Cities 156 (2025) 105513

Contents lists available at ScienceDirect

Cities

journal homepage: www.elsevier.com/locate/cities

Co-producing new knowledge systems for resilient and just coastal cities: A social-ecological-technological systems framework for data visualization

Mathieu Feagan [a,*], Tischa A. Muñoz-Erickson [b], Robert Hobbins [c], Kristin Baja [d], Mikhail Chester [e], Elizabeth M. Cook [f], Nancy Grimm [g], Morgan Grove [h], David M. Iwaniec [i], Seema Iyer [j], Timon McPhearson [k], Pablo Méndez-Lázaro [l], Clark Miller [m], Daniel Sauter [n], William Solecki [o,p], Claudia Tomateo [k], Tiffany Troxler [q], Claire Welty [r]

[a] Faculty of Environment, University of Waterloo, 200 University Avenue West, Waterloo, Ontario N2L 3G1, Canada
[b] International Institute of Tropical Forestry, USDA Forest Service, Jardín Botánico Sur, Calle Ceiba, Río Piedras, PR 00926, Puerto Rico
[c] The CU-Denver Business School, University of Colorado – Denver, 1475 Lawrence Street, Denver, CO 80202, USA
[d] Urban Sustainability Directors Network, USA
[e] School of Sustainable Engineering and the Built Environment, Arizona State University, Tempe, AZ 85287-3005, USA
[f] Department of Environmental Science, Barnard College-Columbia University, 3009 Broadway, New York City, NY 10027, USA
[g] School of Life Sciences, Arizona State University, Tempe, AZ 85287-4501, USA
[h] Urban Forests, Human Health, and Environmental Quality, Suite 350, 5523 Research Park Drive, Baltimore, MD 21228, USA
[i] Urban Studies Institute, Andrew Young School of Policy Studies, Georgia State University, Atlanta, GA 30303, USA
[j] University of Baltimore, 1420 N. Charles Street, Baltimore, MD 21201, USA
[k] Urban Systems Lab, The New School, 79 Fifth Avenue, 16th Fl., New York, NY 10003, USA
[l] Environmental Health Department, Graduate School of Public Health, University of Puerto Rico-Medical Sciences Campus, Puerto Rico
[m] School for the Future of Innovation in Society, Arizona State University, PO Box 875603, Tempe, AZ 85287-5603, USA
[n] Parsons School of Design, The New School, 2 West 13th St, Floor 4, New York, NY 10003, USA
[o] Hunter College - City University of New York, 695 Park Avenue, New York, NY 10021, USA
[p] Earth and Environmental Science Program, Graduate Center - City University of New York, USA
[q] Florida International University, 11200 SW 8th ST, AHC5-368, Miami, FL 33199, USA
[r] University of Maryland, Baltimore County (UMBC), 1000 Hilltop Circle, TRC 102, Baltimore, MD 21250, USA

ARTICLE INFO

Keywords:
Climate change
Coastal cities
Knowledge co-production
Knowledge systems
Social-ecological-technological systems
Urban resilience
Data visualization

ABSTRACT

With increasing frequency and severity, coastal cities are facing the effects of extreme weather events, such as sea-level rise, storm surges, hurricanes, and various types of flooding. Recent urban resilience scholarship suggests that responding to the cascading complexities of climate change requires an understanding of cities as social-ecological-technological systems, or SETS. Advances in data visualization, sensors, and analytics are making it possible for urban planners to gain more comprehensive views of cities. Yet, addressing climate complexity requires more than deploying the latest technologies; it requires transforming the institutional knowledge systems upon which cities rely for preparation and response in a climate-changed future. While debates in the theory and practice of knowledge co-production offer a rich contextual starting point, there are few practical examples of what it means to co-produce new knowledge systems capable of steering urban resilience planning in fundamentally new directions. This paper helps address this gap by offering a case study approach to co-producing new knowledge systems for SETS data visualization in three US coastal cities. Through a series of *innovation spaces* – dialogues, labs, and webinars – with residents, data experts, and other city stakeholders from multiple sectors, we show how to apply a knowledge systems approach to better understand, represent, and support cities as SETS. To illustrate what a redesigned knowledge system for urban resilience

* Corresponding author.

E-mail addresses: Mathieu.feagan@uwaterloo.ca (M. Feagan), tischa.a.munoz-erickson@usda.gov (T.A. Muñoz-Erickson), robert.hobbins@ucdenver.edu (R. Hobbins), baja@usdn.org (K. Baja), mchester@asu.edu (M. Chester), ecook@barnard.edu (E.M. Cook), nbgrimm@asu.edu (N. Grimm), morgan.grove@usda.gov (M. Grove), diwaniec@gsu.edu (D.M. Iwaniec), siyer@ubalt.edu (S. Iyer), timon.mcphearson@newschool.edu (T. McPhearson), pablo.mendez1@upr.edu (P. Méndez-Lázaro), clark.miller@asu.edu (C. Miller), sauter@newschool.edu (D. Sauter), wsolecki@hunter.cuny.edu (W. Solecki), tomateoc@newschool.edu (C. Tomateo), troxlert@fiu.edu (T. Troxler), weltyc@umbc.edu (C. Welty).

URL: http://www.geo.hunter.cuny.edu (W. Solecki).

https://doi.org/10.1016/j.cities.2024.105513
Received 19 November 2022; Received in revised form 18 September 2024; Accepted 7 October 2024
Available online 7 November 2024

planning entails, we document the key steps and activities that led to a new prototype SETS platform that works with a wider range of ways of knowing — including community-based expertise, interdisciplinary research contributions, and various municipal actors' know-how — to build anticipatory capacity for visualizing and navigating the complex dynamics of a climate-changed future. Our findings point to new roles for activity-based learning, conflict, and SETS visualization technologies in connecting, amplifying, and reorganizing the knowledge assets of community perspectives previously ignored. We conclude with a new understanding of how innovation towards coastal city resilience resides within the co-production process for (re)designing knowledge systems to make them more robust and responsive to cross-sector and cross-city learning.

1. Introduction

Given their concentration of people and interdependent infrastructure, coastal cities are particularly vulnerable to the impacts of climate change, such as sea-level rise, storm surge, hurricanes, and extreme rainfall events (Grimm et al., 2008; Najafi et al., 2021). Coastal disasters such as Hurricanes Harvey (2017), María (2017), Dorian (2019), Sandy (2012), and Katrina (2005) have starkly exposed deficiencies not solely within the physical infrastructure but, crucially, within the institutional knowledge systems upon which cities rely for preparation and response to such cataclysmic events (Eakin et al., 2018; Lugo, 2019; Munoz-Erickson et al., 2017; Woods, 2017). Knowledge systems, also known as knowledge infrastructures (Pearsall et al., 2022), encompass the networks, organizational practices, norms, values, technologies, and relationships that influence the production, validation, dissemination, and utilization of knowledge (Hobbins et al., 2021; Miller et al., 2018; Miller and Munoz-Erickson, 2018; Munoz-Erickson, 2014). Given that existing urban planning knowledge systems were founded upon a more stationary and predictable climate of the past (Munoz-Erickson et al., 2021) and were designed according to the assumptions, standards, and technologies of dominant groups (Wijsman & Feagan, 2019; Winner, 1986; Woods, 2017), there is a need to transform city knowledge systems to navigate the current impacts and uncertainties of climate change to promote resilience in a just and equitable manner (Chester et al., 2020,b; Considine et al., 2017). Yet, there is a lack of empirical studies showing *how* to diagnose, re-think, and re-imagine knowledge systems for the future, especially with a focus on underserved communities (Fazey et al., 2020).

In this paper, we seek to address this gap by exploring the co-production of novel knowledge systems aimed at enhancing resilience in coastal citieas, working with communities in Miami, San Juan, and Baltimore. We ask: how can changing knowledge systems through a co-production process enhance our capacity to diagnose, visualize, anticipate, and respond to changes in the future? Through a case studies approach to the use of data visualization, we argue that coastal city resilience planning can move beyond replicating and tweaking existing practices towards envisioning new knowledge systems with greater anticipatory capabilities and contextual relevance to community wisdom and experiences across sectors and scales.

We begin by reviewing the literature to establish why a knowledge systems approach to co-production involving different groups of people, ways of knowing, and ways people interact with data is needed to reorient urban resilience planning in transformative directions. We then describe a series of innovation spaces — dialogues, labs, and webinars — we carried out with participants from multiple communities, municipalities, state and federal governments, non-governmental organizations, scientists, and students in Miami, San Juan, and Baltimore. Within each city, we sought to collaborate in the diagnosis of existing knowledge systems and the co-design of new knowledge systems, leading to a prototype data visualization platform that supports a stronger understanding of cities as social-ecological-technological systems, or SETS (see Fig. 1). Finally, we discuss new insights into the praxis of co-production through a knowledge systems approach that values emergent, reflexive, and relational activity-based learning, the role of conflict in societal change, and the potential for technology to support how differently positioned actors build trust relations in learning how to implement resilience work with a view towards long-term, collective, transformation across different urban contexts.

2. Literature background

Coastal urban areas worldwide are grappling with increasingly urgent climate change challenges, underscoring the need for innovative strategies, technologies, and equity in adaptation and resilience planning. To support these efforts, climate services such as the National Climate Assessment Atlas and advancements in climate modeling, urban informatics, and urban systems science have transformed urban resilience planning by integrating sensors, dashboards, Internet of Things (IoT) and new data visualization technologies, empowering municipalities to foresee potential flooding impacts (Hofmeister et al., 2024; Le Coz et al., 2016; Paska, 2018; Sheppard, 2012; Yao & Wang, 2020). However, bigger and faster data processing capabilities cannot in-and-of-themselves address the complex origins or cascading effects of climate change and urbanization. Emphasis on the potential efficiencies of new technologies as 'solutions' (e.g., Bakhtiari et al., 2023; Marasinghe et al., 2024; Schumann, 2023) has ignored the negative impacts of long-standing inequities and injustices stemming from the neoliberal logic of urban development (Cardullo & Kitchin, 2019; Grossi & Pianezzi, 2017; Liberty, 2013; Pineda-Pinto et al., 2021). Urban form — itself an artifact of racist, capitalist, colonial, and patriarchal technologies and infrastructures (Whyte, 2017; Winner, 1986; Woods, 2017) — generates 70 % of the carbon dioxide emissions causing global climate change (IPCC, 2022), and given the current trajectory of planetary urbanization (Brenner, 2014), urban resilience planning must now question what aspects of cities are to be made more resilient and for the benefit of whom (Meerow & Newell, 2016; Walker, 2020). Local-scale planning continues to face challenges due to a lack of locally-specific and community-trusted data, exacerbating gaps between community knowledge and city knowledge systems dominated by technocratic and engineering-centric planning epistemologies (Helmrich et al., 2021; McAllister et al., 2019; Yumagulova & Vertinsky, 2019).

