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Urban and infrastructure resilience: Diverging concepts and the need for cross-boundary learning

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ABSTRACT

The concept of resilience has attracted considerable attention in policy and research communities in the fields of both urban and infrastructure development and governance. Resilience has been framed as a boundary concept bridging different communities of knowledge production and practice. However, a closer look at the joint enterprise, the shared repertoire, and the mutual engagement of respective knowledge communities in urban and infrastructure research and planning practice reveals that resilience is understood and dealt with in rather diverging ways. This paper explores some of these divides, then argues that differences in knowledge production can induce somewhat disconnected policy outcomes and governance approaches which consequently weaken cities' ability to address current and future challenges. Therefore, we call for more interaction and cross-boundary learning between respective knowledge communities.

1. Introduction

Global environmental change poses huge challenges to both cities and technical infrastructures. Researchers and practitioners in both realms are seeking ways to prepare for and deal with rising sea levels and extreme weather events, like hurricanes, droughts and heavy rainfall. Numerous extreme weather events have vividly exposed some of these challenges as well as the intricate relationship between urban and infrastructural vulnerability. As was the case of New Orleans, which was hit by Hurricane Katrina in 2005, the city was not only exposed to the immediate destructive impacts of storms and floods on its residents and built environments, but also to immense secondary impacts caused by cascading failures of energy, water, sanitation and transportation infrastructures (cf. Little, 2010). These secondary impacts significantly damaged the social fabric of the city, as the hardest-hit communities were also among the poorest (Campanella, 2006). Moreover, infrastructure failure had enormous consequences on the city's and the region's environment by triggering the emission of hazardous materials from industrial facilities, storage terminals and pipelines (Cruz and Krausmann, 2009).

As cities are geographical nodes in infrastructurally mediated flows and as they accommodate high densities of people, they are particularly vulnerable to infrastructure failures (Monstadt and Schmidt, 2019). A power blackout can, for instance, pose far-reaching risks to the safety of urban populations and damage economies, natural and built environments and other technical infrastructures. Therefore, a city's ability to prevent and to prepare for infrastructural failures is a major component of a resilient urban system. Urban and infrastructure resilience are inherently intertwined.

However, during empirical research on resilience in Germany, the Netherlands, and New Zealand, we discovered in numerous expert interviews an epistemic divide between stakeholders of urban and infrastructural resilience. The experts indicated that this divide between communities can result in incoherent policy and managerial responses in risk mitigation and preparedness consequently reducing the effectiveness of crisis management. Several interviewees reported instances where infrastructure managers and urban planners make use of similar vocabulary whilst referring to fundamentally different aspects of their work. For instance, a community manager in Christchurch, New Zealand states: "The problem is we all use the same words. We all say 'resilience' […]. But to me it means something different compared to infrastructure or engineering people. […] There are lots of people who are talking about resilience, but there is only a small group of people who are able to talk about resilience across disciplines or sectors." These indications from expert interviews raised questions about how the knowledge on resilience is being produced and how the challenge of

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building resilience is dealt with in different expert communities.

The objective of this paper is thus to disclose and compare how knowledge production takes place in two different knowledge communities dealing with urban and infrastructure resilience, then to critically reflect on the widespread conjecture of resilience as a boundary concept—a concept that is malleable enough to adapt to the epistemological approaches, methods and knowledge interests of epistemic communities but which is, at the same time, precise enough to bridge epistemic divides, to create identity and to structure common practices across communities of knowledge production (Baggio et al., 2015). We ask how boundaries between knowledge communities are created and reinforced, and how in turn this shapes respectively disparate policy making and governance practices. Therefore, our paper assesses ongoing academic debates on urban and infrastructure resilience through a set of variables derived from established theories and concepts of knowledge production. Based on a qualitative assessment of academic literature and grey literature published by selected multipliers, we argue that a better understanding of the particular and often disparate patterns of knowledge production on resilience is crucial to comprehend the opportunities and challenges of integrated approaches to urban and infrastructural resilience. The aim of our study is not to systematically test existing hypotheses in a representative way but to explore and describe different ways of knowledge production and dissemination.

In the following section, we provide a brief introduction into the debate on epistemic cultures, epistemic communities and communities of practice, then operationalise our analysis along three dimensions, namely common enterprise, shared repertoire and mutual engagement (Section 2). We then outline the applied methodology and scope of this study (Section 3). In Section 4 we compare the knowledge production in communities of practice in the fields of urban and infrastructure resilience. Hereafter, we discuss the identified epistemic and cultural divides and their consequences for policy making and the governance of urban and infrastructure resilience (Section 5). Finally, we challenge the common framing of resilience as a boundary concept. We conclude by arguing that cross-boundary learning and the co-production of new knowledge may benefit both realms in dealing with the multi-layered complexities of urban and infrastructure resilience (Section 6).

