Chapter 13
Urban Risks and Resilience

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Abstract The resilience concept has become more significant in the past decade as a means for understanding how cities prepare and plan for, absorb, recover from, and more successfully adapt to adverse events. Definitional differences—resilience as an outcome or end-point versus resilience as a process of building capacity—dominate the literature. Lagging behind are efforts to systematically measure resilience to produce a baseline and subsequent monitoring, in order to gauge what, where, and how intervention or mitigation strategies would strengthen or weaken urban resilience. The chapter reviews research and practitioner attempts to develop urban informatics for resilience and provides selected case studies of cities as exemplars.

13.1 Introduction

Disaster risks are increasing and becoming more pronounced in urban areas as populations increase and migrate to cities, turning them into megacities, and ultimately megaregions. Whether originating from natural forces such as hurricane-produced flooding (Houston), hurricanes (San Juan), wildfires (Los Angeles), earthquakes (Mexico City), or anthropogenic sources like unhealthy air pollution days (New Delhi), or the more insidious slow-onset events such as sea-level rise with increased "blue sky" coastal flooding (Jakarta), the health, safety, and welfare of urban residents is clearly at risk. In a world that is rapidly urbanizing, where more than 70% of the global population will live in cities by 2050, the nature and significance of urban disaster risk has garnered attention in research, policy, and practice. The looming question is how can urban informatics assist in the reduction of such disaster risks, and equally enhance resilience to them?

The need to reduce disaster risk in cities roared into public consciousness in 2010 when two violent earthquakes struck Port-au-Prince, Haiti (7.0Mw) and Concepcion, Chile (8.8Mw) within six weeks of each other. The impacts were catastrophic but unequal: more than 316,000 estimated lives lost in Haiti compared to 520 in Chile, and

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$30 billion in damages in Chile compared to the $14 billion in Haiti (Table 13.1). Such disparities in earthquake impacts reflected the pre-existing vulnerabilities in both places and brought more attention and pressure to address disaster risk reduction in cities (International Federation of Red Cross and Red Crescent Societies 2010). In many urban areas where poor-quality, overcrowded housing, and basic infrastructure and services are insufficient to protect people from harm, health hazards such as cholera or an infectious disease outbreak, an extreme environmental condition like a heat wave or harmful or unhealthy air pollution episode becomes more deadly. Reducing disaster risk, especially in urban areas, has become the rallying call for civil

Table 13.1 Selected urban disasters 2010–2018

Date	Urban area	Event	Deaths	Damage[a]
2010	Japan cities	Heat wave	1718	
	Port-au-Prince, Haiti	Earthquake	316,000	~$14b
	Concepcion, Chile	Earthquake/tsunami	520	$30b
2011	Bangkok, Thailand	Flooding	815	$32b
	Christchurch, New Zealand	Earthquake	185	$24b
	Tohoku, Japan	Earthquake/tsunami	20,000	$211b
	Rio de Janeiro, Brazil	Flooding/landslides	900	$1.2b
	Mindanao Island, Philippines	Tropical Storm Washi (Sendong)	1300	<$1b
2012	New York City	Hurricane Sandy	44	$71.4b
	Ibadan and Lagos, Nigeria	Flooding	363	$7.2b
2013	Tacloban and Cebu City, Philippines	Typhoon Haiyan (Super Typhoon Yolanda)	7300	$10b
	Passau, Magdeburg, Halle, and Wittenberge, Germany	Flooding	9	$13b
2015	Southern India	Heat wave	2500	
	Southern Pakistan	Heat wave	2000	
	Katmandu, Nepal	Earthquake	9000	$10b
2016	Kunamoto, Japan	Earthquake	205	$32b
2017	Houston	Hurricane Harvey	103	$125b
	San Juan, Puerto Rico	Hurricane Maria	4475	$90b
	Puebla, Mexico	Earthquake	369	$6b
2018	Palu, Sulawesi, Indonesia	Earthquake/tsunami	4340	<$1b
	Southern California	Wildfires	3	$5.2b
	Denver, Dallas–Ft. Worth	Hail storms		$3.6b
	Osaka, Japan	Super Typhoon Jebi	11	$15b

[a]Estimates of deaths and economic damage (in US$ billions) vary widely depending on the source and when the estimation was done. They illustrate the magnitude of the events, but are not definitive of the real loss or damage. Information is compiled from a variety of Internet sources

society globally in the second decade of the twenty-first century. One of the avenues for reducing risk is to increase the resilience of cities to absorb and withstand the everyday stressors and occasional shocks that lead to disastrous outcomes (Rodin 2014). The foundation for increasing resilience is the creation and application of relevant information and data for assessment and monitoring.