Scholarship on knowledge systems for urban resilience works to understand and build capacity to reorganize the current assumptions, values, standards, and frameworks guiding responses to climate change within a given context (Miller et al., 2018). It explores the details of local decision-making, aiming to change how cities 'think' and 'act' (Munoz-Erickson et al., 2017), while steering conventional urbanization towards more just and sustainable futures (Feagan et al., 2019). Knowledge systems analysis uncovers underlying structures and processes whether by reconsidering the different ontological and epistemological starting points of feminist and decolonial approaches (Wijsman & Feagan, 2019), augmenting formal municipal decision-making with informal community-based knowledge (Ramsey et al., 2019), or examining different cities' policy responses to extreme weather events to promote cross-city learning (Rosenzweig et al., 2019). Knowledge systems may take formalized shapes within universities, research institutes, and governmental bodies or emerge informally from networks, communities of practice, social media groups, and activist communities (Hobbins et al., 2021; Munoz-Erickson, 2014). Maintained by rules, codes, procedures, ceremonies, economic incentives, and ideologies, knowledge

Fig. 1. Social-Ecological-Technological Systems approaches emphasize the interactions across domains, to better anticipate the cascading complexities of achieving climate resilience.

systems may appear permanent, yet changes inevitably occur over time (Gim & Miller, 2022; Miller et al., 2013; Tengö et al., 2014). Therefore, the challenge for urban resilience planning is to transgress the nested obduracy of current knowledge politics and decision-making processes and intentionally instigate changes in how dominant knowledge systems operate (Caniglia & Vogel, 2023; Eakin et al., 2018; McPhearson et al., 2021; Solecki et al., 2021; Wyborn et al., 2019).

More specifically, in looking at the history and future of urban planning, Muñoz-Erickson et al. (2021) call for a shift towards "anticipatory resilience," arguing that the field cannot rely on predictive forecasting or quantitative modeling based on the steady states of the past, and must instead work towards embracing foresight methods and other futures thinking tools better equipped to deal with the complexity and uncertainty of a climate-changed future. Kim et al. (2022) argue that governance and infrastructure design ought to move away from promises of a 'fail-safe' model, towards accepting the reality of extreme weather events and developing a 'safe-to-fail' approach across dynamic SETS. This argument resonates with Chester et al. (2023), who document how fail-safe approaches are linked to a "command-and-control" management style that is ineffective under conditions of deep uncertainty and climate change. Urban resilience scholars are thus calling for a fundamental paradigm shift away from 'protecting' cities from climate change, towards a better understanding of how to work with cities as SETS (Branny et al., 2022; Chang et al., 2021; Hamstead et al., 2021; Keeler et al., 2019; Markolf et al., 2018; McPhearson et al., 2022), underscoring the need for new knowledge systems capable of working with data and insights from various stakeholders, scales, and sectors (Fazey et al., 2020; Iyer, 2015; Sajjad et al., 2021).

To this end, advancement in the theory and practice of knowledge co-production has become a cornerstone in the broad field of sustainability transitions (Frantzeskaki & Kabisch, 2016; Norstrom et al., 2020). To better harness the power of science and technology in achieving sustainable development, Cash et al. s (2003) knowledge systems framework emphasized the role of knowledge managers capable of communicating the salience, credibility, and legitimacy of information across different stakeholder groups, including scientific experts, community wisdom holders, and policy/decision makers. However, critics argue that co-production often fails to deliver in practice the transformations promised in theory because co-production requires more than an exchange of information between different actors; it requires changing the underlying power relations and systems that over-privilege or undervalue different ways of knowing (Klenk & Meehan, 2015; Turnhout et al., 2020). Delivering on this transformative potential thus requires transgressing the status quo, changing mindsets, and reorganizing dominant structures (Caniglia et al., 2023; Caniglia & Vogel, 2023). As Fazey et al. (2020) suggest: Rather than producing ever more knowledge about bio-physical and social phenomena, new systems need to be oriented towards developing wisdom about how to act appropriately in the world. The challenge is that: This western dominant system tends to be driven by a growth-based economy with knowledge viewed as a commodity, emphasising speed over quality, profit over wellbeing, achievement over fulfilment, and competition over collaboration (Fazey et al., 2020). Rather than accept this system or shy away from conflict, a new generation of diverse actors must learn how to embrace the political nature of creating greater institutional capacity for SETS-based approaches within urban resilience planning (Feagan et al., 2023). Co-production is not just about integrating data from different sources; it is about transforming the science/policy interface itself, reordering the relationships between knowledge and power, science and society, and state and citizens (Wyborn et al., 2019).

However, the urban resilience literature has yet to adequately explore the necessary links between shifting the role of data and data visualization technologies away from providing ready-made ‘solutions , towards changing the underlying relations between various types of knowledge to fundamentally reorganize conventional knowledge systems. For example, Wolff et al. (2020) provide key insights for supporting collaborations across professional and citizen groups in co-designing community-relevant smart-city technologies; however, they stop short of engaging with deeper questions of knowledge system reorientation or redesign. Sauter et al. demonstrate the technological means for a SETS data visualization framework that can organiz[e] a web of spatial relationships and representations into one integrated visualization platform [with] the potential to change how we think about, plan, and design our cities (Sauter et al., 2021, p. 155); however, there is a lack of practical examples illustrating how to embed this technological capacity into actual community-based use-cases. Angheloiu and Tennant (2020) find that calls for deep, systemic change in urban resilience planning lack a process of understanding and negotiating trade-offs [between] the different worldviews and values that underpin them, and they suggest that [a]ddressing this entails going beyond technocratic skills [towards] cultivating reflexivity, effective communities of practice and new forms of organising for knowledge production. Our paper responds to these gaps, showing how co-producing new knowledge systems for SETS data visualization can go beyond a one-off instrumental application of co-production, towards harnessing the tensions and complementarities in a networked approach to envisioning long-term transformative, anticipatory, inclusive, and responsive knowledge systems for coastal resilience planning.

3. Methods

Knowledge co-production has been implemented in urban sustainability projects through various approaches such as innovation labs, shadow networks, transition arenas, transformative spaces, and co-design processes, which foster real-world learning and discovery (Frantzeskaki & Kabisch, 2016; Iwaniec et al., 2016, 2020; Nesti, 2018; Pereira et al., 2019; Troxler et al., 2021). Our project opens new spaces and opportunities for exploring the relationship between the available technological tools (various visualization and communication tools described below) and the various types of knowledge held in different community spaces through an iterative, participatory process for co-designing what a SETS data visualization platform might entail. Given our focus on SETS data visualization and changing the knowledge systems underpinning coastal resilience efforts, we leveraged our connections with the Urban Resilience to Extremes Sustainability Research Network (Iwaniec et al., 2021) to form an interdisciplinary team including data visualization professionals, equity-based community partnerships, and researchers with different social, ecological, and technological expertise across the engineering, natural and social sciences. With partners in Miami (City of Miami, City of Miami Beach, Miami-Dade County), Santurce (a district of San Juan, Puerto Rico), and the City of Baltimore (Maryland), we embarked on an 18-month journey of discovery, co-learning, and ideation, inviting different stakeholders from each city to help us experiment with the co-production of fundamentally new knowledge systems for coastal city resilience. From the outset, our partners noted how their cities were affected by sea-level rise, coastal storms, inefficient stormwater systems, flooding, and water-quality issues, reflecting unique geological and climatological features, as well as differing social, governance, and infrastructure challenges (Table 1). We sought to understand how each city was responding and what role data visualization might play.

3.1. Case study approaches to innovation spaces in three coastal cities

We refer to our co-production process as *innovation spaces*, which included three components dialogues, labs/workshops, and webinars involving groups of municipal, academic, non-governmental, and community experts working on coastal resilience to climate change. As we will discuss later, we see value in a co-production process that is iterative, responsive, and open-ended, since this allows for some variation to accommodate different cities needs and starting points. Overall, our *Innovation dialogues* were one-hour virtual meetings with 5 7 people sharing their perceptions of coastal climate risks and discussing the availability of relevant data and communication technologies. We aimed for three *dialogues* in each city, to identify priorities from municipal, academic, and community perspectives, respectively. *Innovation labs* were one-day, face-to-face workshops bringing together participants from one city in a core set of activities: asset mapping, card sorting, and platform design (Fig. 2). Finally, *innovation webinars* connected participants from across the three cities in a process of co-learning and reflection, sharing emerging insights, and testing how they might work together to inform new practices, concepts, and designs.

The activities and discussions of the *innovation spaces* were captured and recorded through note-taking and audio recordings. Each *innovation lab* led to a synthesis report describing what took place and next steps (Mendez-Lazaro et al., 2018; Troxler et al., 2018; Welty et al., 2018). After reviewing photographs, reports, audio recordings, and notes, several team members triangulated their observations and interpretations to ensure accuracy (Carter et al., 2014). Having a large and diverse research team embedded in all aspects of the *innovation spaces* created a capacity for listening on different levels, *hearing the actual information provided by participants* (lists of key actors, types of work they are engaged in, gaps or barriers experienced etc.), *experiencing the interactions in the room* (tensions, arising questions, outlier opinions etc.), and *evaluating our own positions* as organizers with different assumptions

Table 1
Cities, participants, and SETS challenges (including hurricanes, storms, extreme heat, drought, sea-level rise, and flooding).

	Miami Region	San Juan	Baltimore
City actors and organizations	Catalyst Miami, City of Miami, City of Miami Beach, CLEOInstitute, Everglades Foundation, Florida Immigrant Coalition, Florida International University, Global Resilience Initiatives, Inhabit Earth, Miami Climate Alliance, Miami-Dade County, New Florida Majority, Shorecrest residents, Unitarian Universalist Justice Florida	Calidad de Vida Vecinal, CAMBIO, Enlace Latino de Accion Climatica, Fundacion Comunitaria de Puerto Rico, La Marana, Municipality of San Juan, San Juan Bay Estuary Program San Juan, Rossi Lugo Arquitectos, University of Puerto Rico, Urban Waters Federal Partnership, San Juan ULTRA, US Forest Service, local residents from the barrio of Santurce including, Barrio Obrero, Coalicion Restauracion Ecosistemas Santurcinos, Negocios de la Calle Loíza, Puerta de Tierra	Baltimore City, Baltimore Neighborhood Indicators Alliance, National Aquarium, Eastern Shore Land Conservancy, Parks and People, Save a Tree, University of Maryland Baltimore County, US Fish and Wildlife, US Forest Service, US Geological Survey, Urban Sustainability Directors Network
Social challenges	- Gentrification - Increasing cost of living - Inequality, equity, justice - Governance - Decision-making	- Declining population - Declining property values - Underserved communities - Environmental justice issues - Public health - Governance	- Declining population - Vacant lots - Uneven distribution of poverty and disinvestment - Planning and coordination across numerous vastly distinct neighborhoods
Ecological challenges	- High water table - King tides - Erosion and sedimentation - Wetland destruction	- Tropical estuary - Erosion and sedimentation - Mangrove destruction - Water quality	- Erosion and sedimentation - Urban canopy
Technological challenges	- Infrastructure (roads, pumps, sea walls) - Abundance of different tools/apps	- Exposed critical infrastructure (Port Authority, electric power plants, airport, government buildings) - Inadequate sewers	- Power outages - Integrating technologies and data across federal and local agencies - Port/rail logistics

shaping our engagement (Cook et al., 2021). The *innovation spaces* provided an iterative, collective, and in-depth process for analyzing the different knowledge systems organizing current urban resilience efforts, while developing new capacity to reorganize key elements into new knowledge systems that better reflect and visually represent cities SETS dimensions.

4. Results: approaching knowledge system redesign in three cities

First, we share results from each city, and then we explain how these informed the development of a new SETS data visualization platform working across the three cities. Note: there is insufficient room here to present all of the results from each city, so we focus on key takeaways; additional results can be found in the Supplemental materials.