2. Knowledge communities and cross-boundary learning

Whilst urban and infrastructure resilience might practically be difficult to separate, resilience is understood and dealt with in diverging ways depending on the discipline of a researcher or the institutional affiliation of a decision maker. As knowledge production and governance outcomes are mutually constitutive (Frantzeskaki and Kabisch, 2016; Muñoz-Erickson et al., 2017), it is not surprising that current governance practices seem to struggle to combine different knowledge elements that are required to deal with complex realities of urban and infrastructure resilience (cf. Hommels, 2018). Therefore, in our analysis, we focus on different 'knowledge systems' as 'the organizational practices and routines that make, validate, communicate, and apply knowledge' (Muñoz-Erickson et al., 2017, p. 1). In order to draw conclusions on how knowledge systems shape policy making and governance practices in urban and infrastructure resilience, we make use of the notions of epistemic communities, epistemic cultures and communities of practice.

Firstly, epistemic communities influence policymaking and governance practices because these groups have 'recognised expertise and competence in a particular domain and an authoritative claim to policy-relevant knowledge' (Haas, 1992, p. 3). Knowledge production shapes, and is shaped by, the social practices in urban and infrastructure management and governance. Hence, an epistemic community in the field of urban resilience does not comprise urban resilience scholars alone, but also practitioners like city planners, agencies like UN-Habitat, consultancies, and non-governmental actors such as the Rockefeller Foundation. Similarly, epistemic communities in the field of infrastructure resilience comprise infrastructure scholars as well as service and network providers, asset managers and respective regulators, agencies and companies active in the field. This understanding frames knowledge as a cultural phenomenon rather than a set of abstract propositions (Knorr-Cetina, 1981).

Secondly, the notion of epistemic cultures brings into view 'a nexus of life worlds and the machineries of knowing that develop within a specialty' (Knorr-Cetina and Reichmann, 2015, p. 874). Epistemic cultures guide and constrain both knowledge and practice by establishing available ways of thinking, knowing and acting. This allows us to question the idea of resilience as a boundary concept, as it may be dealt with in fundamentally different ways within the fields of urban and infrastructure resilience. Because knowledge and practice are mutually constitutive (Orlikowski, 2002) as well as socially, culturally and historically situated (Handley et al., 2006), different 'machineries' of knowledge production (Knorr-Cetina, 2003) in their respective fields might actually hamper the required co-production of knowledge between urban and infrastructure scholars and practitioners. Resilience can only serve as a boundary concept if it helps to meaningfully link different machineries of knowledge production.

Thirdly, focusing on the epistemic subjects themselves, namely communities of practice (Lave and Wenger, 1991), allows us to compare different knowledge communities and their different means of knowledge production. Fundamentally, the notion of communities of practice tells us that 'different knowledge communities will have, not just different methods, but different epistemic machineries and understandings' (van House, 2002, p. 235). Wenger (2008) describes three ways in which practice contributes to building knowledge communities, namely through mutual engagement, joint enterprise and shared repertoire. In our analysis, we focus on these three constitutive elements of knowledge communities to get to the bottom of knowledge production and epistemic divergence.

Fig. 1, illustrates our analytical framework. First, we focus on the joint enterprise of respective communities of practice; that is, an identity defined by a shared domain of interest. We ask: *How is resilience understood, and how was this understanding established over time? How are cities and infrastructures conceptualised? How are research problems framed?* Second, we compare the shared repertoire of the respective communities of practice, namely the development of resources like experiences, stories, tools and ways of addressing recurring problems. We ask: *What kinds of solutions are envisioned to solve identified problems, and what kinds of methods, techniques and instruments are used for knowledge production?* Third, we analyse the mutual engagement within respective communities of practice, viz. the engagement in joint discussions and the sharing of information. We ask: *Who represents the respective knowledge communities, and how do they organise social and professional interaction and knowledge exchange?* The concepts of epistemic communities and epistemic cultures help us to place knowledge production in the context of governance and policy making and to discuss critically the notion of resilience as a boundary concept.

3. Methodology

To assess the two bodies of literature on urban and infrastructure resilience, we draw on elements of qualitative comparative analysis, which are referred to by Leech and Onwuegbuzie (2008, p. 593), as presenting "a systematic analysis of similarities and differences across cases". More specifically, we analyse and compare existing literature on urban and infrastructure resilience based on the analytical categories