The resilience concept is not new (Alexander 2013), but has gained currency in the past two decades as a means for understanding how communities prepare for, absorb, recover from, and successfully adapt to stressors or adverse events. There are multiple disciplines engaged in conceptualizing resilience and methods for operationalizing it that run the gamut from descriptive to normative to analytical approaches (Meerow et al. 2016). The units of analysis are equally variable ranging from individuals (person, building, bridge) to functional groups (households, economic sector) or social groups (elderly) to systems (ecosystem, infrastructure, community) (Cutter 2016a). A community or a city functions as a system of systems where resilience is measureable within individual systems (e.g., governance, environment, financial) and in the interactions and interdependencies between and among systems. In this respect, cities operate as complex adaptive systems. Given the multiple, and often conflicting meanings of resilience, the objects of study, and the types of resilience examined (social, economic, etc.), application tensions arise between policy discourses and local actions.

Ultimately, however, the development of strategies for enhancing resilience in urban places requires three sets of information: (1) the existing and potential vulnerabilities and exposures to risks and hazards; (2) the inherent resilience or capacity to cope with such risks; and (3) empirical measurements, in order to gauge what, where, and how intervention or mitigation strategies would strengthen or weaken resilience. The chapter reviews research and practitioner attempts to develop urban informatics for resilience during the past decade.

13.2 Risks, Exposure, and Vulnerability

There are a variety of social and environmental trends from local to global scales contributing to increasing disaster risk and vulnerability (Ismail-Zadeh et al. 2017; UN Office for Disaster Risk Reduction 2019). This is partly a function of the ongoing global patterns of urbanization not only in the world's megacities, but also in small to mid-sized cities. Infrastructure assets in hazard-prone coastal and riverine areas create more physical exposure with potentially catastrophic economic damage because of the changing frequency in weather extremes and sea-level rise due to climate change (Wong et al. 2014). Another process affecting increasing exposure is globalization and economic interdependencies, whereby production and consumption activities are no longer locally or regionally constrained, but occur within a larger global economic system. The juxtaposition of economic globalization with climate change produces the double exposure of impacts across regions, social groups, or sectors (Leichenko and O'Brien 2008).

Along with increasing risk exposure, there is also growing population vulnerability. As income and wealth gaps widen between and within urban areas, the most disadvantaged bear most of the risk burdens. These often relate to lack of locational choice, whereby formal and informal housing locates in high-risk areas such and floodplains, low-lying coastal areas subject to tidal inundation, or on steep slopes subject to failure. In many cases, the settlements lack basic municipal services such as potable water, sanitation, and power, which in turn generate additional public health risks such as diarrhea, cholera, typhoid, or asthma from indoor pollutants from open-fire cooking.

As the demographic profiles of urban areas change, many cities in Western Europe and the USA are seeing increased levels of dependent social groups, especially the elderly and immigrant populations. The elderly in western cities live on fixed retirement incomes, with fewer and fewer living in multi-generational homes. Elderly persons living alone become more socially isolated and suffer daily stressors related to medical disabilities, limited mobility, limited financial resources, and fear of crime. When a shock occurs such as a heat wave, mortality among this vulnerable cohort is especially high, leading to further inequalities in risk impacts (Fleming et al. 2018; Klinenberg 2002).

The escalation of risk exposure and vulnerability in urban areas is also a function of the variability in coping capacities and resilience, the latter of particular concern for small to mid-sized cities (Birkmann et al. 2016). Strong governance structures, political, and social engagement by stakeholders, and understanding of cities as interdependent systems of systems all influence coping capacities (the term used in hazards and disasters) or adaptive capacities (the term preferred in climate change research) in either negative or positive ways (Cutter et al. 2008). Equally influential are culture, institutions, infrastructure, technology, collective action, historical experience, environmental quality, and planning (e.g., growth management, climate change, hazard mitigation) (Carter et al. 2015).

The social transformations that are taking place globally occur within the context of hazard extremes from not only climate-sensitive hazards, but equally from geophysical events. Table 13.1 provides a sampling of these singular events (shocks) in terms of death tolls and economic damage associated with urban disasters in the past decade. While the periodicity of geophysical hazards is uncertain, it is clear that weather-related extremes are increasing globally, affecting many of the world's urban areas. Declining air quality, water scarcity, and food insecurity are everyday stressors, which compound the impacts of the shocks, but also serve to reduce the coping capacity when such shocks do occur.

