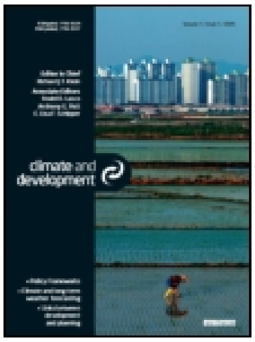

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REVIEW ARTICLE

A framework for urban climate resilience

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Climate change will have unavoidable impacts on urban systems and populations, especially in Asia where many large cities are exposed. Climate adaptation will be essential, and planning for adaptation can be simplified through operationalizing concepts of climate resilience and vulnerability. This article reviews concepts and theories in a range of diverse fields to illustrate how the general notion of urban climate resilience can be developed into an operational framework for planning practitioners. The framework integrates theoretical and empirical knowledge of the factors contributing to resilience with processes for translating those concepts into practice. The framework includes characteristics of urban systems, the agents (people and organizations) that depend on and manage those systems, institutions that link systems and agents, and patterns of exposure to climate change. It operationalizes these concepts through structured and iterative shared learning approaches that allow local planners to define these factors in their own context, in order to develop practical strategies for local action. The viability of the framework is demonstrated through examples from resilience planning activities undertaken in 10 cities across Asia through the Asian Cities Climate Change Resilience Network funded by the Rockefeller Foundation.

Keywords: resilience; adaptation; urban systems; adaptive capacity; institutions; planning; vulnerability

1. Introduction – the need for an urban climate resilience framework

There is mounting international concern about how to address the implications of climate change for urban areas, particularly in developing countries, where cities are growing rapidly and a high proportion of urban populations are poor or otherwise vulnerable to climate-related disruptions (Balk et al., 2009; Satterthwaite, Huq, Pelling, Reid, & Lankao, 2007; United Nations Human Settlements Programme, 2011; Wilbanks et al., 2007). The literature points to the need for measures, including investment in infrastructure and capacity, to adapt to projected climate impacts. In addition, a growing number of guidebooks and manuals are now available to support local governments in assessing climate change impacts and developing responses (see, for example, USAID, 2009; for the USA: Snover et al., 2007, NOAA & EPA, 2009; for Australia, ICLEI Oceania, 2008; Ecoplan International Inc. & Compass Resource Mgmt Ltd, 2011). There is, however, limited practical experience with local planning for urban adaptation, and that mostly is in Europe and North America (Birkmann, Garschagen, Kraas, & Quang, 2010; Ecologic Institute, 2011; Lowe, Foster, & Winkelmann, 2009).

Half of the world's urban population is in Asia (United Nations Human Settlements Programme, 2011). In response to the need for urban adaptation in Asia's rapidly growing cities, and in recognition of the limited practical experience in planning and implementing adaptation measures, the Rockefeller Foundation committed in 2008 to fund climate change adaptation planning and implementation measures in 10 medium-size cities in India, Indonesia, Thailand and Vietnam over a 5-year period (subsequently extended to 7 years) through a programme they named the Asian Cities Climate Change Resilience Network (ACCCRN).

The Rockefeller Foundation selected Surat, Indore, Gorakhpur, Semarang, Bandar Lampung, Hat Yai, Chiang Rai, Can Tho, Da Nang and Quy Nhon as the cities to participate in the programme, and partnered with a wide range of local and national organizations in each country to build capacity, and undertake local planning and implementation of adaptation measures. During the initial engagement and local planning phase of the project, the Institute for Social and Environmental Transition (ISET) provided technical support to develop a methodology for planning for climate resilience in all 10 cities, working in collaboration with local and regional partners. That experience is described by the authors and others elsewhere (Moench, Tyler, & Lage, 2011; see also http://www.acccrn.org). This paper explains the origins of the framework developed for ACCCRN by reviewing the relevant literature from a number of related fields to build a practical conceptual framework for urban climate resilience. While the components of this resilience framework have already been described by others, they have not been previously

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assembled in a package that can be used to guide practitioners who will need to make adaptation decisions[1].

Why resilience? Adaptation studies on Asian cities have emphasised the application of climate projections to determine future risks and the identification of specific measures for responding to these (Asian Development Bank, 2010; World Bank, 2010). The standard approach to planning for climate adaptation, as in these studies, is to frame the task as adjusting policies, practices and plans in order to avoid negative impacts of climate change. In essence, this approach relies on prediction as the basis to identify avenues for prevention.

The logic of this approach is clear in principle. But a number of challenges arise in practice. In the face of climate conditions that will become increasingly variable, dynamic and uncertain, local planners may have difficulty using either historical climate data or future projections to identify likely impacts of climate change (Milly et al., 2008; Opitz-Stapleton, 2011). These 'predict and prevent' approaches have also been criticized for their limited ability to deal with surprise (Wardekker, de Jong, Knopp, & van der Sluijs, 2010). In addition, by focusing on adaptation interventions that respond to specific climate impacts, this approach may neglect indirect effects, systemic weaknesses or institutional constraints (Ericksen, Ingram, & Liverman, 2009; Nelson, Adger, & Brown, 2007; Schipper, 2007; Verner, 2010; da Silva, Kernaghan, & Luque, 2012). Finally, this adaptation planning approach tends to under-emphasize the role of learning and governance as essential elements of ongoing adaptive management (Armitage, Berkes, & Doubleday, 2007).

Instead of focusing on discrete measures to adapt to specific perceived future climate risks, it may be more effective for cities to consider the problem as one of *building resilience*. The IPCC defines resilience as 'the ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity of self-organization, and the capacity to adapt to stress and change.' (IPCC, 2007). This definition is broadly consistent with definitions from ecological sciences (Carpenter Walker, Anderies, & Abel, 2001; Resilience Alliance, 2007) and from disaster risk reduction (UNISDR, 2012). The metaphorical extension of the term 'resilience', from its origins in metallurgy and engineering, extends to applications in psychology and community development as well as disaster risk reduction (Norris, Stevens, Pfefferbaum, Wyche, & Pfefferbaum, 2008; Twigg, 2007). Concepts of resilience applied in these other fields have also been shown to be relevant to climate adaptation for large urban regions (Wardekker et al., 2010).

Several authors have described the varied and contradictory definitions of resilience, and the absence of a framework for operationalizing the concept (Klein, Nicholls, & Thomalia, 2003; Leichenko, 2011; Miller et al., 2010). The origins of the term 'resilience' imply strength and resistance, but in its more recent applications in ecology, socio-ecological systems, disaster management and urban sustainability, resilience is understood to require flexibility, learning and change (Adger, Hughes, Folke, Carpenter, & Rockström, 2005; Antrobus, 2011; Berkes, Colding, & Folke, 2003; Fields, 2009; Prasad et al., 2008; Miller et al., 2010; Twigg, 2007). Klein et al. (2003) argue that recent definitions of resilience that include notions of learning and adaptive capacity represent normative social objectives that could be applied to cities.