4.1. Miami

An initial inventory revealed 56 digital tools or applications used in the context of urban resilience at local, national, and global levels (Troxler et al., 2018; also see Supplemental Materials). Participants noted that the inundation of digital tools, data, and applications in Florida was hard to navigate and discussed uncertainty about how to assess the utility, validity and credibility of these different tools. While each tool had certain advantages and disadvantages relative to a given audience, participants also wanted to understand how different tools related to one another within the larger context of steering urban resilience planning (Fig. 3).

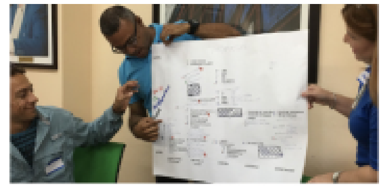
Considering these challenges, participants in the Innovation Lab worked in small groups to discuss and design an ideal SETS visualization platform. In the Miami workshop/Innovation Lab, they envisioned a SETS visualization platform that would integrate some of the best features of the tools already in use and be augmented with locally specific data for planning and anticipating coastal resilience strategies at the community level. Their visualization platform designs reflected a desire for an open-source, multicultural, and multilingual interface tracking the impact of extreme weather events on existing services. Several participants wanted to reveal invisible things such as hidden decision-making processes and financial flows related to real estate development, exposing how elites within the finance sectors were more interested in downplaying or denying the realities of sea-level rise, rather than engaging in public discussion and policy change. They sought a platform to center citizen knowledge often overlooked in official planning processes, such as citizen flood monitoring initiatives using smartphone applications for a stronger local understanding of high tide flood events. They also saw value in a platform that would serve as a one-stop shop, allowing users to rate the functionality, salience, and credibility of different data visualization tools. Groups agreed on the platform s key characteristics accessibility, trustworthiness, provision of core data, and user participation (crowdsourcing, open-source, participatory budgeting, etc.) though small groups emphasized different platform designs (Fig. 4).

Moreover, the process of presenting and discussing different design options revealed key tensions framing the type of information that a visualization platform should provide. For example, in a conversation between two participants, a data expert (Participant A) envisioned a platform with advanced technological capacity to collect real-time data during an extreme weather event and communicate that information in ways that matched the data literacy levels of poor communities. A community organizer (Participant B) rejected the assumption that poor communities (read lower-income communities of color) needed to have their information dumbed down to make it comprehensible. Participant A then attempted to provide some concrete illustrations of what this platform s functionality might look like, but this only confirmed the mismatch between their respective visions of the role of technology in a resilient future.

Participant A: *Okay, let me give you two scenarios. Scenario 1: a community captain has to figure out if they can take their truck from Little Haiti to Liberty City to pick up materials and return to the resilience hub, given all that s happening on the road in terms of debris, traffic, evacuation can we visualize that dynamically with a time scale? Scenario 2: a storm is coming and a Haitian mother with two kids in different schools in different parts of the city needs to figure out which roads to take to reach her children in time for the evacuation.*

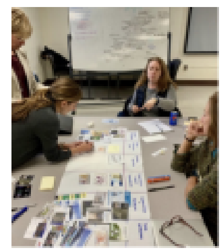
Participant B: *I hope we can have our government close down schools and tell people to stay off the road if there s a storm coming. You have*

Asset Mapping



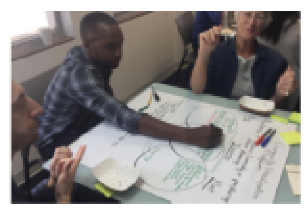
Participants worked in small groups to record all the actor assets working on coastal resilience, with sector categories on the X axis (community, nonprofit, governmental, academic, and private sector) and a scale of different institutional levels from local to global on the Y axis. Participants color-coded their lists according to the types of assets or expertise (information and data; finance, legal and cultural resources; and implementation support). Groups compared notes to generate a single, collective graph, reflecting the different networks, communities, and types of knowledge they could access. Asset mapping helps recognize the strengths and gaps within existing knowledge systems.

Card Sorting



In small groups, participants were given about 25 cards depicting images of digital platforms, applications, and interfaces used to visualize and communicate city-specific climate change data and were asked to select which geovisualization tools, immersive tools, narratives/stories, social media, data analytics, infographics, and drawings/renderings they would use to address use-cases (i.e., planning and plan development, project implementation, data gathering about community needs, standards compliance, risk evaluation, communication and storytelling, community organizing, and education programs) within their own urban resilience work. Each group reported back about their decision-making process, leading to a discussion about which kinds of visualizations are most helpful for thinking about the long-term future of the city from different perspectives.

Visualization Platform Design



In small groups, participants designed a SETS data visualization platform to help cities become more resilient to extreme weather events and meet the needs of their communities. Participants presented the elements, functions, and key features of their ideal visualization platform to the room. This exercise helped envision possible knowledge system designs, exploring the priorities and decision-making processes for building anticipatory capacity within specific communities.

Fig. 2. Activities to co-produce new knowledge systems. Asset mapping, card sorting, and platform design activities in Miami, San Juan, and Baltimore *innovation labs*.

Social media tools like Facebook, Twitter, and Next Door were valued for connecting people, staying informed, and building community around shared ideas despite drawbacks like potential misinformation and limited perspectives. National-level tools, such as tidal prediction databases from NOAA, USGS's groundwater watch website, and Hazus from FEMA, were considered critical for general information but limited in terms of information applicability and user-friendliness within specific local contexts. Local tools like Eyes on the Rise, offering visualizations, citizen science data, and modeling for projecting sea-level rise in Florida, were seen as crucial for increasing awareness and advocacy despite needing additional data for scientific accuracy. Through discussions on tool design and functionality, participants gained a better understanding of the evaluative criteria for their desired knowledge systems.

Fig. 3. Advantages and disadvantages of various coastal resilience tools in Miami.

> *people building these data platforms, when do you stop updating the platform? Is someone updating it during a storm?"*

Whereas Participant A frames a situation in which real-time data sensors and information could help an individual navigate the chaos of a crisis, Participant B suggests there are serious limitations to relying on technology for decision-making in the middle of a storm and would rather see a more preventative approach in which government policy keeps people out of harm's way. After presenting further results from the other cities, we will discuss how such emerging tensions can help understand different options for redesigning a city's knowledge system in

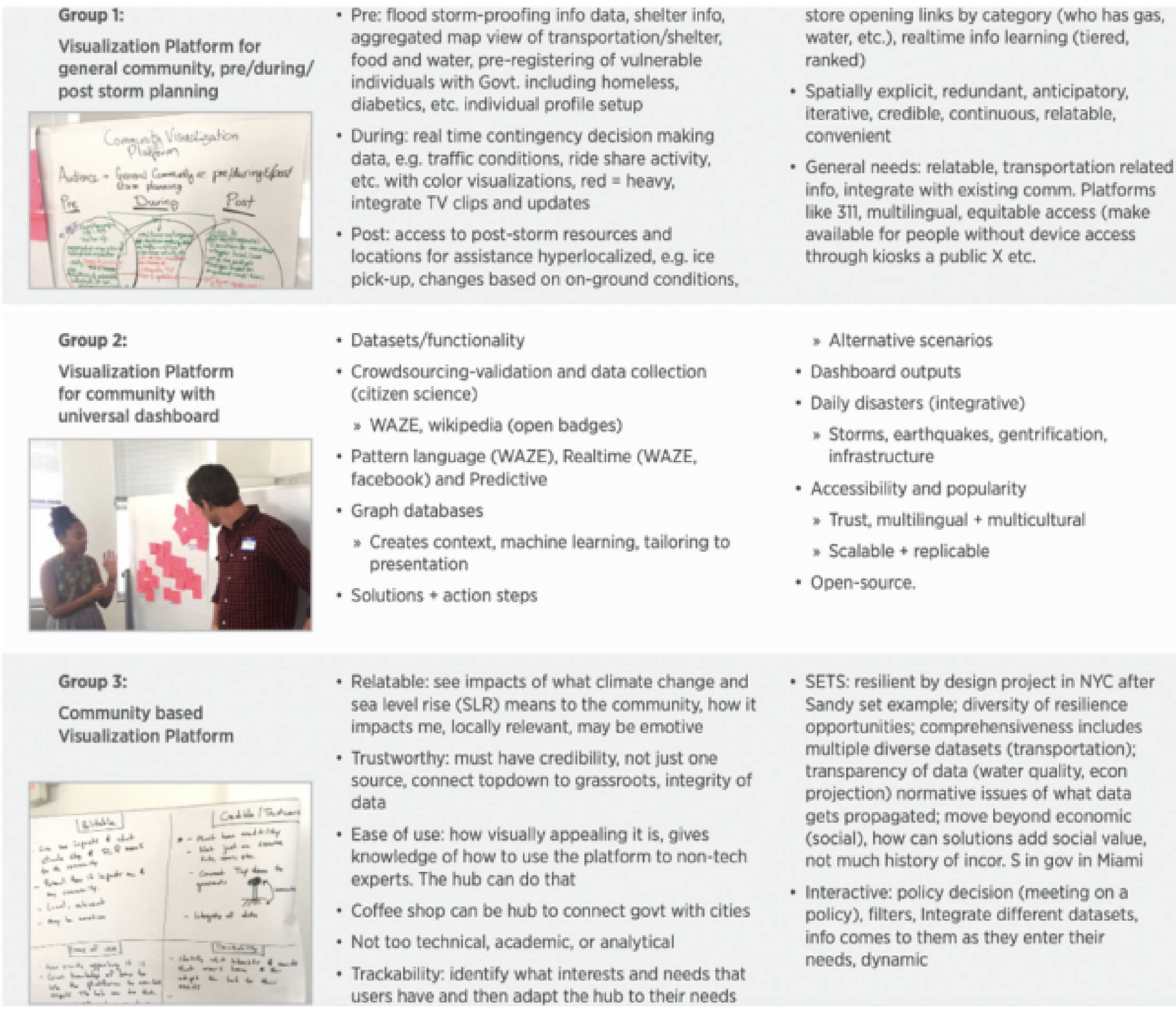


Fig. 4. Three different SETS visualization platforms co-designed by participants in the Miami Innovation Lab. Group 1 proposed a multi-lingual platform to provide information, data, and resources during all phases of an emergency disaster recovery cycle (pre-, during-, and post-disaster). Group 2 proposed an open-source platform with real-time, crowd-sourced data, dashboard outputs, and alternative scenarios presented in a multicultural scalable format. Group 3 offered a platform to collect locally meaningful and experience-based stories/images to help understand the effects of sea level rise with relatable and trustworthy information to inform policy solutions that create social value.

transformative ways.

4.2. Santurce District in San Juan, Puerto Rico

In contrast to Miami, in San Juan there was a lack of locally produced or locally relevant digital tools and technologies, with the exception of the San Juan Urban Long-Term Research Area (ULTRA; www.sanjuanultra.org) and the Puerto Rico Planning Board (https://jp.pr.gov/) that provide locally relevant city and climate data (Méndez-Lázaro et al., 2018). Ensuing conversation during the card sorting activity (Photos 1

Photos 1 & 2. Card sorting in Santurce (SJ, PR.).

and 2) revealed that the majority of digital tools were created by the federal government at the national-level (e.g., NOAA MERIS and Coris tools, US Census Bureau Website, USDA NRS Web Soil Survey) or by NGOs and private entities (e.g., Open Street Map, Google Earth, ESRI, Facebook), but participants emphasized that planners, practitioners, and residents rely mostly on direct observation and trusted individuals and organizations to share information and data through direct communication in meetings, social settings or within established networks using educational pamphlets and infographics posted on social media platforms like Facebook and WhatsApp [Meta Platforms, Inc.].