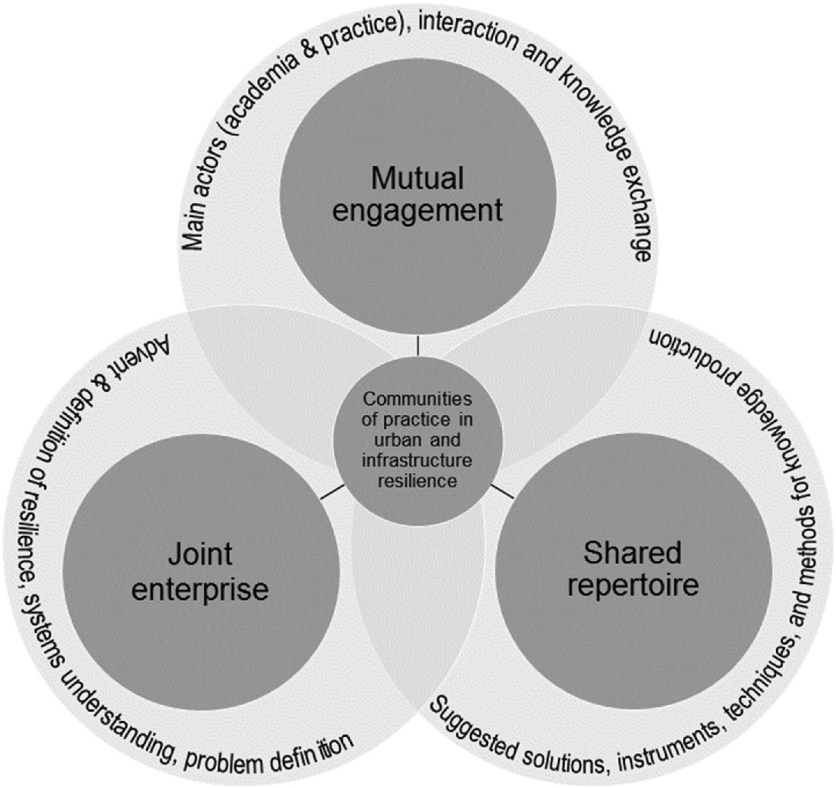

Fig. 1. An analytical framework to compare communities of practice in urban and infrastructure resilience (Own figure based on Wenger, 2006, 2008).

developed in section two. As opposed to quantitative bibliometric surveys, the aim of this qualitative analysis is to generate and refine hypotheses to be tested by future quantitative analyses or empirical case studies.

Throughout the research projects on resilience mentioned in the introduction, we first established a database of international journal publications, books, edited volumes, and research reports using library databases and Google Scholar. Google Scholar was used because it contains no restrictions with regard to the time of publication. The databases were searched for publications containing the key words [urban OR city OR cities AND resilience OR resilient] and [infrastructure OR infrastructures AND resilience OR resilient] and were sorted by relevance. Our inductive approach took the form of a structured snowball process—checking reference lists and indicated key words of the most relevant publications—so consequently we extended and updated our database. Out of approximately 400 references, we identified 122 discrete publications that referred directly to “urban resilience” and 86 references that referred directly to “infrastructure resilience”. These cover the period from 1973 to 2017, and more current publications have been added selectively to the analysis in cases where they provided additional evidence.

In order to generate our hypotheses, the literature has been analysed according to the analytical questions developed in section two. Existing literature reviews (e.g. Meerow et al., 2016; Bach et al., 2014), critical conceptual debates (e.g. Pizzo, 2015; GMU, 2007), and the review sections of empirical papers were especially helpful in answering some of the questions, because they often contain informed judgements about general developments in each respective field. In cases where our questions could not be completely answered by the academic literature, we include grey literature published by select multipliers in our analysis. To wit, we analysed the websites, key publications, and conference programmes and proceedings of international action networks that play a major role in practical application of both concepts. For urban resilience, arguably one of the main players is the Rockefeller Foundation which pioneers the 100 Resilient Cities Programme (100RC) (www.100resilientcities.org). Moreover, the city network ICLEI (www.iclei.org) has established itself as major organisation for knowledge production and dissemination in the field, for instance through their yearly Resilient Cities series (http://resilient-cities.iclei.org/). For an overview of players in the field of urban resilience see UN-Habitat (2017). With regard to infrastructure resilience, comparable international organisations have yet not been formed. The International Association of Critical Infrastructure Protection Professionals might come closest as an association aiming at “leadership in the domain of critical infrastructure security and resilience” (www.cip-association.org). Moreover, infrastructure providers are often active in organisations that provide best practice guidelines, link to international standards, and offer opportunities to exchange knowledge in the field of business continuity. Therefore, we selected the Business Continuity Institute (www.thebci.org) as another major source of information.

Working hypotheses based on the comparison were then presented and discussed in regular group discussions within an interdisciplinary group of researchers working on cities and critical infrastructures, including urban sociologists, engineers, political scientists, historians, and philosophers. This gave space to consider diverse ways of interpretation and to include current developments in the respective academic debates. Whilst we acknowledge the limitations that come along with qualitative literature reviews and the selection of exemplary sources of information (see Haddaway and Macura, 2018 for potential limitations and biases), we are confident that our review covers the main arguments and most prevalent epistemologies in the respective fields. With our results, we want to contribute to the emerging dialogue on knowledge production for urban resilience and to lay groundwork for further representative bibliometric analysis, in-depth case studies

and representative surveys of the respective communities of practice.

4. Knowledge communities with regard to urban and infrastructure resilience

While resilience was originally used by engineers and physical scientists, ecological scientists have taken up the concept along with systems thinking since the 1960s (Lindseth, 2011; Elsner et al., 2018), prominently advocated by Holling's seminal article (Holling, 1973). Within the plethora of debates that gather under the umbrella of urban and infrastructure resilience, there is significant overlap in both fields of research and practice. Subsequently, the boundaries between urban resilience, infrastructure resilience, climate change adaptation, disaster risk reduction and sustainable development are blurred. However, as we will show in the following sections, both concepts contain specific knowledge elements from their respective communities that rarely address the intricate interlinkage of resilient cities and infrastructures.

