).

D1. Information Literacy: "Literacy" differs across all users and within categories of users ranging from **novice** to **expert** (**C9**). Both the metrics chosen and the information design must fit these literacy levels (**C1, C3, C4**). The understanding of CityVis users has evolved through the workshop series, as has the idea of what constitutes an expert. For example, although many users may not understand the data of an energy monitoring application, those users may have advanced understanding of how the tracked electrical appliances work. Designers need to ensure visualizations take this into consideration (**C2, C6**). We must seek to understand pre-existing knowledge, incorporate diverse perspectives (**C8**), and learn how to balance increased data awareness expectations with distractions and burdens (**C8**).

D2. Task Complexity: All systems vary in complexity depending on the complexity of the task (**C4, C5**). **Simple** tasks need a relatively simple system with discoverable features, whilst by contrast, a **complex** task may require a more complex interface that allows deeper exploration of data viewed from multiple perspectives (**C3, C6, C8, C9**). The latter may necessitate training or the decomposition of complex tasks into smaller tasks (**C6, C9**).

D3. Generalization: Some systems are **general** in that the data they surface are common to most modern cities, such as traffic or crime rates. **Specific** systems may address highly-localized needs, and may focus on the needs of a small population of users within the city (**C7**). We note however that local features may often be necessary to frame general data to account for cultural or social differences (**C6, C8**), varied data sources (**C2, C3**) or other unknowns. Similarly, specific visualizations may have mappings to the challenges facing other cities, where they can be transferred given appropriate consideration of the differences between the two contexts.

D4. Transparency: Trust is essential in acceptance, use and engagement with data (**C7, C10**); fostering trust may require **explicit** representation of data provenance, quality and visualization choice (**C1, C3, C4, C6**). Understanding where data are sourced in showing public health outbreaks, for example, would be important for public confidence. Alternately, many data uses can be satisfied with more **implicit** transparency, where users are content to assume data are reliable (consider a transit map with traffic rates used in a rezoning process.) A transparent application will include features to inform users about its behavior, for instance to reveal why it is visualizing data in a certain way.

D5. Context of Use: Finally, designers must consider the circumstance in which someone uses the data, presenting a visualization that is appropriate to that context (**C6**). This introduces questions of time, attentional focus and whether the visualization is a separate tool or is situated in a larger context (an analysis app vs an in-home display). For instance, homeowners using a mobile app to check energy use will only want to spend a frequent passing **glance** inspecting the data to ensure that everything is working as expected (**C4**). Expert users, such as the electrician summoned to diagnose and repair a problem, may spend many hours inspecting the data in support of a **focused** task and require access to data within their field of expertise that would be unusable by the homeowner (**C9**).

Ultimately, for visualizations to be widely used and have a greater impact, designers should take into consideration all five dimensions of the design space and provide the users with the most appropriate visualization for their particular needs and experience.

We believe this research complements existing visualization design space research delving deeper into the complex *domain situation* [19] of CityVis applications. We demonstrate that CityVis is a unique design space with many different users, uses and applications. The five dimensions with sliding scales and interweaving considerations aims to aid CityVis designers in narrowing their design scope and tailoring their visualization solutions. We furthermore believe our research complements visualization design practices and can be beneficial for designers to investigate prior to more well known visualization design methodologies, such as Munzner's what-why-how framework [19]. Future work will involve more in-depth validation of the design space during CityVis projects.

4 Reflection and Conclusion

In this paper we have discussed the outcomes of the CityVis workshop series as well as described the methods used to obtain them. Through the combination of focused exploration with exemplary use cases and the backing of a diverse and international program

[4] https://decodeproject.eu/, https://mydata.org/

committee, we have engaged in rich and vibrant discussions amongst the visualization community and connected to the wide field of urban data practitioners. Feedback from all workshops has been very positive. The diversity of talks was appreciated and the interactive element of the workshop was noted as an essential element lacking from most conference workshops. We acknowledge the need to continue to diversify the attendee audience. In an attempt to diversify discussions and reach wider audiences the invited speaker panels (W2 and W3) were added and W3 targeted a domain-specific venue.