13.3 Urban Resilience and Capacities

As complex adaptive systems with social, infrastructural, and ecological networks, cities are a particular focus for resilience research given their scale, spatial form, and overlapping governance structures. While definitions of urban resilience abound based on disciplinary and theoretical orientation, this chapter defines urban resilience in its simplest form as "… the ability of a city or urban system to withstand a wide array of shocks and stresses" (Leichenko 2011, p. 164). Definitions and the range of approaches to urban resilience are as varied as the interdisciplinary schools of thought involved, ranging from socio-ecological systems, to engineering, to ecology, to public health. Despite nuanced differences, there is consistency among the perspectives in terms of fostering positive social change, leading to longer-term sustainability, in other words moving forward to what could be, not bouncing back to what was.

13.3.1 The Definitional Quagmire

The exponential growth in urban resilience research began in earnest in the early twenty-first century. According to bibliometric analyses of the academic literature (Meerow and Newell 2019; Meerow et al. 2016; Moser et al. 2019; Nunes et al. 2019; Wang et al. 2018), studies were primarily focused on definitions, characterizations, unpacking of a number of conceptual tensions, and theoretical inconsistencies in the literature. Among these are resilience as an equilibrium or non-equilibrium state; resilience as a positive construct (e.g., return to normal); resilience as a system trait, outcome, or process; pathways for achieving a resilient state (persistence, transition, transformation); adaptation versus adaptability; and timescale (rapid or slow).

Resilience resonates among a wide array of disciplines and stakeholders precisely because it is a descriptively flexible term that enables different parties to adapt the term for their own usage, or what is often termed a boundary object (Brand and Jax 2007). It also projects a positive action (becoming resilient) rather than its affiliate (reducing vulnerability), recognizing that vulnerability and resilience are not the opposite of one another—just because an individual, group, or system is vulnerable does not mean that it lacks resilience (Cutter 2018). The definitional quagmire presents both opportunities and constraints. The opportunities are the flexible definitions, as well as a robust academic discourse on terminology and philosophy, which has permeated the literature in the past decade. The constraints include an inability to move beyond the semantics into measurement, let alone into policy and practice. As it now stands, there is little integration in the research literature within the social sciences on resilience (based on climate change adaptation versus disaster risk reduction fields), let alone integration among disciplinary perspectives (engineering, health, ecology, social sciences) even when working with the same unit of analysis (a city).

13.3.2 Objects of Analysis

During the past decade, much of the urban resilience literature focused on climate change, urban ecological systems, and disasters with specific threats (floods, earthquakes) as stressors. There were relatively few examples of integrated urban system resilience. Instead, the literature remained stove-piped by discipline into three main types (or schools of thought) of urban resilience: ecological resilience, engineering resilience, and socio-ecological resilience. Focusing on the dynamics of ecological processes and patterns within cities, ecological resilience narrowly focused on understanding ecosystem dynamics in specific cities, making broader comparisons and generalizations across cities difficult. For example, much has been learned from the program of long-term ecological research in urban areas (LTER sites in Baltimore and Phoenix) in the USA. This includes the role of urban ecosystem services in resilience (McPhearson et al. 2015), and the increasing prevalence of green infrastructure (integration of ecology and urban design) as a mechanism for increasing urban resilience (Childers et al. 2015). Particularly, in the urban realm, convergence of urban ecology and socio-ecological perspectives in recognizing cites as complex and dynamic systems subject to natural and anthropogenic agents of change from local to global scales (Grimm et al. 2008; McPhearson et al. 2016) has prompted new research approaches and measurements for analyzing the ecology of cities.

Engineering resilience, also termed equilibrium or functional resilience, conveys intrinsic value-neutral decision making, whereby the attributes of the systems in the resilient city are described in network performance terms: rapidity of systems restoration; robustness to withstand damage without losing form or function; and systems backup and redundancies (Borsekova et al. 2018; Bristow 2019; Heeks and Ospina 2016). There were some attempts to transcend boundaries through socio-technical studies but much of that research is either system-specific (e.g., transportation, ICT, power, or water), or asset-specific such as buildings or roads. Integration with socio-ecological perspectives is less common, but increasing in the disasters field.