4.1. Joint enterprise in knowledge communities of urban and infrastructure resilience

4.1.1. Advent of the concepts

It is only since the 1990s that academic debates on urban resilience and their inherent social, institutional and material frameworks have attracted significant attention—mostly as a response to global environmental change (Lu and Stead, 2013, p. 200). In the US, the UK and Japan, manmade and naturally induced disasters—such as 9/11, Hurricane Katrina, and the Japanese earthquakes and tsunami in 2011—quickly pushed the resilience concept to the top of urban planning agendas, along with a concern that urban systems are ill-equipped for similar future events (Coaffee and Clarke, 2015, p. 250). In mainland Europe, the integration of resilience as a concept in urban planning and policy discourses emerged more slowly and mainly focused on climate adaptation, with a focus on flood risks (Coaffee and Clarke, 2015). The number of fields in which the concept of urban resilience is used has rapidly increased, covering the domains of urban ecology, urban sociology, climate change adaptation and disaster research, as well as development studies (Meerow et al., 2016). The latter developed as a mainstream of urban resilience research focusing on cities in the global South and linking debates on resilience with those on good governance (e.g. Allen et al., 2017). The movement has recently been taken up by international networks such as ICLEI and the Rockefeller Foundation, who are forming networks of knowledge exchange and action programmes.

In the US, critical infrastructure protection evolved as a matter of national security during the Cold War in response to the recognition of societal dependence on critical infrastructures (Collier and Lakoff, 2015). Increasingly, resilience has gained prominence as a concept that stresses the notion of preparedness for infrastructure failures and that acknowledges the character of infrastructures as complex, adaptive systems (GMU, 2007). Coaffee and Clarke (2016, p. 1) argue that the increased acknowledgement of system interdependencies and the risk of cascading failures (Rinaldi et al., 2001) has, over time, resulted in a "resilience turn": a "paradigm shift from protective-based risk management towards adaptive-based resilience" (see also Coaffee, 2013). Coaffee and Clarke (2016) depict a stepwise shift from the protection of technical assets prioritizing robustness and effective response in the aftermath of a crisis to an increased awareness of the socio-technical character of infrastructures, the social impacts of their failure and the role of governance for preparedness and adaptability (see also Bach et al., 2014; Dunn-Cavelty and Suter, 2009). Consequently, the concept was taken up by organisations such as the Business Continuity Institute and the International Association of Critical Infrastructure Protection Professionals in their mission statements and working programmes. Whilst a there is a branch of literature on urban resilience of vulnerable urban communities in the global South (e.g. Allen et al., 2017), literature on infrastructure resilience mostly addresses infrastructures in Europe and North America.

4.1.2. Definition of resilience

Olazabal et al. (2012, p. 11), state that urban resilience has been often used as an analytical tool for assessing physical structures, functions, and services in the context of climate change. Moreover, Pizzo (2015, p. 134) argues that urban resilience has often been presented as a politically neutral. Lately, however, the concept has increasingly been exploited in a normative sense by stating that 'enhancing adaptive capacity should be the overall goal of resilience' (Klein et al., 2003, p. 43). Existing reviews of academic literature on urban resilience point to the concept's interpretive flexibility and its increasingly expansive use (Chelleri, 2012; Meerow et al., 2016; Elsner et al., 2018). The concept has been used to address various issues, e.g., social dynamics, metabolic flows, governance networks or the built environment (Chelleri, 2012, p. 300). Moreover, Chelleri (2012) identifies a shift from engineering resilience to socio-ecological resilience, acknowledging the existence of multiple possible equilibria and highlighting the ability of a system to learn, adapt and transform over time (see also Davoudi, 2012). Authors that make use of this understanding often assume that conventional engineering understandings of resilience—emphasising the characteristics of safety, stability and robustness—involve trade-offs with flexibility and hence weaken the resilience of urban environments and communities (e.g. Welsh, 2014, p. 20).

Conventionally, engineering debates in the field of infrastructure resilience have understood resilience as 'the ability of a system to return to an equilibrium or steady-state after a disturbance' (Davoudi, 2012, p. 300; Holling, 1973), reflecting a 'bounce-back' mentality (Gay and Sinha, 2013; Rogers et al., 2012). Akin to the concept of urban resilience, infrastructure resilience has broadened its meaning. Over time, its initial focus on ideas of robustness, stability, protection and prevention of failures as well as on quick recovery from crisis has shifted to notions of pro-activity, adaptability and flexibility (Bach et al., 2014), echoing a shift of mentality from *fail-safe* to *safe-to-fail* (Ahern, 2011). This shift stems—at least partly—from work in the social studies of technology, implying a socio-technical understanding of infrastructures (Amir and Kant, 2018; Hommels, 2018) and acknowledging organisational (Hollnagel et al., 2006) and institutional components of infrastructure resilience (Labaka et al., 2016; Boin and McConnell, 2007). However, Yumagulova (2012, p. 22) argues that out of the three dimensions of infrastructure resilience—technological, organisational and institutional—the one that is most exploited in the field is still the technological one.

4.1.3. Systems understanding

Traditionally, urban resilience literature has often conceptualised cities as complex socioecological systems (e.g. Wagenaar and Wilkinson, 2015; Gleeson, 2008). However, the sociotechnical dimension of cityscapes has regularly been neglected. Even as an increasing number of researchers refer to critical infrastructures in their urban resilience frameworks (e.g. Chen et al., 2013; Marana et al., 2018), they barely acknowledge the material politics inherent in their creation, maintenance and transformation as well as the canalising effects of technologies on urban governance and decision making (Bijker, 2006; Winner, 1980). Only recently, sociotechnical system understandings enter urban resilience debates (e.g. Hommels, 2018) and scholars have combined socioecological and sociotechnical systems (Krumme, 2016). What remains is that urban resilience is often bound to municipal jurisdictions. Whilst some scholars particularly highlight the relationships

of cities with other cities (e.g. Harman et al., 2015), or embed cities in a multilevel governance perspective (e.g. Dewulf et al., 2015), Meerow (2016, p. 43) argues that many of them neglect such relational dimensions of urbanity.