In the case of urban climate adaptation, an approach based on resilience encourages practitioners to consider innovation and change to aid recovery from stresses and shocks that may or may not be predictable. Resilience-building as a strategic approach has many advantages over conventional system management for complex social–ecological systems that are dynamic and facing high uncertainty (Walker et al., 2002).

In this way, the application of the concept of resilience to urban climate adaptation practice would help to address some of the weaknesses of a 'predict and prevent' approach and prepare for climate change even under high uncertainty. There are numerous guidebooks and cases that use this terminology already in relation to climate change and disaster risk reduction (Prasad et al., 2008; Twigg, 2007; UNISDR, 2012; World Bank, 2011). However, with very few exceptions, the term 'resilience' is used in a general or descriptive sense, and operational guidelines cannot be usefully derived from its definition. In other words, while the literature provides examples of actions that are construed to build resilience, there is not a clear connection between the definition, or inherent qualities, of resilience and the required actions.

In order for city-level planners and professionals to deliberately build urban climate resilience, they need a framework that provides guidance for what climate resilience means in practice and points to how it can be strengthened. For this to be applicable by local practitioners in a wide range of circumstances, it should be simple and comprehensible.

2. Urban resilience elements – components of the framework

In this section, we identify three generalizable elements of urban resilience: systems, agents and institutions. By abstracting the key normative characteristics of each of these elements from a diverse body of literature, we develop a simple conceptual framework that can be operationalised for local planning.

2.1. *Systems*

Cities require high levels of infrastructure to deliver essential services. Cities are also linked across multiple scales to other systems, such as regional food production that relies on ecosystems to deliver provisioning services. At the global scale, cities are connected through international trade and investment patterns, which can have direct effects on local employment and livelihoods as well as on supplies ranging from pharmaceuticals to imported staple foods. For example, in the Bangkok floods of October–November 2011, the flooding of local manufacturing facilities affected global supply chains for computer and automobile components and led to temporary factory closures and layoffs in many cities outside Thailand (Chachavalpongpun, 2011).

The underlying support systems that enable networks of provisioning and exchange for urban populations are therefore an essential element of urban resilience. They include physical infrastructure and ecosystems, either within the city, immediately adjacent or remote ecosystems that provide key services such as food production, runoff management or flood control. While local managers may have limited influence beyond city boundaries, their systems can be strongly affected by factors at multiple scales and at long distances. City electricity distribution depends on the performance of distant reservoirs, generators and grids. Crop losses on the other side of the world can affect local supplies and prices for widely traded food commodities.

Core or 'critical' systems are essential to urban function (Little, 2002). Their failure jeopardizes human well-being in all affected areas, and precludes higher order economic activity until their function is restored. These systems include water and food supply, and the ecosystems that support these, as well as energy, transport, shelter and communications. In assessing the potential for these systems to fail under climate-induced stress, it is crucial to recognize the interdependencies of complex linked systems because failures of one system often lead to cascading failures in linked systems (Kirshen, Ruth, & Anderson, 2008).

Resilient systems differ from an engineering approach to *robust* systems, which rely primarily on hard protective structures (e.g. sea walls) or are designed in ways that emphasize the strength of specific individual components to ensure functionality. *Resilient* systems, in contrast, ensure that functionality is retained and can be rapidly re-instated through system linkages despite some failures or operational disruptions (Bruneau et al., 2003; McBain, Wilkes, & Retter, 2010; O'Rourke, 2007). Rather than relying on the strength of individual components, resilient systems retain functionality through flexibility and diversifying functional dependence.

From the study of complex engineering and ecological systems, characteristics that are widely cited as contributing to the resilience of systems include the following (Alberti et al., 2003; Andersson, 2006; Bruneau et al., 2003; Ernstson et al., 2010; Folke et al., 2002; Gunderson & Holling, 2002; Leichenko, 2011; Liu et al., 2007; Meadows, 1999; Resilience Alliance, 2007):

- *Flexibility and diversity:* The ability to perform essential tasks under a wide range of conditions, and to convert assets or modify structures to introduce new ways of doing so. A resilient system has key assets and functions physically distributed so that they are not all affected by a given event at any one time (spatial diversity) and has multiple ways of meeting a given need (functional diversity).
- *Redundancy, modularity:* Spare capacity for contingency situations, to accommodate increasing or extreme surge pressures or demand; multiple pathways and a variety of options for service delivery; or interacting components composed of similar parts that can replace each other if one, or even many, fail. Redundancy is also supported by the presence of buffer stocks within systems that can compensate if flows are disrupted (e.g. local water or food supplies to buffer imports).
- *Safe failure:* Ability to absorb sudden shocks (including those that exceed design thresholds) or the cumulative effects of slow-onset stress in ways that avoid catastrophic failure. Safe failure also refers to the interdependence of various systems, which support each other; failures in one structure or linkage being unlikely to result in cascading impacts across other systems (Little, 2002).

These characteristics of resilient systems should be seen as guidelines for thinking about complex urban systems in new ways, rather than as technical prescriptions. Each context and system will be different, and it is impossible to provide specific prescriptions for all conditions, although there is a growing body of research looking at the resilience of specific systems and the wider consequences and costs of disruption or failure due to climate change (Bruneau et al., 2003; Brunner, Steelman, Coe-Juell, Edwards, & Tucker, 2005; FEMA, 2012; McBain et al., 2010). Table 1 presents examples of typical performance specifications and system configuration in relation to water supply, so that readers can better grasp how the general descriptions above can be interpreted in light of hypothetical local conditions. From these examples, it can be seen that system characteristics should not be considered as mutually exclusive categories. In any given system, a particular desired performance factor might be ascribed to more than one category (in some systems, modularity may be similar to diversity, e.g. multiple water pumping stations in various locations). Users of the framework could construct their own descriptions in sectors of interest based on their specific local conditions.

2.2. *Agents*

The recent literature on resilience in complex adaptive systems emphasises the integration of social agents and institutions along with biophysical elements as components

Table 1. Illustrating the concept of resilience: systems.