These direct communication practices were amplified after Hurricane María (2017) when electric and communication technologies failed. As frequently happens in disaster contexts, a large number of civic and private organizations arrived or were newly created to help with relief and recovery efforts, but then disappeared six months later, making it challenging to have consistent and reliable access to trustworthy information. In the asset mapping activity, Santurce participants identified over 90 organizations relevant to disaster response and resilience across local, national, and international scales (Fig. 5). Locally engaged non-profit NGOs and community organizations were deemed the most credible and legitimate sources of information and knowledge, and it was noted that universities and their students played a key role as knowledge brokers connecting communities with resources, information, and legal advice through a network of experts in Puerto Rico and the continental US. Federal and state government agencies were viewed as the least trustworthy actors. Participants explained that in communities without stable internet access, certain individuals played a key role in keeping analog records of resources and supplies for each household, which was not only crucial to meet the needs of the most vulnerable, especially the elderly and children, but also to communicate back to the NGOs and agencies such as FEMA that were organizing relief efforts to ensure that the supplies delivered matched the needs of communities, thus minimizing waste and corrupt practices. These leaders served as knowledge brokers within the community's knowledge system, keeping people informed through face-to-face dialogue, meetings, and pamphlets (Photo 3).

Given the important role of community leaders within existing social networks, relationships, and non-digital modes of communication, the Santurce participants emphasized the need to locate their desired SETS visualization platform within a physical hub that fosters community connections, community-government relations, and supports interpersonal relationships as foundational to any data visualization effort. The ideal platform would then be designed with a specific place and context in mind, since it is through embedding the platform within certain established networks that the platform's information becomes practical and usable to community members. For example, community centers, cafes, magazine shops, and centers where people already gather are the information hubs in which any socially useful platform must be

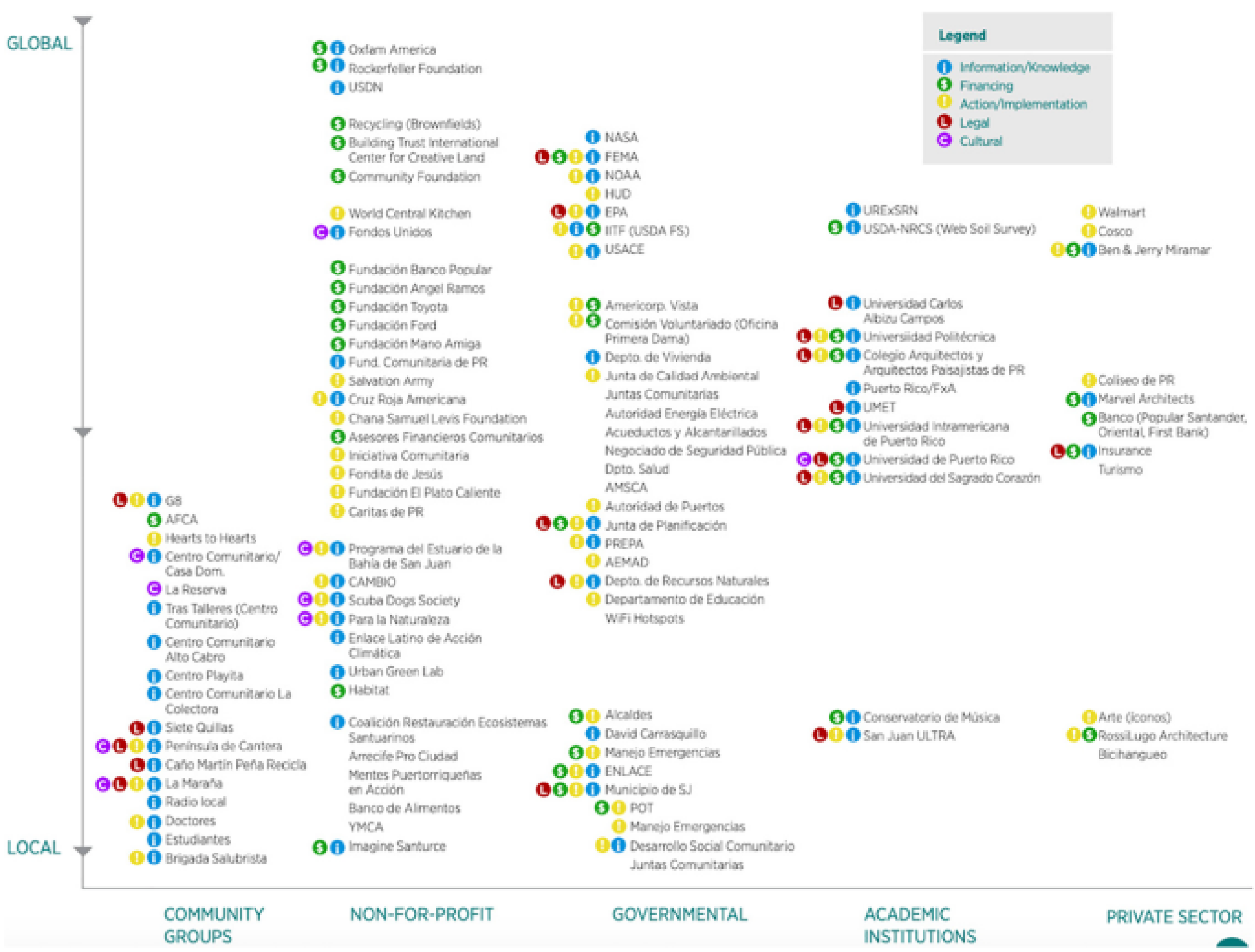


Fig. 5. Consolidated results from the asset mapping activity in the Santurce Innovation Lab. Participants listed all the actors (e.g., organizations and groups) relevant and active in disaster response and resilience activities in Santurce following Hurricane María. The Y axis indicates the actors' institutional level from local to global, and the X axis indicates the type of organization, from community groups to the private sector. The colored dots indicate the types of roles, services, and capacities: information and knowledge (blue dots), financing (red dots), action and implementation (yellow dots), legal (red dots), and cultural (purple dots). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Photo 3. Asset mapping in Santurce (San Juan), Puerto Rico.

embedded to be effectively utilized to meet local needs. The virtual component of this knowledge system would recognize an expanded definition of data and data visualization, including options that are reliable in power outages, such as stories, photographs, word-of-mouth, experiential knowledge, and more traditional communication venues such as radio, television, murals, and flyers. Finally, rather than a single resilience hub physically located in one place, multiple hubs would be located in existing community meeting places, though building meaningful virtual connections across these different places would take time, as each community has a sense of its turf and norms.

4.3. Baltimore

Participants at the Baltimore Innovation Lab started by emphasizing just how distinct and diverse each of the city's more than 250 neighborhoods were, raising questions about how data visualization tools might redress or exacerbate the unequal distribution of power and privilege across the city. Given the complexities and power relations within upstream decision-making and downstream consequences, they acknowledged the need for better coordination across different communities, but they questioned who might be the right messengers for embedding new roles for data visualization tools within specific communities. Participants thus sought a role for data visualization in building a more coordinated approach to resilience work across neighborhoods (Photos 4 and 5).

In the card sorting activity, Baltimore participants identified how certain data visualization tools were more effective in communicating with certain audiences, and they categorized the various tools presented accordingly (Fig. 6). This led to a breakthrough moment as participants envisioned a platform that could provide different kinds of data visualizations at different moments based on the evolution of a project rather than pitting one data visualization tool against another based on audience preference in a static sense. For instance, practices of plan development and metrics reporting (e.g., for accountability to the city mayor and council) would perhaps demand more data heavy visualizations (e.g., NOAA Sea Level Rise Viewer) compared to communicating and sharing the same results with the public (e.g., infographics).

Participants also mentioned two other important elements of their desired SETS data visualization knowledge system: (1) the long-term maintenance of the system (given the rapid pace of technological change) to keep data up-to-date, verify its credibility, and ensure users can interpret data correctly or update their privacy settings and ethical guidelines on data use and sharing, and (2) the importance of spaces like the Innovation Labs in facilitating social learning and reflexivity. Just as in San Juan, Baltimore participants suggested that the value of data visualization could not be realized in isolation from a social co-production process.

4.4. A prototype SETS visualization platform for coastal resilience

After moving through the innovation spaces for co-producing new knowledge systems in Miami, San Juan, and Baltimore, the task was to understand the implications for designing a data visualization platform that would build capacity for SETS resilience, responsive to different stakeholder needs. Participants in each city made it clear they did not want another tool or app but rather a platform, dashboard, or even a

Photos 4 & 5. Card sorting in Baltimore.

Tools		Planning and Plan Development	Project Implementation (Scale)	Response & Monitoring	Prioritization & Metrics (Accountability)	Communications and Storytelling	Data Gathering
Facebook							✓
Twitter						✓	
YouTube (virtual reality video of Zuckerberg in PR after Maria)							✓
Nextdoor							✓
Coastal Protection and Restoration Authority (CIMS Spatial Viewer)			✓				
Urban Footprint		✓					
Coastal Resilience		✓					
The New School Urban Systems Lab		✓			✓		
USDA Forest Service (Stewardship Mapping and Assessment Project)							✓
EPA (Environmental Justice Screening and Mapping Tool)		✓			✓		
Baltimore Green Network Vision Map		✓					
Urban Tree Canopy					✓		
Land Cover Data Project					✓		
NOAA (Sea Level Rise Viewer)		✓					
NOAA (National Storm Surge Hazard Map)		✓					
USGS Land Use Viewer					✓		
Flood iQ		✓				✓	
FEMA (Immersed)							✓
Owlized							
Miami Murals							✓
Eyes on the Rise (Virtual Eyes)						✓	✓
ProPublica (News article with interactive story board)						✓	
The Eye (Printed news article)							
Renderings		✓				✓	
Mark up on map		✓					
Hand drawn map		✓					
Newsprint article						✓	
Graph				✓			
Infograph							
Infographic (Coastal Resilience)							
Infographic (Rising Sea Levels)						✓	
Infographic (Hurricane Maria)						✓	
Infographic (Hurricane Maria 2)						✓	
Dashboard Infographic					✓		
Flood Alert System				✓			
Design guidelines (resilience, floodplain, stormwater)			✓				
IMAP							
Reporting & Compliance (SSO, STAR, etc)					✓		

Fig. 6. Results of the card sorting activity generated by the municipal planning group during the Baltimore Innovation Lab. The "tools" column lists the diverse visualization and communication tools that all groups were given as examples to sort according to specific use-cases at different times in the project cycle. The check marks show the placement of the cards once sorted by the tool's utility.

physical space that enhances understanding of the interactions across existing social, ecological, and technological systems. They desired a knowledge system capable of evolving and offering multiple visualizations for varying audiences at different times according to their needs.

To address these requirements, we designed a prototype SETS visualization platform as a 'network of networks' containing three equal layers of knowledge system components discussed in the innovation spaces: the people (actor-network), use-cases (decision tree), and tools (tool index) (Fig. 7). Fig. 8 displays a segment of the decision tree demonstrating the linkage between types of organizations, use-cases, data, and data visualization tools available. We also developed a demonstration video to illustrate the functionality of the platform through a fictional user, Lucía, interacting with the platform (see Supplemental Materials).