In contrast, resilience as portrayed in the reviewed infrastructure debates was traditionally often considered to be mediated by complex technical systems (e.g. Rinaldi et al., 2001; Kröger, 2008). This understanding has been broadened by debates in social studies of technology, which introduce a sociotechnical perspective (Guy et al., 2012). Recently, researchers have even made use of the notion of social-ecological-technical systems to define interdependent infrastructures (Markolf et al., 2018). Whilst users are often still rendered as passive recipients of infrastructure provision rather than as active agents in a sociotechnical system (Bach et al., 2014, p. 7), the criticality of infrastructures is often defined with terms related to the severity in the case of their failure: 'if disrupted or destroyed, [they] would have a serious impact on the health, safety, security or economic well-being of citizens or the effective functioning of governments' (Bouchon, 2006, p. 38). With regard to spatial dimensions, the reviewed debates often overlook the particular spatialities of urban centres and their respective social fabrics (e.g. Labaka et al., 2016). However, as the infrastructural crisis in the aftermath of Hurricane Katrina showed, knowledge about place-based vulnerabilities of infrastructure systems as well as of the spatially uneven vulnerabilities of different social groups is of utmost importance in case of technical failure.

4.1.4. Problem definition

The majority of reviewed literature in the field of urban resilience refers to the exposure of cities to climate change, extreme weather events and rising sea levels. Worldwide urbanisation trends and the vulnerability of specific urban places to coastal or river flooding, droughts, and fire hazards is often used as a rationale for urban resilience initiatives (e.g. Johnson and Blackburn, 2014; Klein et al., 2003). Many studies point to the tremendous practical difficulties in implementing resilience ideas in urban planning practices and decision-making (e.g. Coaffee and Lee, 2016). This implementation gap is regularly presented as an urban governance problem, typically characterised by uncertainty and ambiguity (Coaffee and Lee, 2016) as well as a lack of collaboration or citizen and wider stakeholder participation (Goldstein, 2012). Initiatives of ICLEI and the Rockefeller Foundation clearly follow this argumentation and aim at closing this implementation gap.

Research in the field of infrastructure resilience regularly points to threats posed by natural hazards, terrorism, ageing infrastructures and technical failures (Bach et al., 2014; Graham and Thrift, 2007). The rationale for focusing on technical infrastructures is often based on the assumption that modern societies strongly rely on complex and increasingly interdependent infrastructure systems (see e.g. Almklov et al., 2012; Brassett and Vaughan-Williams, 2015). Interdependency, again, increases the risk of cascading effects and the vulnerability of these systems in case of failure (Rinaldi et al., 2001). Increasingly, scholarship on infrastructure resilience frames the challenge of resilience not as a technical issue, but as a governance challenge pointing to fragmented policies and actors in the field (Almklov et al., 2012) or to the exclusion of a wide range of relevant stakeholders in infrastructure decision making (Labaka et al., 2014).

4.2. Shared repertoire in knowledge communities of urban and infrastructure resilience

4.2.1. Suggested solutions

The way urban resilience is approached clearly differs across cities and nation states and is shaped by different institutional contexts and planning cultures (Spaans and Waterhout, 2017; Johnson and Blackburn, 2014). However, a significant part of these approaches go together with governmental encouragement of active citizenship, stakeholder engagement, decentralised responsibility and self-organisation (see e.g. Chandler, 2014a). Many are based on multi-stakeholder collaboration and lead in strategy development or master planning (e.g. 100RC). Literature in the field proposes different governance modes as suggested solutions, such as 'networked governance' (Jordan and Schout, 2006), 'governance of complexity' (Chandler, 2014b) and 'adaptive urban governance' (Birkmann et al., 2010) and often focuses on climate change adaptation as response to climate change impacts (e.g. Birkmann et al., 2010; Harman et al., 2015).

Whilst urban resilience debates often centre on climate change adaptation, the reviewed literature on infrastructure resilience regularly promulgates an all-hazards approach that no longer allows assumptions to be based exclusively on knowledge gained from experience (see e.g. GMU, 2007). This viewpoint induces a strong focus on the mitigation of risk and on risk preparedness in engineering systems (e.g. Hollnagel et al., 2006). In addition to this, other solutions have been proposed such as the re-arrangement of institutional settings (de Bruijne and van Eeten, 2007), close linkages to crisis management (Boin and McConnell, 2007), collaborative governance (Labaka et al., 2016), public-private partnerships (Chen et al., 2013) and networked governance (Dunn-Cavelty and Suter, 2009). Moreover, vulnerability mapping is frequently used in national infrastructure resilience strategies—e.g. in the US, the UK and Australia (Collier and Lakoff, 2015). Next to this, national governments often require infrastructure providers and utilities to establish business continuity management—a management approach that identifies potential threats and their impacts on business operations as well as plans and prepares for disturbances and crises (Herbane, 2010). In contrast to vulnerability mapping, business continuity management uses a process-oriented approach that is embedded in business plans and operational strategies. Whilst business continuity management supports the notion of self-reliance, its use in the context of resilience also supports Joseph's (2013) claim that it delegates responsibility from the state to individual infrastructure providers.