System characteristic	Performance description	What would this look like for water supply systems (as an example)	Other examples
Flexibility and diversity	The system can meet service needs under a wide range of climate conditions. Key elements are spatially distributed and can substitute for each other but are functionally linked	Multiple, geographically distributed water sources (ground and surface water) Pumping stations in multiple sites with overlapping service Demand side management to ensure water is used efficiently Expandable fleet of water tankers	Transportation: multiple modes and capacities for transporting key goods and people Food supply sourced from diverse geographic areas
Redundancy and modularity	Spare capacity to accommodate unexpected service demand or extreme climate events. System components and pathways provide multiple options or substitutable components for service delivery	Reservoir storage capacity exceeds demand under drought conditions Groundwater recharge exceeds withdrawal rate Storage sufficient to buffer annual variability or other supply disruptions Backup systems for water pumping Rainwater harvesting systems to supplement domestic water supply	Transportation: multiple access routes Communications: redundant transmission towers Energy: backup generators for crucial services Food and medicines: maintain high stock/flow balance in case of disruption
Safe failure	Failure in one part of the system will not lead to cascading failures of other elements or related systems. Key service delivery can be maintained even under failures	Protection and monitoring of source quality under conditions of climate stress Failure of one pumping station does not lead to distribution system failure Distribution network interlinked, so local failure will not cause major service interruptions	Dikes can be opened to flood retention zones outside the city, if threatened

of socio-ecological systems (Folke, 2006; Folke et al., 2002; Gunderson & Holling, 2002). It is also argued that the adaptive capacity of social organizations and individuals is a concept closely related to resilience (Berkes, 2007; Folke et al., 2002; Gallopin, 2006). Key aspects of resilience addressed in relation to hazard assessment and disaster risk reduction in cities have included flexibility and diversity (addressed under the Systems section) and capacity for learning and innovation (Leichenko, 2011). The capacities of social agents therefore comprise an important part of any urban climate resilience framework.

Social agency differs from system function in that outcomes arise not only from interaction between elements but also from purposive decisions. Agents, unlike systems, are capable of deliberation, independent analysis, voluntary interaction and strategic choice in the face of new information. Agents are actors in the sense that they introduce volition and intent into choice; they behave in ways that reflect their location and structure within society (i.e. as government entities, businesses, community advocates, households and individuals), their preferences, and the opportunities and constraints they perceive. Techniques for analysing agent behaviour and capacity are different from those required for systems.

Agents, or actors in urban systems, comprise the second key element in the resilience framework. They include individuals (e.g. farmers, consumers); households (as units for consumption, social reproduction, education, capital accumulation); and private and public sector organizations (government departments or bureaus, private firms, civil society organizations). They have identifiable but differentiated interests and are able to change behaviour based on strategy, experience and learning. In order to work effectively with agents it is important to recognize the opportunities and constraints they face and the incentives to which they respond. Agent behaviour can be changed, but depending on the circumstances this may not be any easier than modifying complex technical infrastructure systems.

Many agents (e.g. households) depend on urban systems and demand services but are not proactively involved in the creation, management or operation of those systems. Other agents are directly concerned with management of critical urban systems. In the case of water supply, for example, these might include the municipal water utility, key water quality or regulatory agencies, private water market suppliers and civil society organizations involved in water-related advocacy.

Resilience is not a characteristic that is evenly spread through the urban population. It depends crucially on the socially differentiated capacities of different groups and individuals. Poverty, gender, ethnicity and age have all been documented as contributing to differential vulnerability of social groups in cities to climate hazards, through features such as the quality of housing, location and access to services or social networks (Moser & Satterthwaite, 2010; Pelling, 2003; Satterthwaite, Dodman, & Bicknell, 2009).

For individuals and households in particular, key capacities can be considered as assets, that is, a stock of resources upon which individuals and social groups can call in order to advance their well-being. The main asset categories that comprise these resources include financial assets (wealth or access to credit), physical assets (house, possessions), natural assets (land or rights to streams of ecosystem services such as fish or water), social assets such as family or clan networks, and human assets (health and skills) (Moser, 2006). Even the very poor have assets such as knowledge or social contacts. These serve as the basis for an agent's power to act. For these categories of agents, the social differentiation of climate vulnerability is closely linked to differential asset profiles. Losses caused by climate hazards typically erode multiple types of assets and further impoverish such groups (Moser & Satterthwaite, 2010; Pelling, 2003).

But adaptive capacities of other social organizations are also important to resilience. The role of local governments and of community organizations is crucial here, as these are the primary sources of organization and delivery of key planning, prevention and response services (e.g. land use, building controls, emergency services) that are essential for ensuring urban resilience and climate adaptation (Satterthwaite et al., 2009). The capacity to access a range of assets or resources in order to take adaptation action includes the collective effort to use a wide range of knowledge to assess risks (Berkes, 2007).

Positive examples of asset-based adaptation demonstrate the opportunities for poor urban communities to organise and plan for preventive risk reduction strategies, either autonomously through community groups such as savings or credit groups, or in collaboration with local governments (Moser & Satterthwaite, 2010). This includes the ability to organise, plan and coordinate for disaster preparedness and emergency response as contributing to resilience (UNISDR, 2012).

The capacity of individuals and organizations to learn is a crucial aspect of resilience approaches across a range of disciplines (Berkes, 2007; Diduck, 2010; Folke, 2006; Gunderson & Holling, 2002). Learning includes not only the mobilization and sharing of knowledge but also such factors as basic literacy and access to education. These kinds of factors have been identified empirically as contributing to community resilience to disasters (Twigg, 2007).

We summarize and label these agent capacities consistent with the terminology used in resilience thinking and in disaster risk reduction as follows (Gunderson & Holling, 2002; Twigg, 2007):

- *Responsiveness*: Capacity to organize and re-organize in an opportune fashion; ability to identify problems, anticipate, plan and prepare for a disruptive event or organizational failure, and to respond quickly in its aftermath.
- *Resourcefulness*: Capacity to mobilize various assets and resources in order to take action. It also includes the ability to access financial and other assets, including those of other agents and systems through collaboration.
- *Capacity to learn*: Ability to internalize past experiences, avoid repeated failures and innovate to improve performance; as well as to learn new skills.

High-capacity agents have the ability to anticipate and act in order to adjust to external changes and stresses. Organizations have the authority and mandate to take action, as well as the financing to do so. Agents' ability to act is facilitated by adequate resources and by access to supporting systems, including the ability to access resources provided by other agents. Agents may develop these capacities through experience, gradually acquiring a repertoire of responses to stresses and shocks. The awareness of hazards, the ability to learn new responses and the ability to acquire information needed to assess hazards and outcomes are, therefore, all important elements in strengthening the capacity of agents.

The illustration in Table 2 presents examples of agent capacities that are consistent with the concepts derived from the literature summarized above, using the urban water sector as an example.