This prototype was presented to participants from the three cities as part of the final *innovation webinar*, and the feedback was positive: stakeholders valued the prototype for aiding individual knowledge brokers, allowing users to connect with each other, expand networks,

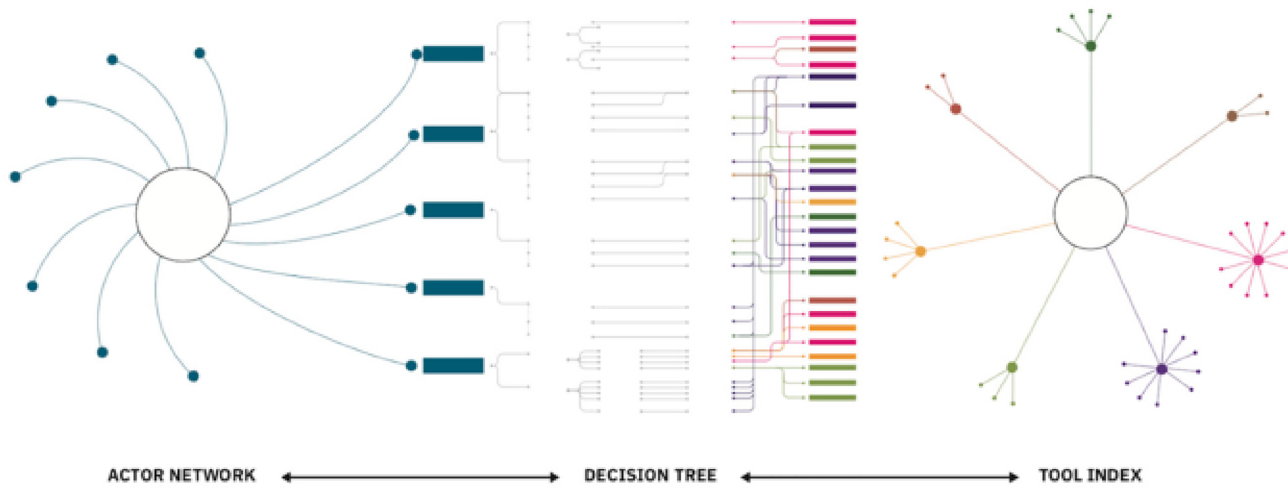


Fig. 7. Prototype of a SETS visualization platform that serves as a 'network of networks.' This bird's eye view shows how a user could enter through either the list of tools, use-cases (decision tree), or actors to then see how elements from each align, e.g., how a given actor uses a particular tool in a particular use-case.

and gain a comprehensive overview of coastal resilience efforts across the three cities. Participants valued the platform's capacity to display different people, projects, and related literature, including gray literature that provides details about specific community projects in different sectors and cities. Users appreciated the platform's ability to share materials and personal contact information through permission and privacy settings controlled by the users themselves—as one participant said, just having the name and phone number of someone directly connected to a resilience project in one of these cities is immensely helpful. Users also could rate a tool's usefulness, and new actors, use-cases, and tools could be infused into the platform as the network grows organically. Suggestions for improvements included adding color coding for individual cities to indicate potential resource gaps and vetting all posted information by a group of experts.

In sum, the results from Miami, San Juan, and Baltimore indicate that while participants want accessible, credible, and real-time community-relevant data, their desire for a SETS visualization platform is not just about visualizing data per se, but about building relationships between the different groups of people working with these data as part of ongoing struggles in specific neighborhood contexts to gain greater steering power over the direction, decision-making, and priorities of urban development. Rather than a singular data visualization tool, what emerges is a network-of-networks approach for sharing expertise, insights, and visions of urban resilience that help coordinate efforts and support collective learning about how to better navigate and transform dominant power relations within and across cities.

5. Discussion: co-producing SETS visualization through knowledge systems innovation

Co-producing new climate resilience knowledge systems shifts the emphasis of data visualization away from simply providing information, towards transforming and sustaining new relations between actors capable of bringing to bear different insights across the SETS domains of coastal resilience planning. Furthermore, this shift orientates co-production beyond a one-time instrumental application, for example where new information is simply inserted into conventional knowledge systems, towards envisioning longer term changes in the underlying relations that organize how different groups understand and anticipate the complex and cascading effects of climate change issues *writ large*. Below, we discuss insights into the praxis of co-producing new knowledge systems, namely, (1) the value of emergent, activity-based learning, (2) the role of conflict in finding just orientations, and (3) the changing function of data visualization technologies to support stronger and wider social networks. For each of these points, we reflect on their contribution to taking the theory and practice of co-production to the deeper and broader level of knowledge systems innovation, advancing an emerging understanding of cities as SETS.

5.1. *Emergent, activity-based learning*

The activity-based learning approach (asset mapping, card sorting, and SETS visualization platform design) used in our *innovation labs* balanced structure with a certain open-ended messiness, pushing co-production beyond the collection of information, towards listening to and learning from the context-specific conditions of different actors' experiences (Cook et al., 2021). Previous studies have emphasized the value of specific pedagogical designs in allowing differently positioned knowledge to be heard (Feagan et al., 2023; Webb et al., 2023; Wolff et al., 2020), but our focus on designing new knowledge systems emphasized the need for a longer-term vision for sustaining the network formed through our co-production process. This focus takes the challenges of co-production – different timelines, epistemologies, norms, among others (Turnhout et al., 2020) – and turns them into opportunities for learning how to navigate the dominant power-relations of conventional knowledge systems in transformative ways. For example, at the invitation of participants, we proceeded with a second innovation lab in Miami; in all three cities, we relied on participants to indicate the most appropriate venues for hosting the innovation labs on their own terms and turf; and in Baltimore, rather than starting with online innovation dialogues, we changed the process to start with the in-person innovation lab, based on the advice that this would build stronger trust relations among participants from the outset. Far from imposing a rigid, pre-designed process, these examples show how we embraced co-production as a responsive and emergent process centering trust relations. Emergent, activity-based learning opens space for this to happen, allowing the different actors to consider their own organizational structures, incentives, values, ideologies, norms, and frameworks, and how these need to change to create conditions for ongoing, collective responsibilities to each other. Co-producing new knowledge systems is necessarily an iterative, messy, and long-term process, challenging multi-dimensional aspects of power relations in society—but this is why the work matters, not a reason not to do it (Wyborn et al., 2019).

5.2. *The role of conflict in finding just orientations*

Co-production has been criticized for insisting on a knowledge integration imperative that masks tensions and incommensurability

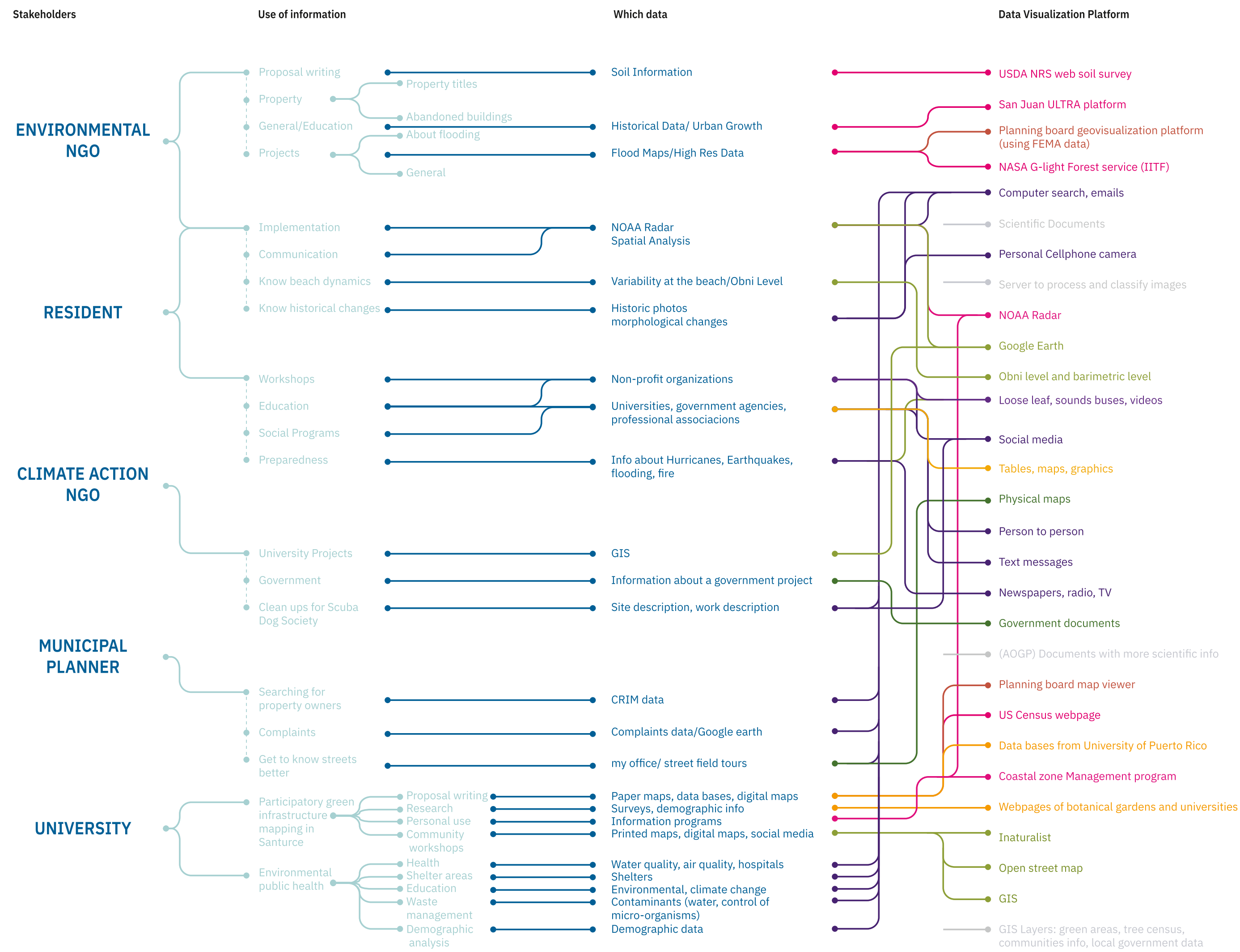


Fig. 8. Prototype SETS data visualization platform as a 'network of networks this view zooms in on the decision tree to reveal examples of use-cases that align particular actors with the information and type of data/visualization that supports this use. In this example view, an environmental NGO in San Juan has listed four uses of information (proposal writing, property, general/education, and projects), which are linked to data types (e.g., soil information, historical data/urban growth, and flood maps/high-res data) and relevant tools for data visualization (USDA NRCS, San Juan ULTRA platform, FEMA, NASA).

between different ontological and epistemological ways of knowing, generally favoring the reproduction of dominant knowledge systems (Klenk & Meehan, 2015). This is exactly why holding space for the conversation between Participant A and B matters: it brings to light key tensions between different framings and levels of privilege as a necessary part of a co-production process open to fundamental knowledge system redesign, not just a temporary compromise within the immediate workshop context. The community organizers with years of experience in struggles in each city were particularly strong at challenging assumptions, offering alternative framings, and opening room for considering fundamental re-orientations in the role of data visualization in resilience planning. For example, Santurce community organizers insisted on the value of low-tech data visualization through in-person communications within trusted networks, over the radio and television, and through keeping physical lists of people and their medication needs with pen and paper thus challenging the assumption that the newest data visualization technologies were necessarily the most useful. Likewise, in Baltimore, those with the most experience working directly with neighborhood groups insisted that members of those groups not outside experts would be the appropriate messengers for sharing the value of a SETS data visualization platform in specific communities, thus challenging the assumption that data visualization tools in-and-of themselves can bring about transformation. While it is understandable that those initiating a co-production process would seek to avoid conflict, conflict and transgression play a critical role in societal transformation by supporting deep epistemic change (Caniglia & Vogel, 2023). By confronting the limitations of conventional knowledge systems, we open space in which tensions are useful for building collective capacity for deeper transformations that move beyond the comfort zone of a particular cadre of climate and resilience experts, towards centering community-based experiences and expertise (Baja, 2021; Fazey et al., 2020).