4.2.2. Instruments and techniques for knowledge production

In the reviewed debates on UR, knowledge production for climate change adaptation regularly makes use of modelling and simulations of droughts, floods or heat islands to inform planning and development decisions (e.g. Gersonius et al., 2016; Chapman et al., 2013). Moreover, we found numerous examples that made use of site visits, interviews and workshops—often building on local community engagement (e.g. Birkmann et al., 2010; Lu and Stead, 2013). The programmes and projects in the field frequently develop new tools to analyse, measure or increase resilience, as for example the City Resilience Index of 100RC (Arup and RF, 2015). However, an examination of ICLEI's resilient cities conference programmes and reports since 2010 (available at http://resilient-cities.iclei.org/) shows that the need for partnerships with the private sector is only gradually receiving more attention. Moreover, the technological vulnerability of cities is often neglected.

Because the proposed solutions for infrastructure vulnerability often centre on protecting physical systems from external threats, different instruments and techniques of risk assessment are used in the reviewed literature and in practice. They range from risk analyses, threat assessments, vulnerability assessments, and impact assessments (de Bruijne and van Eeten, 2007, p. 22) to interdependency assessments (Rinaldi et al., 2001), probabilistic modelling of cascading failures (Kröger and Zio, 2011) and other modelling and simulation techniques (Huang et al., 2014; Kröger and Zio, 2011). This indicates engineers' and infrastructure managers' ambition to make the future more

predictable and to reduce complexity of resilience management. However, as described above, the resilience shift also comes along with a greater acknowledgement of uncertainty and gradually includes strategies of *safe-to-fail* (Bach et al., 2014).

4.3. Mutual engagement in knowledge communities of urban and infrastructure resilience

4.3.1. Main actors

Our literature review reveals that urban resilience debates are largely shaped by international organisations (e.g. United Nations), consultancies (e.g. Arup), foundations (e.g. Rockefeller Foundation), city networks (e.g. ICLEI) and the philanthropic sector (see also UN-Habitat, 2017). ICLEI's resilient cities conference series shows that urban stakeholders at the city level predominantly stem from the fields of planning, landscape architecture and environmental policy, and focus on climate mitigation and adaptation, drought and flood risks, storm water, urban heat islands and green infrastructures. Infrastructure providers, network owners and asset managers, however, rarely take part in these urban resilience initiatives.

The reviewed debates in infrastructure resilience are mainly framed by engineers, regulatory governmental agencies, standardisation institutes and consultancies from the fields of engineering (e.g. Siemens Management Consulting). Moreover, infrastructure resilience plays an important role in local and national crisis management (see e.g. Boin and McConnell, 2007). Although a range of public-private partnerships emerged in the field of infrastructure resilience (Dunn-Cavelty and Suter, 2009), close contact and information sharing with infrastructure providers and network owners across sectors seems to be the exception rather than the rule (de Bruijne and van Eeten, 2007). Non-governmental, philanthropic and environmental organisations as well as representatives from city administrations, urban planners and landscape architects are largely absent from respective conferences (see section below).

4.3.2. Interaction and knowledge exchange

Over the last decade, urban resilience has become a buzzword in urban planning and policymaking (Davoudi, 2012, p. 329). The concept has been taken up by urban sustainability networks such as ICLEI, providing links between researchers, activists and local governments. Knowledge production and information sharing on urban resilience takes place internationally at academic, semi-academic and practitioner-oriented conferences and workshops (e.g. ICLEI's annual Resilient Cities series), through the publication of reports (e.g. World Bank Group), or through international programmes such as 100RC. These initiatives regularly promulgate the sharing of best practices and are often linked to academic work in fields such as urban studies (e.g. Spaans and Waterhout, 2017), and sustainability sciences (e.g. Birkmann et al., 2010), while engineering studies have a rather marginal role.

Communities in the realm of infrastructure resilience meet, for example, at annual conferences such as Critical Infrastructure Protection and Resilience Europe (www.cipre-expo.com) or its counterpart Critical Infrastructure Protection and Resilience Americas (www.ciprna-expo.com). These conferences are strongly shaped by debates on civil protection and homeland security, and the main groups of participants stem from government agencies as well as private companies in the security sector and some security-related researchers. Informal networking and partnering approaches are not as popular in the field of infrastructure resilience compared to that of urban resilience. An exception can be found in Lloyd's Register Foundation's "The Resilience Shift" (www.resilienceshift.org). However, up to today, formal policymaking at the national level (strategic) and corporate decision making of infrastructure providers (operational) seem to play a more prominent role.