2.3. *Institutions*

The concept of institutions in social sciences refers to the social rules or conventions that structure human behaviour and exchange in social and economic interactions (Hodgson, 2006). Institutions may be formal or informal, overt or implicit, and are created to reduce uncertainty, to maintain continuity of social patterns and social order, and to stabilize forms of human interaction in more predictable ways (Campbell, 1998; North, 1990; Ostrom, 1990). Institutions condition the way that agents and systems interact to respond to climate stress, so this is the third element of the resilience framework.

Institutions of property and tenure, of social inclusion or marginalization and of collective action influence the vulnerability of particular social groups (Adger et al., 2005). Institutions that enable or constrain individuals to organize or to engage in decision making (i.e. who is seen as a legitimate 'stakeholder') determine whose interests are considered in political decision making. Similarly, the standards to which systems are designed and managed, as with building and engineering codes, have a strong influence on whether those systems will reliably meet the needs of users. Finally, the pricing structure for urban services is an institution that influences access to infrastructure systems and the resilience they offer, particularly for the urban poor (McGranahan, 2002).

Institutions may enable and support, or constrain and inhibit, the capacities of vulnerable urban groups (Moser & Satterthwaite, 2010). For example, the migration of farm labourers in times of drought depends on formal

Table 2. Illustration of the concept of resilience: agent capacities.

Agent capacities	Performance description	What would this look like? (for water supply)	Other examples
Responsiveness	Ability to organize, or reorganize in a timely manner; ability to identify, anticipate, plan and prepare for a threat, disruptive event or organizational failure; and to respond quickly in its aftermath	*Suppliers* build planning, technical and other capabilities for water management. They respond rapidly to customer service disruptions or larger disasters. They monitor system condition and devote required finances to maintenance (leak detection, supply sources) *User groups* proactively lobby government and market actors to improve service quality. They identify alternative sources of water supply if needed.	*Government, private and civil society actors* organize and respond rapidly to signals including: (1) disaster warnings; (2) projected climate impacts; and (3) changes in the needs of populations. Changes in conditions catalyse action – e.g. if floods increase, government actors change zoning regulations, markets shift exposed regions to low vulnerability uses (agriculture versus housing), civil society advocates for resettlement. New local organizations emerge in response to need
Resourcefulness	Capacity to mobilize assets and resources for action. This includes the ability to access financial and other assets, including those of other agents and systems, through collaboration	*Suppliers* have recognized authority as well as financial and technical resources and deploy these effectively. They proactively work with other actors both within and outside government to address issues that cross sectors or scales *Users* mobilize support to address issues such as water quality or reliable supply. They use their resources and networks to access water supplies even when distribution systems fail	Individuals and organizations have the ability to communicate and access social networks for information, finances and capacities. They mobilize the finances required to shift livelihoods or modify physical and social structures as climate conditions reduce the viability of existing ones
Capacity to learn	Ability to internalize past experiences, avoid repeated failures and innovate to improve performance. This includes the capacity to build and retain knowledge over time	Experience from extreme events is incorporated into planning and implementation activities. Water supply projections and scenarios are routinely included in planning. Plans are revisited regularly and refined based on emerging information. Required information is collected, analysed and shared. *User groups* regularly access water resource information and have the capacity to use it as a basis for advocacy	Urban plans are updated based on long-term climate impact scenarios with the involvement of a broad range of knowledge holders. Research is used to support planning decisions

and informal institutional structures that organize the labour market through communication, recruitment, transport and remittances. Those institutions facilitate migration as an adaptive response and enable households to diversify their sources of income (Moench & Dixit, 2004). Urban planning decisions such as slum clearance and resettlement may increase or decrease climate vulnerability depending on the institutions governing rights, compensation, participatory planning and decision making associated with the resettlement process (Satterthwaite et al., 2009). With inadequate consultation or participation, minimal rights and only token compensation, resettlement could increase impoverishment and vulnerability. However, under different institutional conditions, the outcomes could be opposite. Institutions for collective action and governance can also be designed to strengthen resilience by supporting ecosystem restoration and sustainability (Adger et al., 2005; Folke, Hahn, Olsson, & Norberg, 2005; Ostrom, 1990; Tompkins & Adger, 2004).

Social marginalization – the process whereby some social groups are excluded either formally or informally from access to critical services or resources – is closely linked to institutions (Beck & Fajber, 2006). The concept of entitlements has been introduced to explain the way that institutions shape how individuals are able to claim access to resources, food supplies or other services (Leach, Mearns, & Scoones, 1999; Sen, 1981). An example of an institution that fosters marginalization is the requirement for legal registration of residence in

Vietnam or China, which can make it difficult for migrants to gain access to services, social benefits or to government compensation for disaster impacts. Those individuals and groups who are systematically marginalized through institutions that delegitimize their claims to the services provided by urban systems (i.e. have fewer entitlements) are likely to be more vulnerable to similar climate impacts (Moser & Satterthwaite, 2010; Pelling, 2003).

Governance (i.e. the process of decision making) is an important factor affecting resilience. Decision-making processes that build resilience for vulnerable groups are likely to be participatory and inclusive, allowing those individuals and groups most affected by climate hazards to play an active role in determining how best to avoid them (Lebel et al., 2006; Satterthwaite et al., 2009). Many authors argue that adaptation and resilience require local governments to be accountable to marginalized populations, which is different from current practices that often actively discriminate against them (Moser & Satterthwaite, 2010). And because proactive attempts to build climate resilience require coordinated actions by many different local government departments, new mechanisms for collaboration between these departments, and with civil society organizations, are typically needed.

Public information is an important component of a positive institutional environment. Communities who have access to timely hazard information are better able to respond to climate threats, even in vulnerable sites, especially when this is matched with credible and supportive advice on appropriate response such as evacuation routes and transport support (Moser & Satterthwaite, 2010).

Institutional structures that foster learning and change are important tools to build agent capacity. Public and private support for applied research, for publication and presentation of new evidence, and for facilitating critical assessment of new knowledge and its implications all speed the introduction of effective innovation. In the absence of these types of institutions, professional norms and legislated codes or standards may act as barriers to innovative practices. Institutions capable of fostering evolutionary change, and of adapting to new information, lend themselves to building resilience (Berkes, 2007).

From studies of economic behaviour, collective action, social marginalization and decision making, the key aspects of institutions linking agents and systems that should be considered in assessing whether they enhance or constrain resilience appear to be those outlined below[2]:

- *Rights and entitlements linked to system access*: Rights and entitlements to use key resources or access urban systems should be clear. Institutions that differentially constrain rights and entitlements can limit access to systems or services and thus reduce resilience for marginalized groups.
- *Decision-making processes*: Decision-making processes, particularly in relation to urban development and urban systems management, should follow widely accepted principles of good governance: transparency, accountability and responsiveness (United Nations Development Programme, 1997). This includes recognition of those groups most affected and ensuring they have legitimate inputs to decision making (Huntjens et al., 2012). .
- *Information flows*: Households, enterprises, community organizations and other decision-making agents should have ready access to credible and meaningful information to enable judgments about risk and vulnerability, and to assess adaptation options.
- *Application of new knowledge*: Institutions that facilitate the generation, exchange and application of new knowledge enhance resilience.