5.3. Changing the relationship between technology and co-production

While technological tools may help visualize different kinds of data for different audiences, participants across the three cities made it clear that simply introducing new visualization tools does little to address the complexities and context-specific challenges of climate change. Instead, what was called for was a more comprehensive approach in which the role of technology would support learning across various tools, groups of experts, and context-specific practices. This shift aligns with other studies that recognize that addressing climate-related vulnerabilities requires listening to diverse forms of knowledge, including narratives, histories, stories, images, and experiences from specific neighborhoods, without which a city s capacity to anticipate outcomes across SETS interactions could be diminished (Pitidis et al., 2024; Ramsey et al., 2019). A city s social, ecological, and technological infrastructure must be connected as lived experiences, not just as information on a screen   this is why transforming the SETS relations underpinning the production and use of knowledge more generally matters (Branny et al., 2022). By connecting not only the tools but also the networks of people and their specific use-case contexts, our prototype SETS data visualization platform demonstrates in practice what Sauter et al. (2021) had partially described in theory.

Miami participants noted the urgent need to leverage the data abundance and best design features of the tools currently available into an inclusive, open-source, multilingual platform, augmented with community-relevant, localized data and methods (such as stories, images, and social networks) that build local adaptive capacity and help make visible the hidden power dynamics shaping urban development. In San Juan, having experienced information and communication failures in the wake of hurricanes Irma and María, the most valuable and trusted form of information and knowledge management was direct communication and traditional means of transferring knowledge. Thus, in the new knowledge system envisioned by Santurce participants, the value of SETS data visualization would be realized through multiple physical hubs that fostered community discourse and maintained the reliability of non-digital modes of communication alongside the use of any technological tools. In Baltimore, the desire was for a SETS visualization platform that could adapt to the changing information needs of an individual project over its lifecycle, with regular opportunities (like the innovation spaces) to test, validate, and explore emerging lessons. These examples illustrate how the function of data visualization can shift from showing the 'answer , towards supporting how different groups learn collectively about their different efforts to address the cascading complexity of climate change.

5.4. Implications for co-producing new knowledge systems

Research on co-producing knowledge systems for coastal urban resilience is evolving, and our work contributes to ongoing efforts to achieve fundamental redesign, re-orienting cities towards a SETS approach. From a knowledge systems perspective, the praxis of co-production has implications that go all the way to how we understand ourselves: as we begin to question the norms, habits, and working conditions that organize our data and conceptions of the world, we open ourselves to the possibility that the categories of understanding we have come-to-know are not natural and eternal, but rather *naturalized* containers that we have taken for granted as the 'normal and 'unavoidable parameters for our thoughts and actions (Caniglia et al., 2023). This realization is the encounter with the ideological nature of knowledge systems: you do not know that they are organizing your thoughts until you become aware of a different knowledge system option.

Munoz-Erickson et al. (2021) argue that urban planning as a field needs to adopt more transformative, inclusive, anticipatory, and futures-oriented approaches. Our research provides a practical model for what changing knowledge systems can entail, showing that discussions concerning the necessary data, information, tools, and technologies for informing climate adaptation and resilience strategies should not be confined solely to city managers, engineers, or scientists   civic actors and community members have unique expertise in helping cities orient their knowledge systems to address the distinct needs of coastal communities. The envisioned changes in the knowledge systems of all three cities reflect innovations in social structures and practices with the potential to address significant gaps and blind spots in the data and tools currently supporting climate adaptation and resilience planning. The prototype data visualization platform emerged as an attempt to mirror the social relations we created in person, with a technological functionality that would support the development of those relationships into the future. In this way, data visualization becomes about supporting ongoing transformative change by providing new ways for academic, municipal, and community-based expertise to be in relationship and naturalizing a new set of conditions in which collective action happens.

5.5. Limitations and next steps

Transforming dominant power relations is never a finished project, but rather always requires ongoing work. We acknowledge the limitations of our project. Although our city partners connections to local community organizers, non-profits, municipal decision-makers, and other stakeholders allowed us to build on existing relations of trust, this same reliance set limits on who was included and excluded from the process. Were we effective in centering frontline communities in all three cities? Participants in Miami included key actors from the nonprofit sector who raised issues of power, challenging other participants views on what it means to support underserved communities in planning for the future. In San Juan, our centering of local actors in the Santurce neighborhood ensured that the complexities of local organizing efforts were a central feature of workshop discussions, leading to an emphasis on embedding visualization tools within established local networks of trust with multiple nodes rather than one centralized location. In Baltimore, representatives from African American communities were missing. The participants, however, raised key points about the need to better understand the intricacies of Baltimore neighborhoods and what technologies can help coordinate across communities to better respond to upstream decision-making. Moving forward, the outcomes of this research have laid a foundation for applied work to (1) finalize and implement the prototype visualization platform, (2) expand the circle of established trust relations to learn with other communities, and (3) document and share the ongoing transformations in achieving the envisioned SETS knowledge systems in each city.

6. Conclusion

This article contributes to advancing knowledge co-production theory and practice through a knowledge systems approach to SETS data visualization and urban resilience planning in coastal cities. Responding to calls by sustainability and resilience scholars to go beyond research on *what* kinds of new knowledge systems may be needed to support societal adaptation and transformation, towards a detailed account of *how* new knowledge systems might be encouraged and co-designed, we offer case studies from Miami, San Juan, and Baltimore on co-producing new knowledge systems that are more capable of understanding, representing, and supporting coastal cities as SETS in navigating a climate-changed future.

A knowledge systems approach suggests a shift from seeing technology as a solution in itself, towards contextualizing its role within a broader challenge of transforming current knowledge systems through an iterative and messy co-production process that embraces the role of conflict and uses activity-based learning to reveal potential complementarities and critical tensions between differently positioned groups. We operationalized our approach through a series of *innovation spaces* where community members and stakeholders from multiple sectors co-designed a SETS data visualization platform that connects different types of expertise, knowledge, and ideas through various tools and context-specific projects within a network-of-networks prototype. With a focus on empirically diagnosing, experimenting, and reflecting on what it entails to co-create novel arrangements, practices, and new normative orientations, we argue that a knowledge systems approach helps take co-production towards envisioning systemic and long-term transformation based on building relationships of trust.

This is not a simple or straightforward process. There are tensions between what different communities know. Institutionally reinforced habits and power relations need to be questioned to recognize alternative possibilities. Knowledge systems change is multi-dimensional. But fundamental change does emerge through professional silos but rather through hearing the real-world lived experiences of different communities, and collectively redesigning how various understandings intersect or could intersect otherwise. More work is needed to further these understandings and act on their implications. The long-term vision of this SETS visualization platform is that it is coupled within physical community hubs where participants come together to co-produce, visualize, evaluate, and deliberate across the SETS spectrum. We argue that this type of knowledge system has the potential to build adaptive and anticipatory capacities in city governance systems and across communities, including the evaluation of risks and emerging vulnerabilities over the short, medium, and long term.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cities.2024.105513.

CRediT authorship contribution statement

Mathieu Feagan: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing original draft, Writing review & editing. **Tischa A. Munoz-Erickson:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing original draft, Writing review & editing. **Robert Hobbins:** Data curation, Investigation, Methodology, Project administration, Resources, Software, Visualization, Writing review & editing. **Kristin Baja:** Investigation, Validation, Writing review & editing. **Mikhail Chester:** Writing review & editing. **Elizabeth M. Cook:** Data curation, Formal analysis, Investigation, Validation, Writing review & editing. **Nancy Grimm:** Conceptualization, Funding acquisition, Investigation, Project administration, Supervision, Writing review & editing. **Morgan Grove:** Investigation, Project administration, Validation. **David M. Iwaniec:** Conceptualization, Formal analysis, Investigation, Writing review & editing. **Seema Iyer:** Investigation, Validation, Writing review & editing. **Timon McPhearson:** Data curation, Funding acquisition, Investigation, Project administration, Resources, Software, Supervision, Visualization, Writing review & editing. **Pablo Mendez-Lazaro:** Investigation, Project administration, Writing review & editing. **Clark Miller:** Data curation, Formal analysis. **Daniel Sauter:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing review & editing. **William Solecki:** Writing review & editing. **Claudia Tomateo:** Data curation, Investigation, Project administration, Resources, Software, Validation, Visualization, Writing review & editing. **Tiffany Troxler:** Investigation, Project administration, Writing review & editing. **Claire Welty:** Investigation, Project administration, Writing review & editing.

Funding

This work was supported by the National Science Foundation (NSF) 1737626, SCC-Planning: Building resilient coastal cities through smart and connected communities (Grant # 1737626), the NSF Urban Resilience to Extremes Weather-Related Events Sustainability Research Network (Grant # 1444755) and the Growing Convergence Network: SETS Convergence (Grant # 193493).

Declaration of competing interest

None.

Acknowledgements

This project was funded by NSF grant #1737626, with additional support from the UREx SRN (NSF #1444755, 1934933, 2203718). TME, PML, and DMI also acknowledge partial support from NOAA Adaptation Sciences Program (Grant Number NA23OAR4310485) and NOAA Caribbean Climate Adaptation Network a NOAA Climate Adaptation Partnerships team (Grant Number NA22OAR4310545).

Data availability

The data that has been used is confidential.

References

Angheloiu, C., & Tennant, M. (2020). Urban futures: Systemic or system changing interventions? A literature review using Meadows leverage points as analytical framework. *Cities, 104*, Article 102808. ISSN 0264-2751 https://doi.org/10.1016/j.cities.2020.102808.

Baja, K. (2021). Resilience hubs: Shifting power to communities through action. In *Climate Adaptation and Resilience Across Scales* (1st Edition, pp. 89 109). Routledge. https://doi.org/10.4324/9781003030720-6.

Bakhtiari, V., Piadeh, F., Behzadian, K., & Kapelan, Z. (2023). A critical review for the application of cutting-edge digital visualisation technologies for effective urban flood risk management. *Sustainable Cities and Society, 99*, Article 104958. ISSN 2210-6707.

Branny, A., M ller, M. S., Korpilo, S., McPhearson, T., Gulsrud, N., Olafsson, A. S., Andersson, E. (2022). Smarter greener cities through a social-ecological-technological systems approach. *Current Opinion in Environmental Sustainability, 55* (Complete). https://doi.org/10.1016/j.cosust.2022.101168

Brenner, N. (Ed.). (2014). *Implosions/explosions: Towards a study of planetary urbanization*. Berlin: Jovis.