5. Discussion

Our analysis discloses that knowledge elements of both communities of practice intermingle, and mutually shape each other. For instance, the field of infrastructure resilience increasingly makes use of collaborative governance approaches. However, it became apparent that there are a range of prevalent understandings and beliefs that dominate debates in the respective fields. These dominant viewpoints are condensed in the following Table 1. The table shows first that the concepts of urban and infrastructure resilience are rooted in different histories, use the term resilience in different ways and have discrete systems understandings. This leads to diverging problem definitions, which can create knowledge boundaries between the respective communities. Second, urban and infrastructure resilience debates centre on distinct ideas to solve problems and make use of distinct sets of instruments and techniques to produce knowledge. Consequently, dissimilar understandings and visions of the future emerge, which further amplify epistemic divides. Third, concepts of urban and infrastructure resilience develop within largely separated knowledge communities composed of particular experts who interact and share their knowledge within specific venues and with limited overlap. This fosters intrinsic views confined to specific objects of resilience and constrains cross-boundary learning by inducing certain path-dependent learning practices. As Wenger argues, 'shared practice by its very nature creates boundaries' Wenger (2000, p. 232). When separated, different knowledge communities are likely to devalue each other, particularly if there is no direct contact between them (Albert et al., 2008).

The above table may depict differences between urban and infrastructure research and practice in a highly condensed and schematic manner without acknowledging the full scope of existing interfaces and in-between conditions. Moreover, the qualitative review based on selective sources is by far not representative. However, our study indicates that divides in major elements of knowledge production do not solely entail particular implications for distinct conceptual perspectives but also for distinct governance approaches of cities and infrastructures. Following Haas (1992), policy-relevant knowledge produced in expert communities has a considerable influence on policymaking. Accordingly, it can be assumed that a range of infrastructure resilience strategies, business continuity plans, and national regulations are rooted in the idea of protecting physical assets and downplay their entanglement with social and natural systems or other key characteristics of resilience described in urban resilience debates, such as adaptability and transformative capacity. Although local crisis management may be inherently responsible for some infrastructural aspects, it is often restricted to reactive measures and lacks authority in preventive approaches (cf. Monstadt and Schmidt, 2019). What remains, then, are infrastructure resilience strategies at national levels and business continuity plans of individual infrastructure providers. This seems problematic, as they reinforce the dichotomy between nation-states being held responsible for providing protection strategies and cities being directly affected by potential infrastructure failure due to their geographic location as physical nodes in infrastructural flows. At the same time, as Hommels (2018) describes, governance attempts to approach urban resilience might recognise the importance of technical infrastructures for the functioning of the city but still substantially lack the authority and technical knowledge to address the interdependencies of different infrastructure domains and the risks of cascading failures beyond municipal territories.

A range of researchers have picked up on these kind of discrepancies and argue that urban resilience requires a 'multidisciplinary theory that

Table 1
Comparing prevalent knowledge communities in urban and infrastructure resilience (Own figure).

Variable	Operationalisation	Urban resilience	Critical infrastructure resilience
Common enterprise	*Advent of the concepts*	- US/UK: originally disaster focused - Europe: focus on climate change adaptation and flood risks - Amplification of use due to natural disasters (Katrina, Sandy)	- Homeland security focused - From protection to resilience of critical infrastructures - Widened understanding of critical infrastructures by highlighting their sociotechnical character
	Definition of resilience	- Socio-ecological/evolutionary understanding of resilience - Focus on adaptability and transformation	- Engineering/sociotechnical understanding of resilience - Focus on stability, protection, prevention, and recovery
	Systems understanding	- Cities as complex socio-ecological systems - Starting use of a social-ecological-technical system understanding - Focus on spatial scope of municipal jurisdictions	- Critical infrastructures as complex sociotechnical systems - Starting use of a social-ecological-technical system understanding - Focus on spatial scope of (interconnected) technical networks
	Problem definition	- Global environmental change, anthropogenic and natural hazards - Urbanisation - Focus on socio-ecological issues in the cityscape - Social inequality and/or lack of democracy/ participation - Urban governance issues	- Natural hazards, terrorism, ageing infrastructure, vulnerability of complex, interdependent systems - Increasing reliance on complex, interdependent systems - Focus on material and technical issues and on interdependences - National regulation; emphasis on public-private partnerships
Shared repertoire	*Suggested solutions*	- Climate change adaptation - Participatory planning, community engagement, informal cooperation - Strategy development - Master planning	- All-hazard approach - Focus on risks - Mitigation, preparedness - Regulation - Business continuity management - Public-private partnerships
	Instruments, techniques and methods for knowledge production	- Drought/flood/heat island simulations - Resilience analysis tools (quantitative and qualitative) - Empirical research making use of case studies, site visits and workshops	- Risk assessments (risk analysis, threat assessment, vulnerability assessment, impact assessment, interdependence assessment) - Empirical research making use of modelling and simulation techniques
Mutual engagement	*Main actors (practice)*	- Local governments (urban planning, landscape architecture, environmental policy) - International organisations - Philanthropic sector - Consultancies	- National governments (civil defence, infrastructure policies) - Infrastructure providers/network owners - Consultancies, security service providers
	Main actors (academia)	- Urban studies - Planning and geography - Environmental studies	- Engineering sciences - Science and technology studies - Increasingly planning and geography
	Interaction and knowledge exchange	- Ample informal interaction - City networks - Reports/rankings - Academic/semi-academic conferences - Sharing of best practices	- Little informal interaction - Special purpose conferences (e.g. security) - Special purpose projects (e.g. interdependence modelling)