An important right that can enhance resilience is that of groups to self-organize and to engage in collective choice mechanisms (Huntjens et al., 2012) in order to respond to climate hazards (e.g. to improve local drainage, or to deliver disaster preparedness training). The ability of self-organizing groups to assess fees or levies on members in order to undertake investments in service delivery, maintenance or resilience investments is central to their ability to act but sometimes may be constrained by legal limitations on the organization of civil society (Table 3).

2.4. *Resilience, exposure and vulnerability: using the framework to understand vulnerability*

The terminology of resilience, exposure and vulnerability is widely used across several related fields, but with little consistency or consensus on definitions (Berkes, 2007; Gallopin, 2006; Klein et al., 2003). Low resilience systems are intrinsically vulnerable to stress and shock, so in this sense increasing resilience reduces vulnerability (Folke, 2006). However, these two concepts have different origins and published studies: resilience has emerged from a positivist biophysical scientific perspective, while vulnerability has been described mainly from a constructivist social science and political ecology framework (Miller et al., 2010).

Most of the literature reviewed for this paper presents vulnerability as a lack of resilience. An exception is Gallopin (2006) who describes vulnerability as a different concept, broader than resilience, which he links more closely to the notion of 'adaptive capacity'. An important distinction is that most authors (excepting Gallopin again) include hazard exposure as a component of vulnerability. In other words, vulnerability is argued to have meaning only in relation to a particular hazard (Klein et al., 2003). Mountain dwellers are not vulnerable to sea level rise. Vulnerability to flooding involves assessing different factors

Table 3. Illustration of resilience: characteristics of institutions that foster resilience.

Institutional features	Performance description	What would this look like? (for water supply)	Other examples
Rights and entitlements	Structures of rights and entitlements do not systematically exclude specific groups from access to critical systems or capacities. They enable groups to form and act, and foster access to basic resources	Water supply systems make potable water widely available to all social groups in the city. Lifeline tariff structures ensure affordability *Community groups* may be able to organize water management structures and, in coordination with other actors, raise funds and implement management activities. Private individuals and organizations have well-defined rights with regard to water resources, access to information and standing to participate with other agents in water-related policy deliberations or other initiatives	Simple procedures that enable groups to form legal voluntary organizations, raise funds and undertake activities in relation to emerging needs
Decision making	Decision-making processes related to key urban systems are transparent, representative and accountable. Diverse stakeholders have a way to provide input to decisions. Dispute resolution processes are accessible and fair	Water allocation process follows clear rules and legal procedures. Water supply and distribution investments reflect the interests of all urban residents. Water provider is accountable to legitimate government agencies and can be sanctioned for unjustified actions. Formal or informal systems are in place to mediate water related disputes as they emerge, whether they involve public or private agencies	Mechanisms for providing public input to decisions (hearings, meetings, local consultations) Legitimate structures are in place for transparent resolution of disputes in relation to key systems and the agents that have an interest in their management
Information	Agents have access to relevant information in order to determine effective actions and to make strategic choices for adaptation	*Government agencies* are able to access and use current global scientific information in planning water supply. Basic standards regarding water delivery norms (quantity, quality, reliability, affordability) are set. Standards are also set with respect to the protection and maintenance of the ecosystems that deliver water services	Standards in many arenas (environmental protection, construction, etc.) are publicly available. Norms on freedom of information
Application of new knowledge	Institutions encourage inquiry, application of evidence, critical assessment and application of new knowledge	Water utility supports applied research into groundwater recharge, or salinization rates, and impacts on water supply Water supplier works with civil society and the private sector to develop innovative approaches to managing water resources under changing climate conditions	Recurrent processes that allow changes in codes and standard practices as climate conditions change

than those assessed for vulnerability to earthquake. By comparison, resilience is seen as an intrinsic or emergent feature of complex social–ecological systems (Folke, 2006). Resilience is only manifest through exposure to stress or shocks, and in the subsequent recovery or reorganization period, but its latent character exists within a system independent of that exposure.

We pointed out above that marginalization imposes both capacity and institutional barriers to adaptation, but it is important to recognize that depending on the local context, other social groups may be more vulnerable than the poor due to their exposure (e.g. coastal residences, mountain homes subject to wildfire) or due to their greater dependence on critical systems (e.g. electricity for borehole pumps).

The question of exposure is also more complex than it may at first appear. Some of the greatest stresses on urban areas from climate change are likely to be indirect, incremental or both. They will emerge as a consequence of distant changes that are translated to urban areas through interlinked systems as a result of global markets, supply chains and dependence on remote ecosystems or wider infrastructure networks. This suggests again that while such indirect linkages may be missed in vulnerability assessment, they can be managed through resilience building.

While many climate-driven shocks and stresses in urban areas can be projected on the basis of experience and climate science, others will be unanticipated. Vulnerability to such surprises may not be apparent in advance, so building resilience is a useful strategy to prepare. Increasing the inherent capacity of complex systems to manage a range of stresses and shocks, through experience or strategic preparation, better enables such systems to deal with surprise (Tompkins & Adger, 2004; Walker et al., 2002).

The conceptual framework introduced above defines the key constituent elements of urban resilience. Following this framework, vulnerability to climate change occurs when fragile, inflexible systems and/or marginalized or low-capacity agents are exposed to increased climate hazards, and their ability to respond or shift strategies is limited by constraining institutions. Resilience is high where *robust and flexible systems* can be *accessed by high-capacity agents* and where that access is *enabled by* *supportive institutions* (see Figure 1). Figure 1 illustrates that vulnerability occurs in the darker areas of the diagram, where capacities are low, systems fragile and institutional support weak. By building resilience, through intervening with agents, systems and institutions, vulnerability is reduced and well-being strengthened.

2.5. *Linkages between elements in the framework*

The key elements of the framework for urban resilience as outlined above are *infrastructure and ecosystems* (both captured under the rubric of 'systems'), *social agents* and *institutions*. For analytical purposes, we separate these elements, although we recognize that other analysts frequently refer to 'urban systems' that are integrated to include all these categories (da Silva et al., 2012). We find that analysing component dimensions separately is more practical. While we characterize infrastructure and ecosystems alike as 'systems' in our categories above, each of these elements requires quite different kinds of analytical methods in order to understand their resilience characteristics. In addition, by identifying and treating these elements separately it is easier for local government or civil society organizations, with limited sectoral or thematic interests, to engage in the framework and to identify relevant issues. With a variety of entry points and analytical approaches available, local experts and practitioners should be able to relatively easily identify starting points that relate to their own domain and expertise.