Given the increasing normative interpretation of resilience, scholars began to question the apolitical nature of urban resilience by asking "Resilience for whom?" and "Resilience to what?" (Cutter 2016b) or what Meerow and Newell (2019) call the "five Ws of urban resilience"—whom, what, when, where, and why. Such concerns about equity fundamentally challenged the asset-based approaches in engineering resilience. Resilience actions within a city shaped by contested views and differing value sets, and further manipulated by unequal power and competing interests, necessitate negotiated implementation strategies and planning (Borie et al. 2019; Leitner et al. 2018; White and O'Hare 2014). Increasingly such evolutionary or transformative resilience is both dynamic and more sensitive to social conditions and change, but also highlights the value-laden nature of urban resilience embedded within the existing sociocultural structure of a city with its own historical identity and context that is as variable as the cities themselves. It also becomes more difficult to assess.

13.4 Measurement and Assessment Informatics

The definitional ambiguity of urban resilience is significant insofar as it influences its assessment and measurement. For example, the engineering perspective focuses on the efficiency of the built environment to resist or absorb shocks (robustness), redundancies in systems to maintain functioning, and the return time for such systems to return to normal operations—all static approaches. On the other hand, socio-ecological frameworks presume dynamic interactive processes that learn, transform, and adapt to new conditions in nonlinear and uncertain ways, thereby building capacity to withstand the next shock while simultaneously maintaining both social and ecosystem services. As many authors have recognized, resilience measurement is in its nascent state, whereby resilience policy is further ahead than the science of resilience assessment and measurement (The National Academies 2012).

A number of reviews of existing resilience measurement schemes appear in the recent literature (Asadzadeh et al. 2017; Beccari 2016; Brown et al. 2018; Cai et al. 2018; Ostadtaghizadeh et al. 2015; Rus et al. 2018; Sharifi 2016; The National Academies of Sciences, Engineering and Medicine 2019). Many of these are not specific to urban resilience, but instead focus more broadly on community resilience and resilience to climate change or natural hazards. Evaluation or assessments of resilience generally include one of the following: measuring baselines, measuring initiatives against accepted definitions or pre-determined indicators, or measuring resilience compared to achieving project or program goals (Brown et al. 2018).

As described in these reviews, many of the measurement efforts are mesoscale top-down quantitative efforts employing secondary data collected by governmental agencies, to produce an empirically-based view of resilience characteristics and drivers at metropolitan, county, or community scales. Many studies use indexing procedures with weighted or unweighted composite indices to derive a value for the entire enumeration unit, arguing that such a baseline or screening approach (pre-stressor or impact) is an important starting point for subsequent measurement and policy intervention (Cutter et al. 2014, 2016; Cutter and Derakhshan 2018; González et al. 2018; Harwell et al. 2019). A slightly different conceptual orientation by Kammouh et al. (2019) added additional interdependency matrices to their indicator-based approach and then tested it on a post-event case study of 1989s Loma Prieta earthquake. Many of the composite indices referenced above employ geospatial analytics in their construction and visualization of results.

The non-indexing methods incorporate fragility analyses (Barría et al. 2019), graph theory and network analytics (in spatial and non-spatial forms; Bristow 2019; Sharifi 2019), and agent-based modeling and simulations (Kanno et al. 2019; Moghadas et al. 2019). Locally based approaches such as those of Eisenman et al. (2014) and Plough et al. (2013) use pre-and post-testing of subjects to assess resilience-building programmatic activities to enhance resilience outcomes. Lastly, while relative few in number, the use of qualitative methods (narratives, focus groups; Borie et al. 2019; Huck and Monstadt 2019) are adding richness to the understanding of bottom-up (or locally based visions) of urban resilience.

What is surprising about the emerging field of resilience measurement is the lack of big data and more sophisticated and innovative geospatial methodologies. The development of crisis informatics (Liu and Palen 2010; Palen and Anderson 2016) is now well-established, but primarily used for emergency response such as during the 2010 Haiti earthquake or more recently in Hurricane Harvey in Houston and Hurricane Maria in Puerto Rico. A review of remote-sensing-based proxies for urban resilience (Ghaffarian et al. 2018) highlights the utility of reflectance of building materials and texture as proxy indicators for resilience (wood versus reinforced concrete structures in seismic areas, for example), or night-time lights as a proxy for economic resilience, as was illustrated with Hurricane Maria in Puerto Rico.