integrates and coordinates a variety of city dimensions such as critical infrastructures, society, economy and environment into a unified conceptual framework' (Marana et al., 2018, p. 40). The recent use of notions like social-ecological-technological systems for defining cities and infrastructures (e.g. Markolf et al., 2018; Krumme, 2016) might point to first interfaces between both fields of research. Moreover, there is a range of academic work at the intersection of urban and infrastructure resilience. For example, Jon Coaffee and colleagues (Coaffee and Clarke, 2016; Coaffee and Lee, 2016) understand resilience as applying to cities and infrastructures at the same time; Hommels (2018), Graham (2010) and Medd and Marvin (2005) approach infrastructure resilience particularly at the urban level; and Monstadt and Schmidt (2019) approach particular urban governance challenges of infrastructure resilience. In addition, initial attempts to combine urban and infrastructure resilience initiatives in practice have been made. For instance, the Rockefeller Foundation's '100 Resilient Cities' programme integrates infrastructures in their urban resilience framework (Arup and RF, 2015), and partners with Ernst & Young to examine why urban governments neglect resilience thinking in their infrastructure strategies (100RC and EY, 2017).

Nevertheless, it seems that such approaches are still rare and often lack sufficient conceptual foundations in academic debates. Whilst both communities refer to the concept of resilience, there are considerable epistemic differences that manifest in social practices and the governance of cities and infrastructures and ultimately undermine the effectiveness of the respective resilience strategies. Following the notion of epistemic cultures, it can be argued that resilience has not yet kept its promise to serve as a boundary concept in the sense of linking different machineries of knowledge production and allowing "groups to coalesce and form stable, if transitory, working relationships" (Kimble et al., 2010, p. 440). Here, the ambition cannot be to realign the boundaries between, or even to merge, different epistemic communities with genuinely different and partially incommensurable perspectives. Rather, our analysis points to the need for more interaction and mutual learning of both epistemic communities' enterprise and repertoire to enable coordinated action despite remaining differences.

6. Conclusion

This paper shows that the notions of epistemic cultures, epistemic

communities and communities of practice can provide means to critically reflect on the character of resilience as a boundary concept. They can broaden our understanding of the relationship between knowledge and practice, and they can help us to analyse specific sub-discourses and how they each shape practical divides in social practices and in the governance of cities and infrastructures. Kastenhofer (2007, p. 363) argues that cultural change can result in strengthened cooperation patterns between different knowledge communities. Along the lines of our three comparative dimensions, we now provide some food for thought concerning how this could be approached.

First, urban and infrastructure resilience debates may benefit from a broader understanding of the term 'resilience' that equally applies to socio-technical as well as to socio-ecological dimensions. This understanding should also focus on potential trade-offs that might exist between certain resilience capacities such as flexibility and robustness and find ways where such capacities can complement or replace each other. In this sense, infrastructure resilience debates might benefit from the insights of place-based social vulnerabilities and locally specific discretions, as much as urban resilience debates might benefit from acknowledging the role of networked infrastructures for urban flows and societal resilience. This does not require any stakeholder to abandon a previously held position or understanding of resilience but rather to widen perspectives by actively seeking positive trade-offs and synergies. 100RC displays a proactive step in this direction by combining social and infrastructural resilience principles in their framework (Arup and RF, 2015). However, as Hommels (2018) shows, linking social and technical resilience faces enormous challenges in today's institutionally fragmented governance frameworks.

Second, the repertoire of urban resilience research and practice could benefit greatly from modelling, simulation and calculation of destructive scenarios of infrastructure failures and from a stronger collaboration with the private sector. Place-based infrastructure resilience strategies and business continuity management plans may well inform community resilience programmes regarding where and when certain measures are needed in a crisis situation. Vice versa, the infrastructure resilience repertoire could benefit from collaborative governance approaches and stakeholder participation mechanisms, from including the users' view in infrastructure resilience action and from improving cross-sector cooperation and the co-production of knowledge. Meaningful links between multi-stakeholder collaboration and business continuity management approaches could further contribute to better coordinate urban and infrastructure resilience strategies. This does not mean that knowledge elements of both communities should merge into a single repertoire. On the contrary, conflicting interests and world views of actors may be very important as a source of inspiration and innovation. However, it requires institutional frameworks that stimulate and enable multilateral learning and interaction.

Third, in order to engage in cross-boundary learning and knowledge sharing, members of both knowledge communities may benefit from cross-boundary resilience research and practice in the sense of mutual engagement across rather than within communities of practice. For instance, in Europe, some action-research projects, funded by the EU[1], include actors from both knowledge communities and provide opportunities for experiential learning, experimentation and the co-production of new knowledge. They might provide means to allow both epistemologies to bring in their strengths and develop new ways of defining problems and understanding reality. However, their success needs to be measured not only at an incremental project-based level. Equally important are changes in design guidelines, regulations, policies and laws to shape broader urban development and infrastructure management practices beyond individual projects.

The establishment of a common playing field of epistemic communities in urban and infrastructure resilience depends significantly, however, on further empirical research to test and elaborate the initial findings presented in this paper. Future research in the form of comprehensive bibliometric literature reviews, representative and quantitative surveys of communities of practices in both fields or in-depth case studies should be used to validate these results.

[1] These include projects like SMR RESIN (http://smr-project.eu/home/), and RAMSES (http://www.ramses-cities.eu/home/).

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