Caniglia, G., Freeth, R., Luederitz, C., et al. (2023). Practical wisdom and virtue ethics for knowledge co-production in sustainability science. *Nature Sustainability, 6*, 493 501. https://doi.org/10.1038/s41893-022-01040-1

Caniglia, G., & Vogel, C. (2023). On being oriented: Strengthening transgressive orientations in transdisciplinary sustainability research through queer theory. *GAIA-Ecological Perspectives for Science and Society, 32*(1). https://doi.org/10.14512/gaia.32.1.15, 2023, pp. 167-171(5).

Cardullo, P., & Kitchin, R. (2019). Smart urbanism and smart citizenship: The neoliberal logic of 'citizen-focused smart cities in Europe. *Environment and Planning C: Politics and Spaces, 37*(5), 813 830. https://doi.org/10.1177/0263774X18806508

Carter, N., Bryant-Lukosius, D., DiCenso, A., Blythe, J., & Neville, A. J. (2014). The use of triangulation in qualitative research. *Oncology Nursing Forum, 41*(5), 545 547. https://doi.org/10.1188/14.ONF.545-547, 2014 Sep 25158659.

Cash, D. W., Clark, W. C., Alcock, F., Dickson, N. M., Eckley, N., Guston, D. H., Mitchell, R. B. (2003). Knowledge systems for sustainable development. *Proceedings of the National Academy of Sciences, 100*(14), 8086 8091. https://doi.org/10.1073/pnas.1231332100

Chang, H., Pallathadka, A., Sauer, J., Grimm, N. B., Zimmerman, R., Cheng, C., Herreros-Cantis, P. (2021). Assessment of urban flood vulnerability using the social-ecological-technological systems framework in six US cities. *Sustainable Cities and Society, 68*(102786), Article 102786. https://doi.org/10.1016/j.scs.2021.102786

Chester, M. V., Miller, T., & Munoz-Erickson, T. (2020). Infrastructure governance for the Anthropocene. *Elementa, 8*(1), 1 14. https://doi.org/10.1525/elementa.2020.078, 078.

Chester, M. V., Miller, T. R., Munoz-Erickson, T. A., et al. (2023). Sensemaking for entangled urban social, ecological, and technological systems in the Anthropocene. *npj Urban Sustainability, 3*, 39. https://doi.org/10.1038/s42949-023-00120-1

Chester, M. V., Underwood, B. S., & Samaras, C. (2020). Keeping infrastructure reliable under climate uncertainty. *Nature Climate Change, 10*, 488 490. https://doi.org/10.1038/s41558-020-0741-0

Considine, C., Covi, M., & Yusuf, J.-E. W. (2017). Mechanisms for cross-scaling, flexibility and social learning in building resilience to sea level rise: Case study of Hampton Roads, Virginia. *American Journal of Climate Change, 6*(2), 385 402. https://doi.org/10.4236/ajcc.2017.62020

Cook, E. M., Berbes-Blazquez, M., Mannetti, L. M., Grimm, N. B., Iwaniec, D. M., & Munoz-Erickson, T. A. (2021). Setting the stage for co-production. In Z. A. Hamstead, D. M. Iwaniec, T. McPhearson, M. Berbes-Blazquez, E. M. Cook, & T. A. Munoz-Erickson (Eds.), *Resilient urban futures* (pp. 99 111). Springer International Publishing. https://doi.org/10.1007/978-3-030-63131-4_7.

Eakin, H., Munoz-Erickson, T. A., & Lemos, M. C. (2018). Critical lines of action for vulnerability and resilience research and practice: Lessons from the 2017 hurricane season. *Journal of Extreme Events, 05*(02n03), Article 1850015. https://doi.org/10.1142/S234573761850015X

Fazey, I., Schapke, N., Caniglia, G., Hodgson, A., Kendrick, I., Lyon, C., Young, H. R. (2020). Transforming knowledge systems for life on Earth: Visions of future systems and how to get there. *Energy Research & Social Science, 70*(101724), Article 101724.

Feagan, M., Fork, M., Gray, G., Hamann, M., Hawes, J. K., Hiroyasu, E. H. T., & Wilkerson, B. (2023). Critical pedagogical designs for SETS knowledge co-production: Online peer- and problem-based learning by and for early career green infrastructure experts. *Urban Transformations, 5*, 6 (2023) https://doi.org/10.1186/s42854-023-00051-1.

Feagan, M., Matsler, M., Meerow, S., Munoz-Erickson, T. A., Hobbins, R., Gim, C., & Miller, C. A. (2019). Redesigning knowledge systems for urban resilience. *Environmental Science & Policy*. https://doi.org/10.1016/j.envsci.2019.07.014

Frantzeskaki, N., & Kabisch, N. (2016). Designing a knowledge co-production operating space for urban environmental governance Lessons from Rotterdam, Netherlands and Berlin, Germany. *Environmental Science & Policy, 62*, 90 98. ISSN 1462-9011 https://doi.org/10.1016/j.envsci.2016.01.010.

Gim, C., & Miller, C. A. (2022). Institutional interdependence and infrastructure resilience. *Current Opinion in Environmental Sustainability, 57*, Article 101203. ISSN 1877-3435 https://doi.org/10.1016/j.cosust.2022.101203.

Grimm, N. B., Stanley, F., Golubiewski, N., Redman, C., Wu, J., Bai, X., & Briggs, J. (2008). Global change and the ecology of cities. *Science (New York, N.Y.), 319*, 756 760. https://doi.org/10.1126/science.1150195

Grossi, G., & Pianezzi, D. (2017). Smart cities: Utopia or neoliberal ideology? *Cities, 69*, 79 85. ISSN 0264-2751 https://doi.org/10.1016/j.cities.2017.07.012.

Hamstead, Z. A., Iwaniec, D. M., McPhearson, T., Berbes-Blazquez, M., Cook, E. M., & Munoz-Erickson, T. A. (2021). *Resilient urban futures*. Springer Nature.

Helmrich, A. M., Ruddell, B. L., Bessem, K., Chester, M. V., Chohan, N., Doerry, E., Zahura, F. T. (2021). Opportunities for crowdsourcing in urban flood monitoring. *Environmental Modelling & Software, 143*, Article 105124. ISSN 1364-8152 https://doi.org/10.1016/j.envsoft.2021.105124.

Hobbins, R., Munoz-Erickson, T. A., & Miller, C. (2021). Producing and communicating flood risk: A knowledge system analysis of FEMA flood maps in New York City. In Z. A. Hamstead, D. M. Iwaniec, T. McPhearson, M. Berbes-Blazquez, E. M. Cook, & T. A. Munoz-Erickson (Eds.), *The urban book seriesResilient urban futures*. Cham: Springer. https://doi.org/10.1007/978-3-030-63131-4_5.

Hofmeister, M., Brownbridge, G., Hillman, M., Mosbach, S., Akroyd, J., Lee, K. F., & Kraft, M. (2024). Cross-domain flood risk assessment for smart cities using dynamic knowledge graphs. *Sustainable Cities and Society, 101*, Article 105113. ISSN 2210-6707 https://doi.org/10.1016/j.scs.2023.105113.

IPCC. (2022). In H.-O. Portner, D. C. Roberts, M. Tignor, E. S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Loschke, V. Moller, A. Okem, & B. Rama (Eds.), *Climate change 2022: Impacts, adaptation and vulnerability. contribution of working group II to the sixth assessment report of the intergovernmental panel on climate change*. Cambridge, UK and New York, NY, USA: Cambridge University Press. https://doi.org/10.1017/9781009325844, 3056 pp.

Iwaniec, D. M., Cook, E. M., Davidson, M. J., Berbes-Blazquez, M., Georgescu, M., Krayenhoff, E. S., Middel, A., Sampson, D. A., & Grimm, N. B. (2020). The co-production of sustainable future scenarios. *Landscape and Urban Planning, 197*, Article 103744. https://doi.org/10.1016/j.landurbplan.2020.103744

Iwaniec, D. M., Grimm, N. B., McPhearson, T., Berbes-Blazquez, M., Cook, E. M., & Munoz-Erickson, T. A. (2021). A framework for resilient urban futures. In Z. A. Hamstead, D. M. Iwaniec, T. McPhearson, M. Berbes-Blazquez, E. M. Cook, & T. A. Munoz-Erickson (Eds.), *Resilient urban futures* (pp. 1 9). Springer International Publishing. https://doi.org/10.1007/978-3-030-63131-4_1.

Iwaniec, D. M., Metson, G. S., & Cordell, D. (2016). P-FUTURES: Towards urban food & water security through collaborative design and impact. *Current Opinion in Environmental Sustainability, 20*, 1 7. https://doi.org/10.1016/j.cosust.2016.03.001

Iyer, S. D. (2015). Barriers to data sharing for inclusive knowledge management: Why WatershedStat in Baltimore City failed. In P. de Lancer Julnes, & E. Gibson (Eds.), *Innovations in the public and nonprofit sectors: A public solutions handbook* (pp. 91 109). M.E. Sharpe Press.

Keeler, B. L., Hamel, P., McPhearson, T., et al. (2019). Social-ecological and technological factors moderate the value of urban nature. *Nature Sustainability, 2*, 29 38 (2019) https://doi.org/10.1038/s41893-018-0202-1.

Kim, Y., Carvalhaes, T., Helmrich, A., Markolf, S., Hoff, R., Chester, M., et al. (2022). Leveraging SETS resilience capabilities for safe-to-fail infrastructure under climate change. *Current Opinion in Environmental Sustainability, 54*. https://doi.org/10.1016/J.COSUST.2022.101153

Klenk, N., & Meehan, K. (2015). Climate change and transdisciplinary science: Problematizing the integration imperative. *Environmental Science & Policy, 54*, 160 167. ISSN 1462-9011 https://doi.org/10.1016/j.envsci.2015.05.017.

Le Coz, J., Patalano, A., Collins, D., Guillen, N. F., Garcia, C. M., et al. (2016). Crowdsourced data for flood hydrology: Feedback from recent citizen science projects in Argentina, France and New Zealand. *Journal of Hydrology, 541*, 766 777. https://doi.org/10.1016/j.jhydrol.2016.07.036ff. Ffhal-01945326f.

Liberty, I. (2013). The (in)equities of superstorm recovery. In *Rutgers Clime: Center on Law, Inequality and Metropolitan Equity*, 20 September 2013 https://www.clime.rutgers.edu/publications-filtered/the-inequities-of-superstorm-recovery.

Lugo, A. E. (2019). *Social-ecological-technological effects of Hurricane María on Puerto Rico planning for resilience under extreme events*. Cham (Switzerland): Springer. https://doi.org/10.1007/978-3-030-02387-4

Marasinghe, R., Yigitcanlar, T., Mayere, S., Washington, T., & Limb, M. (2024). Computer vision applications for urban planning: A systematic review of opportunities and constraints. *Sustainable Cities and Society, 100*, Article 105047. ISSN 2210-6707 https://doi.org/10.1016/j.scs.2023.105047.

Markolf, S. A., Chester, M. V., Eisenberg, D. A., Iwaniec, D. M., Davidson, C. I., Zimmerman, R., Chang, H. (2018). Interdependent infrastructure as linked social, ecological, and technological systems (SETSs) to address lock in and enhance resilience. *Earth s Future, 18*, 1.