The challenges and goals identified throughout the series have resulted in a number of key research themes. The design space dimensions outlined in this paper evolved through the workshop series, initially originating from the *Applications* subtheme discussions in W1 and evolving over discussions and continued work with over three years of collaboration. It is particularly encouraging that each of these dimensions stood out as important during the W3 domain focused discussions. With the continued workshop series we hope to delve deeper into the fundamental issues and challenges that practitioners and researchers alike face in the changing field of urban data visualization and aim to reach a wider audience and increased participation levels across many communities.

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References

[1] M. Billger, L. Thuvander, and B. S. Wästberg. In search of visualization challenges: The development and implementation of visualization tools for supporting dialogue in urban planning processes. *Environment and Planning B: Urban Analytics and City Science*, 44(6):1012–1035, 2017.

[2] P. Ciuccarelli, G. Lupi, and L. Simeone. *Visualizing the data city: social media as a source of knowledge for urban planning and management*. Springer, 2014.

[3] M. De Lange and M. De Waal. Owning the city: New media and citizen engagement in urban design. *First Monday*, 18(11), 2013.

[4] K. C. Desouza and A. Bhagwatwar. Citizen Apps to Solve Complex Urban Problems. *Journal of Urban Technology*, 19(3):107–136, Nov. 2012.

[5] K. C. Desouza and A. Bhagwatwar. Technology-Enabled Participatory Platforms for Civic Engagement: The Case of U.S. Cities. *Journal of Urban Technology*, 21(4):25–50, Dec. 2014.

[6] C. D'Ignazio. Creative data literacy: Bridging the gap between the data-haves and data-have nots. *Information Design Journal*, 23(1):6–18, Jan 2017.

[7] M. Elias, M.-A. Aufaure, and A. Bezerianos. Storytelling in visual analytics tools for business intelligence. In *IFIP Conference on Human-Computer Interaction*, pp. 280–297. Springer, 2013.

[8] M. Hajer. *Smart About Cities: Visualising the challenges for the 21st century urbanism*, chap. On Being smart about cities - Seven Considerations for a New Urban Planning & Design. NAi010 Publishers, 2014.

[9] R. Kitchin. *The Data Revolution: Big Data, Open Data, Data Infrastructures and Their Consequences*. Sage Publications, London; Thousand Oaks, Calif; New Delhi; Singapore, 2014.

[10] R. Kitchin and G. McArdle. Urban data and city dashboards: Six key issues. In *Data and the The City*, pp. 1–21. Programmable City Working Paper 21, 2016.

[11] Y. A. Loukissas. Taking big data apart: local readings of composite media collections. *Information, Communication & Society*, 20(5):651–664, 2016.

[12] M. M. Maharawal and E. McElroy. The anti-eviction mapping project: Counter mapping and oral history toward bay area housing justice. *Annals of the American Association of Geographers*, 108(2):380–389, 2018.

[13] S. Mattern. *Deep Mapping the Media City*. Forerunners: Ideas First. University of Minnesota Press, 2015.

[14] S. Mattern. Mission control: A history of the urban dashboard. *Places Journal*, March 2015.

[15] D. McMillan, A. Engström, A. Lampinen, and B. Brown. Data and the City. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*, CHI '16, pp. 2933–2944. ACM, New York, NY, USA, 2016. event-place: San Jose, California, USA. doi: 10.1145/2858036.2858434

[16] S. Meier and K. Glinka. The individual in the data — the aspect of personal relevance in designing casual data visualisations. *i-com*, 16(3):247–266, 2017. doi: 10.1515/icom-2017-0025

[17] A. Meijer. Datapolis: A Public Governance Perspective on "Smart Cities". *Perspectives on Public Management and Governance*, 1(3):195–206, 12 2017. doi: 10.1093/ppmgov/gvx017

[18] S. J. Mountford. Tools and techniques for creative design. In *Readings in Human–Computer Interaction*, pp. 128–141. Elsevier, 1995.