There are increasing numbers of analyses employing passive citizen-sensor data to support measurement of disaster resilience using mobile-phone or smart-card data. For example, Wilkin et al. (2019) suggest that the use of mobile-phone data for social-network analyses is one unexplored opportunity of big data. Another usage is to track population movements post-event, which is more focused on disaster recovery than on risks or resilience (Bengtsson et al. 2011). Experimentally, Wi-Fi signal data has been used to estimate the location of buried people in a hypothetical building collapse (Moon et al. 2016). The use of social-media data (with a geospatial digital trace) is more prevalent, but again primarily focused on emergency preparedness. Mainly used to show population movements out of mandated hurricane evacuation zones, Twitter data was used to gauge residential compliance with evacuation orders (Martín et al. 2017). Despite data access issues for mobile-phone data in near-real time, and biased demographics and lack of validation of social-media data such as Twitter, opportunities exist to use such data in better understanding urban resilience and its visualization (Li et al. 2015; Zou et al. 2018).

13.5 Science Informs Practice and Practice Informs Science

While research on urban resilience continues its previous bifurcations into the primary schools of thought, there is increasing convergence among them with integration between research and methods from socio-ecological and socio-technical systems approaches, largely led by the social sciences working in conjunction with urban ecologists and engineers. What is absent in much of the work to date is what is called the implementation gap, or turning the science into practice, mindful of urban governance, stakeholder engagement, and local value systems. Instead, cities have moved forward in the resilience space, implementing strategies and projects on their own, often devoid of any theoretical, conceptual, or methodological understanding of differences in the academic resilience concept or orthodoxies. At the same time, transdisciplinary science has been slow to engage practitioners in this arena as well.

One of the largest (and most well funded) of these efforts is the Rockefeller Foundation's 100 Resilient Cities project. The goal of the project was to embed resilience into city policies, programs, and practices using a comprehensive resilience strategy.

Recognizing that cities might be unable to do this alone, the Rockefeller Foundation provided the initial funding for a resilience officer for each of the 100 cities. The project developed standardized domains for measurement in order to eventually compare the global cities using locally generated and collected data based on a top-down matrix of attributes provided by Rockefeller through their City Resilience Index (Arup 2015). The identification of risks and the hazards they face, and the pathways to reduce such exposure, provided the basis for prioritizing implementation projects for enhancing resilience. The entire process was designed to build local capacity to withstand future shocks and stressors within the cities by the people and institutions that were located there.

The 100 Resilient Cities effort was not without critics (Fainstein 2018; Leitner et al. 2018). A mid-term evaluation (5 years into the program) of the experiment in urban transformation found generally positive results in building cooperation and adopting the prescriptive resilience strategy and in developing a peer-to-peer network (Martín et al. 2018). Yet in 2019, the Rockefeller Foundation decided to phase out the program, as it had grown too costly and no longer aligned with Foundation goals (Bliss 2019).

Other communities of practice continue to work toward making cities resilient and measuring progress toward that goal (Table 13.2). The UNDRR has more than 4200 cities participating in its Making Cities Resilient effort, starting with a list of the ten essentials for making a city resilient. The UNDRR also supports using the benchmark Disaster Resilient Scorecard for cities to use in resilience planning, and monitoring progress toward the implementation of the Sendai Framework for Disaster Risk Reduction. Similarly, the World Bank and the Global Facility for Disaster Reduction and Recovery (GFDRR) have an urban resilience initiative. They produced a rapid diagnostic tool to first identify sectoral resilience in cities, and then procedures for integrating the sectors and other cross-linkages for the entire city. The tool provides a locally based, bottom-up qualitative assessment for each city. UN Habitat, through their city resilience profiling tool, provides a framework for data collection and analysis to create a city profile complete with urban characteristics, crosscutting issues, internal stressors, and expected shocks and stresses for use in planning, what-if scenario development, and impact monitoring. Knowledge sharing is the primary purpose of the ICLEI and US National Academies efforts (Resilient America). Other efforts to develop specific metrics for resilient cities include the 100 Resilient Cities City Resilience Index (CRI), and ISO standardized indicators for measuring resilience in cities for benchmarking and comparisons with other cities.

Some of these efforts include remote and smart sensing and citizen science but none is as advanced as New York City's Climate Action Plan. The current plan includes an integrated science-stakeholder-community indicator and monitoring framework embodied in an operational New York City Climate Change Resilience Indicators and Monitoring (NYCLIM) system (Rosenzweig and Solecki 2019).