Within this conceptual framework, building urban climate resilience means:

- Strengthening systems to reduce their fragility in the face of climate impacts and to reduce the risk of cascading failures;
- Building the capacities of social agents to anticipate and develop adaptive responses, to access and maintain supportive urban systems; and
- Addressing the institutional factors that constrain effective responses to system fragility or undermine the ability of agents to take action.

While separating these elements of urban resilience simplifies both diagnosis and analysis for practitioners, they should not lose sight of linkages between them. The most important of these linkages are the institutional links between agents and systems. Local policy decisions, for example, may ignore the tenure claims of marginal groups, deny them access to supportive urban services, or subject them to involuntary climate risks while other groups are protected (Lebel et al., 2006; Moser & Satterthwaite, 2010). Measures to address the resulting ecosystem degradation or climate risk directly are unlikely to succeed without recognition of the underlying injustices.

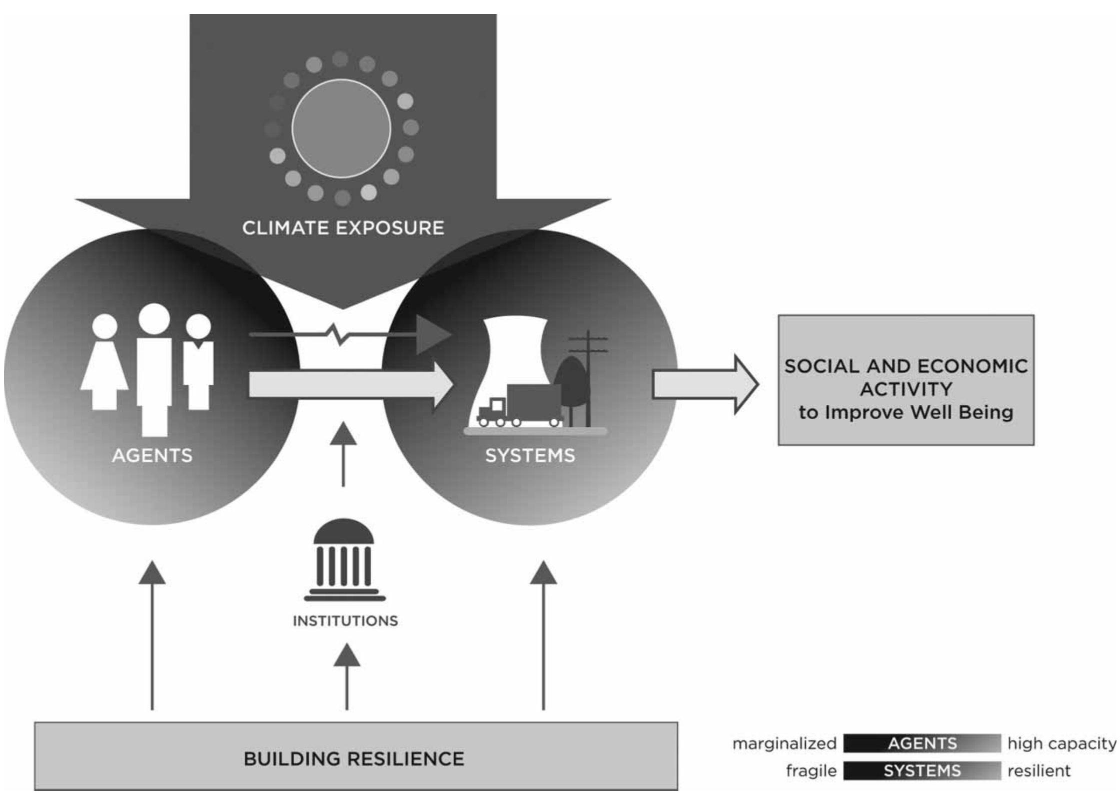

Figure 1. Urban systems enable agents to improve their well-being by adopting new strategies as conditions change. Resilience to climate change increases by building agent capacities, strengthening systems and reinforcing institutions that link agents and systems.

Agent capacities can play an important role in system characteristics as well, as resourcefulness and responsiveness of key organizations can directly influence investment and operations of infrastructure systems, and lack of assets is a contributing factor to ecosystem degradation (Tyler, 2006).

These linkages may be difficult to assess because knowledge of these different factors and systems is held by many different actors. This highlights the importance in the planning process of multiple knowledge perspectives, and of meaningful engagement of multiple stakeholders (Berkes, 2007; Lebel et al., 2006; Tompkins & Adger, 2004). The integration of different factors and the comparison of key areas of urban climate vulnerability rely on participatory and deliberative processes to draw out different perspectives and ensure that stakeholder positions are considered. Social learning should be an essential element of the integration process because of its importance in adaptation and building a shared understanding of complex issues under uncertainty (Huntjens et al., 2012; Parson & Clark, 1995; Pelling, High, Dearing, & Smith, 2008; Tompkins & Adger, 2004).

The nature of vulnerability assessment, which needs to consider not only resilience elements but also climate exposure, suggests that such a process should bring together both global and local information about climate change, as well as information about urban systems (including their linkages beyond city boundaries), key organizations, low-capacity households and the institutions that enable or constrain their behaviour. The process should engage formal and informal knowledge holders and organizations responsible for different dimensions of adaptation action. It should be iterative in recognition of the time needed to build trust and develop responses across multiple scales of activity (Lebel et al., 2006).

One of the effects that can be missed by separating the resilience framework elements for analysis is self-organization. This is an emergent property of complex adaptive systems. An important example of this phenomenon is economic markets, where under a wide range of conditions the interaction of agents, institutions and infrastructure systems results in highly organized and efficient distribution of goods and services (Krugman, 1996). Self-organization and feedback enable a wide range of autonomous responses to climate change and other stresses, but these responses emerge from interactions across all three elements of the framework.

We emphasize the importance of building climate resilience in cities in order to foster adaptation, but we also recognize that resilience is not always a positive feature. Undesirable system conditions may be resilient (or resistant to change, which is not quite the same). Polluted water supplies, authoritarian governments or invasive species provide examples of conditions that are likely to prove both undesirable and possibly resilient (Walker et al., 2002).