[19] T. Munzner. *Visualization Analysis and Design*. AK Peters Visualization Series. CRC Press, 2015.

[20] T. Nagel, M. Maitan, E. Duval, A. Vande Moere, J. Klerkx, K. Kloeckl, and C. Ratti. Touching transport-a case study on visualizing metropolitan public transit on interactive tabletops. In *AVI 2014: Advanced Visual Interfaces*, pp. 281–288, 2014.

[21] T. Nagel, C. Pietsch, and M. Dörk. Staged analysis: From evocative to comparative visualizations of urban mobility. In *VISAP'16: Proceedings of the IEEE VIS Arts Program*, 2016.

[22] A. Noyman, T. Holtz, J. Kröger, J. R. Noennig, and K. Larson. Finding places: HCI platform for public participation in refugees' accommodation process. *Procedia computer science*, 112:2463–2472, 2017.

[23] K. OConnell, Y. Lee, F. Peer, S. Staudaher, A. Godwin, M. Madden, and E. Zegura. Making public safety data accessible in the westside atlanta data dashboard. In *Bloomberg Data for Good*, pp. 1–7. New York, Sept. 2016.

[24] D. Offenhuber and C. Ratti. *Decoding the City: Urbanism in the Age of Big Data*. Birkhäuser, 09 2015.

[25] M. Oppermann and T. Munzner. Uncovering Spatiotemporal Dynamics from Non-Trajectory Data. In *Workshop on CityVis: Urban Data Visualization at IEEE VIS 2018*. Berlin, Germany, 10 2018.

[26] K. Peel and E. Tretter. Waterfront Toronto: Privacy or Piracy? SocArXiv xgz2s, Center for Open Science, June 2019. doi: 10.31219/osf.io/xgz2s

[27] A. Sarikaya, M. Correll, L. Bartram, M. Tory, and D. Fisher. What Do We Talk About When We Talk About Dashboards? *IEEE transactions on visualization and computer graphics*, Aug. 2018.

[28] D. Sharp, S. Goodwin, M. Anwar, and L. Bartram. Engaging Citizens in Data Governance in Net Zero Precincts. Zenodo, Aug. 2020. doi: 10.5281/zenodo.3988104

[29] M. Spur and V. Tourre. Urban DataSphere: Exploring Immersive Multiview Visualizations In Cities. In *Workshop on CityVis: Urban Data Visualization at IEEE VIS 2018*. Berlin, Germany, 10 2018.

[30] N. Valkanova, R. Walter, A. Vande Moere, and J. Müller. Myposition: sparking civic discourse by a public interactive poll visualization. In *Proceedings of the 17th ACM conference on Computer supported cooperative work & social computing*, pp. 1323–1332. ACM, 2014.

[31] A. Vande Moere and D. Hill. Designing for the situated and public visualization of urban data. *Journal of Urban Technology*, 19(2):25–46, 2012.

[32] N. Vossoughian. Mapping the modern city: Otto Neurath, the international congress of modern architecture (ciam), and the politics of information design. *Design Issues*, 22(3):48–65, 2006.

[33] W. Willett, Y. Jansen, and P. Dragicevic. Embedded data representations. *IEEE transactions on visualization and computer graphics*, 23(1):461–470, 2017.

[34] A. Wolff, J. J. C. Montaner, and G. Kortuem. Urban data in the primary classroom: bringing data literacy to the uk curriculum. *The Journal of Community Informatics*, 12(3), 2016.

[35] R. S. Wurman. *Making the city observable*. MIT Press, 1971.

[36] Y. Zheng, W. Wu, Y. Chen, H. Qu, and L. M. Ni. Visual Analytics in Urban Computing: An Overview. *IEEE Transactions on Big Data*, 2(3):276–296, Oct. 2016.