Table 13.2 Communities of practice focused on assessment and measurement of urban resilience

Group/entity	Tool/program	Metric URL
UN Office of Disaster Risk Reduction (UNDRR)	Making cities resilient campaign	https://www.unisdr.org/campaign/resilientcities/assets/toolkit/documents/UNDRR_Making%20Cities%20Resilient%20Report%202019_April2019.pdf
	Disaster resilient scorecard for cities	https://www.preparecenter.org/sites/default/files/unisdr_disaster_resilience_scorecard_for_cities_preliminary.pdf
Global Facility for Disaster Reduction and Recovery (GFDRR), World Bank	Urban resilience initiative, city strength diagnostic	https://www.worldbank.org/en/topic/urbandevelopment/brief/citystrength
UN Habitat	City resilience profiling tool	https://urbanresiliencehub.org/wp-content/uploads/2018/02/CRPT-Guide.pdf
European Union URBACT	Resilient Europe	https://urbact.eu/ready-future-urban-resilience-practice
Rockefeller Foundation	100 resilient cities	https://www.100resilientcities.org/about-us/ and their City Resilience Index developed by Arup https://www.cityresilienceindex.org/#/resources
International Standards Organization (ISO)	Indicators for resilient cities (ISO 37123)	https://www.iso.org/obp/ui#iso:std:iso:37123:dis:ed-1:v1:en
ICLEI	Resilient cities	https://iclei.org/en/publication/resilient-cities-report-2018
US National Academies	Resilient America	https://sites.nationalacademies.org/PGA/resilientamerica/
Urban Land Institute	Urban resilience program	https://americas.uli.org/research/centers-initiatives/urban-resilience-program/
Mississippi-Alabama Sea Grant Consortium	Climate and resilience community of practice	https://masgc.org/climate-resilience-community-of-practice/about1
Resilience Measurement Evidence and Learning	Community of practice	https://www.measuringresilience.org/
C40 Climate Leadership Group	C40 cities	https://www.c40.org/about
Urban Climate Change Research Network (UCCRN)		https://uccrn.org/what-we-do/goals-and-activities/

(continued)

Table 13.2 (continued)

Group/entity	Tool/program	Metric URL
Sustainable Development Solutions Network (SDSN)	Sustainable cities	https://unsdsn.org/what-we-do/thematic-networks/sustainable-cities-inclusive-resilient-and-connected/

13.6 Moving Forward

It is quite clear that the present state of knowledge is insufficient in understanding resilience with its many forms and constructs, especially when applied communities or more specifically cities. More attention is needed on the details of measuring and assessing resilience (informatics), but these methodologies must advance quickly to be of use to cities who want to enhance or build resilience. As stated earlier, the science of resilience measurement in general, and urban resilience metrics specifically, must mature rapidly to be of any practical use to cities who are eager to move to more resilient and sustainable pathways. Efforts to incorporate mixed methodological approaches that engage stakeholders and local knowledge (the so-called bottom-up perspective) with top-down and more quantitative approaches hold the most promise. Similarly, locally grounded input data that serve multiple purposes (resilience indicators, general plans, land-use plans, economic development, emergency plans, etc.) is a must. Aligning city data collection and syntheses with global frameworks such as the Sendai Framework for Disaster Risk Reduction, the Sustainable Development Goals, the Paris Agreement on Climate Change, the World Humanitarian Summit's Agenda for Humanity, and Habitat III's New Urban Agenda saves time and effort in reporting requirements to different entities. It also creates opportunities for enhanced data collection, as the routine parameters are already collected.

Smart cities should be able to make citizen-sensor and geospatial digital trace data more accessible for research purposes (while protecting individual privacy) in near-real time and at a lower cost than at present. Moving from passive to active sensor data, including the use of remote-sensing technologies and data, is another source of proxy data on urban risks and resilience that is underutilized.

Finally, it is incumbent upon researchers and practitioners who are interested in urban risks and resilience to engage more widely beyond their specific and often limited domains of interest. Not only is the urban system complex and multi-faceted, but so too is its resilience. Knowledge across the domains and schools of thought is important, but what is really needed given the complexity and urgency is a new way of thinking about how to achieve urban resilience. Convergence research, spanning beyond multi-, inter- or transdisciplinary framings, is one avenue, as long as it truly integrates societally relevant knowledge, methods, expertise, and values to not only solve problems, but also to advance scientific discovery and innovation and produce usable outcomes for cities in the process.

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