2.6. *The climate resilience framework – a tool for local planning*

This conceptual framework, with three key elements and general components of each, provides a way to think differently about climate adaptation in cities. Instead of focusing on future climate projections and defining uncertainties and climate risks, local planners can address the enabling and service provision role of core infrastructure and ecosystems, together with the capacities of agents and the structure of institutions linking systems and agents, to identify the key factors that affect resilience in their city. By assembling and describing these conceptual features of climate resilience in cities, we provide a framework that can guide planning practitioners.

The premise of the conceptual framework is that, while it is abstract enough to be generalizable in a wide range of different contexts, it can be made operational by interpreting the details of local resilience factors represented by local actors engaged in the planning process. Systems design and performance will be familiar to engineers and managers (with the frequent exception of ecosystems, whose services in cities are often undervalued and unrecognized). Links between systems will usually be apparent to designers, operators or users. Agent capacities can be diagnosed and interpreted using socio-economic data and through engagement of the relevant organizations and social groups, or representative community-based organizations; and examples of institutions related to differential access, decision making and use of information can usually be identified by community organizations or other knowledgeable local actors.

As in any planning approach, issues of cultural reference point and of power relations come into play. But these are not issues specific to climate resilience, and we defer to other treatments of these questions in urban planning to point out that they are important considerations in resilience planning as well. Power relations inevitably constrain decision-making processes and options. However, there are always starting points and feasible actions that can increase resilience, and where institutional manifestations of unequal power are key contributors to vulnerability the framework will help intervenors make these explicit. The framework can also help to identify patterns of vulnerability that cut across social and power divides, enabling the identification of starting points that are likely to have broad support.

As the intention of this framework is to guide practice, a partial test of the approach is whether it can be used in practice for resilience planning.

3. Operationalizing the framework

As pointed out in the introduction, this conceptual framework for resilience was developed and refined to support the engagement and planning stages of the ACCCRN programme in 10 cities in Asia. The elements of the framework were introduced to national and local partners and clarified through discussion, translation and feedback. The main concepts and key analytical issues described above in the framework formed the basis for resilience planning in the ACCCRN cities. Their experience provides some indication of whether the framework can be translated into a planning tool for application in cities in low- and middle-income countries.

The process for applying the resilience framework to resilience planning in ACCCRN is presented in Figure 2. This diagram features two iterative tasks that integrate the elements of the framework and their normative characteristics in both vulnerability assessment (the left hand loop) and resilience building (the right-hand loop). In principle, vulnerability assessment is undertaken first so that subsequent resilience building interventions can focus on those groups or systems that are most vulnerable to the anticipated climate hazards. These planning elements are driven by an iterative process of multistakeholder deliberation and shared learning, which we label as 'Shared Learning Dialogues' or SLDs.

SLDs are structured interaction processes designed to bring together divergent communities, sources of knowledge and perspectives in a manner that builds common understanding and trust while enabling responses to different interests (Reed, Guibert, & Tyler, 2011). SLD processes can be focused on the urban area as a whole or on specific systems or groups of agents that have particular relevance to urban resilience. In either case, the basic principles are the same. Initial dialogues focus on engaging the agents who manage and depend on systems along with external technical or scientific experts to share knowledge from different perspectives regarding the implications of climate change for systems and the services they produce. Once dialogue has been catalysed, more targeted interactions follow to ensure that the voices of marginal groups are heard and to improve understanding among all those engaged of core elements of the framework (e.g. systems, agents, institutions and exposure) and how those interact *in the local context*. These deliberations are facilitated so that specific critical issue areas emerge.

As planning moves to implementation, mechanisms for monitoring and ongoing learning become central to the longer-term shared learning process (right hand loop of Figure 2). Because climate change interacts with other ongoing change processes, knowledge and shared understanding will evolve over time.

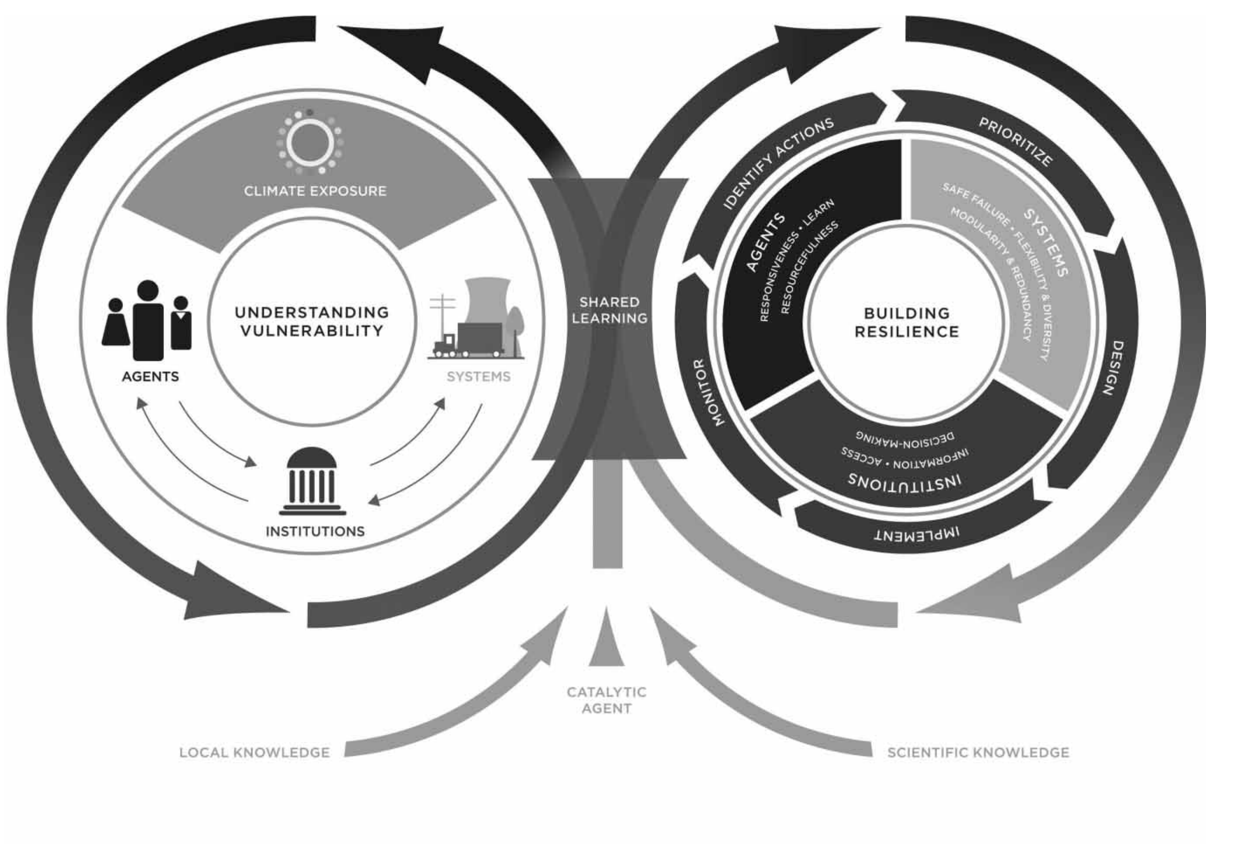

Figure 2. Applying the framework to resilience planning (used by permission).