McAllister, T., Clavin, C., Ellingwood, B., van de Lindt, J., Mizzen, D., & Lavelle, F. (2019). *Data, information, and tools needed for community resilience planning and decision-making*. National Institute of Standards and Technology. US Department of Commerce. https://doi.org/10.6028/NIST.SP.1240. https://nvlpubs.nist.gov/nistpubs/specialpublications/NIST.SP.1240.pdf

McPhearson, T., Cook, E. M., Berbes-Blazquez, M., Cheng, C., Grimm, N. B., Andersson, E., Troxler, T. G. (2022). A social-ecological-technological systems framework for urban ecosystem services. *One Earth, 5*(5), 505 518. ISSN 2590-3322, https://doi.org/10.1016/j.oneear.2022.04.007.

McPhearson, T., Raymond, C., Gulsrud, N., et al. (2021). Radical changes are needed for transformations to a good Anthropocene. *npj Urban Sustainability, 1*, 5. https://doi.org/10.1038/s42949-021-00017-x

Meerow, S., & Newell, J. P. (2016). Urban resilience for whom, what, when, where, and why? *Urban Geography, 40*(3), 309 329. https://doi.org/10.1080/02723638.2016.1206395

Mendez-Lazaro, P., Feagan, M., & Munoz-Erickson, T. A. (2018). *Laboratorio de Innovacion de Santurce: Ciudades Costeras Resilientes Programa de Comunidades Conectadas e Inteligentes. Reporte Final. Red de Investigacion sobre Resiliencia Urbana a Eventos Extremos (UREx SRN)*.

Miller, C. A., Iles, A., & Jones, C. F. (2013). The social dimensions of energy transitions. *Science as Culture, 22*(2), 135 148. https://doi.org/10.1080/09505431.2013.786989

Miller, C. A., & Munoz-Erickson, T. A. (2018). *The rightful place of science: Designing knowledge*. Tempe, AZ: Consortium for Science, Policy & Outcomes.

Miller, T. R., Chester, M., & Munoz-Erickson, T. A. (2018). Rethinking infrastructure in an era of unprecedented weather events. *Issues in Science and Technology*, (Winter), 45 58.

Munoz-Erickson, T. A. (2014). Co-production of knowledge action systems in urban sustainable governance: The KASA approach. *Environmental Science & Policy, 37*, 182 191.

Munoz-Erickson, T. A., Miller, C. A., & Miller, T. R. (2017). How cities think: Knowledge co-production for urban sustainability and resilience. *Forests, Trees and Livelihoods, 8* (6), 203.

Munoz-Erickson, T. A., Selkirk, K., Hobbins, R., Miller, C., Feagan, M., Iwaniec, D. M., Cook, E. M. (2021). Anticipatory resilience bringing back the future into urban planning and knowledge systems. In Z. A. Hamstead, D. M. Iwaniec, T. McPhearson, M. Berbes-Blazquez, E. M. Cook, & T. A. Munoz-Erickson (Eds.), *Resilient urban futures* (pp. 159 172). Springer International Publishing.

Najafi, M. R., Zhang, Y., & Martyn, N. (2021). A flood risk assessment framework for interdependent infrastructure systems in coastal environments. *Sustainable Cities and Society, 64*(Complete). https://doi.org/10.1016/j.scs.2020.102516

Nesti, G. (2018). Co-production for innovation: The urban living lab experience. *Policy and Society, 37*(3), 310 325. https://doi.org/10.1080/14494035.2017.1374692. September.

Norstrom, A. V., Cvitanovic, C., Lof, M. F., et al. (2020). Principles for knowledge co-production in sustainability research. *Nature Sustainability, 3*, 182 190. https://doi.org/10.1038/s41893-019-0448-2

Paska, D. (2018). Digitalized water and smart cities How can telecommunication networks be used for environmental resilience? (Special Issue No. 2, 9 Nov) *ITU Journal: ICT Discoveries*, 17 24.

Pearsall, H., Heck, S., Tablas, M., Pierce, J., Hinrichs, C., Roman, L. A., & Shabazz, J. (2022). Building knowledge infrastructure for diverse stakeholders to scale up co-production equitably. *Current Opinion in Environmental Sustainability, 54*, Article 101156. ISSN 1877 3435 https://doi.org/10.1016/j.cosust.2022.101156.

Pereira, L., Frantzeskaki, N., Hebinck, A., Charli-Joseph, L., Drimie, S., Dyer, M., Vervoort, J. M. (2019). Transformative spaces in the making: Key lessons from nine cases in the Global South. *Sustainability Science*. https://doi.org/10.1007/s11625-019-00749-x

Pineda-Pinto, M., Herreros, P., McPhearson, T., Frantzeskaki, N., & Zhou, W. (2021). Examining ecological justice within the social-ecological-technological system of New York City, USA. *Landscape and Urban Planning, 215*, Article 104228. https://doi.org/10.1016/j.landurbplan.2021.104228

Pitidis, V., Coaffee, J., & Lima-Silva, F. (2024). Advancing equitable 'resilience imaginaries in the Global South through dialogical participatory mapping: Experiences from informal communities in Brazil. *Cities, 150*, Article 105015. ISSN 0264-2751 https://doi.org/10.1016/j.cities.2024.105015.

Ramsey, M. M., Munoz-Erickson, T. A., Melendez-Ackerman, E., Nytch, C. J., Branoff, B. L., & Carrasquillo-Medrano, D. (2019). Overcoming barriers to knowledge integration for urban resilience: A knowledge systems analysis of two-flood prone communities in San Juan, Puerto Rico. *Environmental Science & Policy, 99*, 48 57.

Rosenzweig, B., Ruddell, B. L., McPhillips, L., Hobbins, R., McPhearson, T., Cheng, Z., Kim, Y. (2019). Developing knowledge systems for urban resilience to cloudburst rain events. *Environmental Science & Policy, 99*, 150 159. ISSN 1462-9011 https://doi.org/10.1016/j.envsci.2019.05.020.

Sajjad, M., Chan, J. C. L., & Chopra, S. S. (2021). Rethinking disaster resilience in high-density cities: Towards an urban resilience knowledge system. *Sustainable Cities and Society, 69*(Complete). https://doi.org/10.1016/j.scs.2021.102850

Sauter, D., Randhawa, J., Tomateo, C., & McPhearson, T. (2021). Visualizing urban social ecological technological systems. In Z. A. Hamstead, D. M. Iwaniec, T. McPhearson, M. Berbes-Blazquez, E. M. Cook, & T. A. Munoz-Erickson (Eds.), *The urban book seriesResilient urban futures*. Cham: Springer. https://doi.org/10.1007/978-3-030-63131-4_10.

Schumann, G. (2023). *Increasing climate resilience through visualization. Issue 15*. Innovation News Network. https://www.innovationnewsnetwork.com/increasing-climate-resilience-through-visualisation/34700/.

Sheppard, S. R. J. (2012). *Visualizing climate change: A guide to visual communication of climate change and developing local solutions* (1st ed.). Routledge. https://doi.org/10.4324/9781849776882

Solecki, W., Delgado Ramos, G. C., Roberts, D., Rosenzweig, C., & Walsh, B. (2021). Accelerating climate research and action in cities through advanced science-policy-practice partnerships. *npj Urban Sustainability, 1*(1), 1 8.

Tengo, M., Brondizio, E. S., Elmqvist, T., Malmer, P., & Spierenburg, M. (2014). Connecting diverse knowledge systems for enhanced ecosystem governance: the multiple evidence base approach. *Ambio, 43*(5), 579 591. https://doi.org/10.1007/s13280-014-0501-3, 2014 Sep. PMID: 24659474; PMCID: PMC4132468.

Troxler, T., Feagan, M., & Munoz-Erickson, T. A. (2018). *Miami innovation lab: Resilient coastal cities and smart connected communities (RC2 SCC). Final report. Urban resilience to extreme sustainability research network (UREx SRN)*.

Troxler, T. G., Clement, A. C., Arditi-Rocha, Y., Beesing, G., Bhat, M., Bolson, J., Wheaton, E. (2021). A system for resilience learning: Developing a community-driven, multi-sector research approach for greater preparedness and resilience to long-term climate stressors and extreme events in the Miami Metropolitan Region. *Journal of Extreme Events, 08*(03). https://doi.org/10.1142/S2345737621500196

Turnhout, E., Metze, T., Wyborn, C., Klenk, N., & Louder, E. (2020). The politics of co-production: Participation, power, and transformation. *Current Opinion in Environmental Sustainability, 42*, 15 21. ISSN 1877-3435 https://doi.org/10.1016/j.cosust.2019.11.009.

Walker, B. (2020). Resilience: What it is and is not. *Ecology and Society, 25*(2). https://doi.org/10.5751/ES-11647-250211

Webb, J., Raez-Villanueva, S., Carriere, P. D., Beauchamp, A., Bell, I., Day, A., Vaillancourt, C. (2023). Transformational learning for a sustainable and healthy future through ecosystem approaches to health: Insights from 15 years of co-designed ecohealth teaching and learning experiences. *The Lancet Planetary Health, 7* (1), e86 e96. https://doi.org/10.1016/S2542-5196(22)00305-9

Welty, C., Grove, M., Feagan, M., & Munoz-Erickson, T. A. (2018). *Baltimore innovation lab: Resilient coastal cities and smart connected communities (RC2 SCC). Final report. Urban resilience to extreme sustainability research network (UREx SRN)*.

Whyte, K. (2017). Indigenous climate change studies: Indigenizing futures, decolonizing the anthropocene. *English Language Notes, 55*, 153 162, 1 2 Fall 2017.

Wijsman, K., & Feagan, M. (2019). Rethinking knowledge systems for urban resilience: Feminist and decolonial contributions to just transformations. *Environmental Science & Policy, 98*, 70 76. ISSN 1462-9011 https://doi.org/10.1016/j.envsci.2019.04.017.

Winner, L. (1986). Do artifacts have politics? In L. Winner (Ed.), *The whale and the reactor: A search for limits in an age of high technology* (pp. 19 39). Chicago: University of Chicago Press.

Wolff, A., Barker, M., Hudson, L., & Seffah, A. (2020). Supporting smart citizens: Design templates for co-designing data-intensive technologies. *Cities, 101*, Article 102695. ISSN 0264-2751 https://doi.org/10.1016/j.cities.2020.102695.

Woods, C. (2017). In J. T. Camp, & L. Pulido (Eds.), *Development drowned and reborn: The Blues and Bourbon restorations in post-Katrina New Orleans*. Athens: University of Georgia Press.

Wyborn, C., Datta, A., Montana, J., Ryan, M., Leith, P., Chaffin, B., van Kerkhoff, L. (2019). Co-producing sustainability: Reordering the governance of science, policy, and practice (October 2019). *Annual Review of Environment and Resources, 44*, 319 346, 2019, Available at SSRN: https://ssrn.com/abstract=3472223 or https://doi.org/10.1146/annurev-environ-101718-033103.

Yao, F., & Wang, Y. (2020). Towards resilient and smart cities: A real-time urban analytical and geo-visual system for social media streaming data. *Sustainable Cities and Society, 63*(Complete). https://doi.org/10.1016/j.scs.2020.102448

Yumagulova, L., & Vertinsky, I. (2019). Moving beyond engineering supremacy: Knowledge systems for urban resilience in Canada s Metro Vancouver region. *Environmental Science & Policy, 100*, 66 73. ISSN 1462-9011 https://doi.org/10.1016/j.envsci.2019.05.022.