All the ACCCRN cities were expected to use the conceptual framework and the SLD process to undertake a resilience planning effort that included:

1. Structured and facilitated multistakeholder deliberation to communicate knowledge, ideas and perspectives across scales and communities, and draw conclusions to guide planning decisions;
2. Vulnerability assessments that included analysis of fragile systems, low-capacity agents, constraining institutions and their exposure to climate hazards;
3. Resilience strategies that defined tangible priority interventions, based on the vulnerabilities identified in the previous step, and tied to other existing local planning processes;
4. Implementation and learning from action; and
5. Transmitting learning into new capacities, new knowledge, revised strategies and action.

The first three steps of this process were undertaken over the period 2009–2011 by all 10 cities in ACCCRN. The length of time taken for these steps ranged from about 10 to 20 months. Details of this process are reported elsewhere (Tyler & Reed, 2011). In order to assess whether local partners were able to understand and apply the resilience framework, we ask whether they were able to implement iterative and deliberative multistakeholder processes that integrated all four elements of the framework, first in vulnerability assessment and then in planning to build resilience. If the framework has been understood and applied, the results of the planning exercise should include examples from each of the four elements of the framework (considering ecosystems and infrastructure as different manifestations of systems).

As expected with such a diverse group of cities, the process was implemented differently in different places. However, all of the cities undertook iterative consultation processes of some kind. In some cities, the consultations took the form of workshops with several dozen participants representing government, academic and community organizations. In others the consultations were structured as a series of smaller workshops or meetings with diverse groups who could not easily work together. All of the cities created a new local coordination body, typically labelled a ‘working group’ or advisory committee to direct the work and establish resilience planning priorities. In some cities these working groups were strictly composed of local government officials, while in others they included civil society representatives.

All the cities were able to develop vulnerability assessments, although they used a range of methodologies and analytical tools for this. These assessments all included issues of climate exposure, infrastructure and agent capacity, particularly in an effort to identify vulnerable groups. Most of the cities also included ecosystem vulnerability assessment, and some identified key institutional issues. These vulnerabilities served to then guide the development and prioritization of interventions to build resilience in each of the cities. Priority interventions recommended in the city resilience strategies are listed in Table 4. While each individual city faced a different context and set its priorities accordingly, across all the cities, each of the four resilience elements was represented by multiple examples. None of the proposed priority

Table 4. ACCCRN city proposed interventions in relation to resilience framework elements.

Resilience elements	Priority interventions proposed in city resilience strategies
Infrastructure systems	Flood monitoring and early warning systems
	Storm- and flood-resistant housing
	Hydrological and hydraulic modelling studies to guide flood prevention investments
	Flood shelters
	Rainwater harvesting
Ecosystems	Mangrove restoration and protection
	Watershed planning and forest protection
	Groundwater recharge
	Biological riverbank stabilization
Agent capacities	Build awareness of climate risks
	Engage communities in resilience planning
	Build climate change issues into school curriculum
	Train community groups and local government in disaster risk management and response
	Improve public health surveillance
	Alternative livelihoods to increase choice for peri-urban poor
Institutions	Water demand management
	Limit development rights in floodplains
	New local government coordination and technical support organizations
	Improve public information on flood hazard and evacuation
	Improve climate forecasting and warning services
	Engage communities in climate resilience planning

measures lie outside the four areas of urban resilience captured by the framework.

This brief review of the results from ACCCRN city resilience planning activities carried out by local practitioners suggests that the key elements of the climate resilience framework were incorporated into their work despite the relatively short timeframe and their lack of previous experience with climate change issues. From the range of suggested measures put forward it appears that local experts and advocates in different fields were able to use their knowledge of local conditions to identify key vulnerabilities and interventions based on the general guidelines of the climate resilience framework categories. By developing proposed interventions that responded to these key areas of vulnerability, local partners were able to identify sensible and practical measures to build resilience in the face of uncertainty.

4. Conclusions

This framework for urban climate resilience facilitates planning for climate adaptation in cities by reaching beyond a focus on climate impacts to integrate ecological, infrastructure, social and institutional resilience factors. The framework provides a simple organizing rubric that is well rooted in the theory and practice of multiple fields related to climate adaptation and disaster risk reduction, but has not previously been synthesized in this way. The framework is a tool for scoping and assessing urban vulnerability to climate change by helping practitioners to systematically consider the weaknesses of systems, agents and institutions exposed to climate stress.

The application of the framework through ACCCRN demonstrates that it was not difficult for local practitioners to grasp the implications of the general framework and apply the iterative learning and planning process suggested here. Climate change resilience is a new and unfamiliar concept to local practitioners and planners, but the framework translates this broad objective into readily identifiable issues that pertain to familiar sectors and recognizable vulnerabilities.

Shared learning and resilience planning processes both build resilience themselves, through building agent resourcefulness and foresight and through strengthening capacities and institutions that foster learning. These processes become integral components of urban resilience and key elements of the framework as applied in practice.

As with any guidance tool intended for use by practitioners, the framework simplifies the complexities of urban climate resilience. As a tool, the framework does not yet capture some practical issues well. For example, it is not designed to highlight trade-offs that may occur if resilience building in one area leads to increased vulnerability in another or if different resilience measures conflict (cf. Wardekker et al., 2010). Similarly, while the framework may help to make institutional and governance issues more explicit, the central question of *whose* resilience is increased is not clearly illuminated here. In implementation, a persistent challenge was how to sustain effective engagement of poor and vulnerable communities in the planning process, a challenge by no means limited to planning for climate resilience.

More empirical evidence from practice would help to verify the value of the participatory approach and the key elements of the urban climate resilience framework. In addition, the elements and their normative characteristics should continue to be validated against evolving theories and understandings of adaptation in related fields.

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Notes

1. The authors acknowledge the collaboration of Jo da Silva, Sam Kernaghan and Andres Luque of Arup International Development in early discussions of this framework. Their systems-based perspective has been recently published as da Silva et al. (2012).
2. These include many of the same institutional features as a list developed for a recent empirical review of adaptation governance in the water sector (Huntjens et al., 2012).

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