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Understanding Urban Climate Change and Digital Infrastructure Interventions from a Resilience Perspective

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Understanding Urban Climate Change and Digital Infrastructure Interventions from a Resilience Perspective

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Abstract[1]

Climate change is posing unprecedented challenges to low-income urban communities that are on the front line of its effects. More frequent and intense storms, heat waves, drought, and floods/sea level rise directly damage lives, livelihoods and infrastructure, and have knock-on impacts on existing vulnerability dimensions. In response to those challenges, the concept of resilience is gaining significant momentum in both the climate change and urban development fields. Yet, to date resilience – the capacity of low-income urban communities to cope with, adjust to and potentially transform amidst change and uncertainty – has often been well-understood but poorly-applied or, when applied, has been poorly-understood.

The purpose of this paper is therefore to develop a well-conceptualised model of resilience that can be used in both research and practice to understand and evaluate climate change and other interventions in urban settlements. That model bases itself on systems theory and sees urban communities as systems. The sustainable livelihoods approach and Sen's capability approach are used to explain the structures and functions of communities-as-adaptive-systems which are responding to climate change and other stressors. But resilience is something different – a system property – which literature synthesis explains as a set of dynamic foundational and enabling sub-properties.

This model of resilience is then used to analyse two types of urban intervention: first adaptive interventions responding directly to climate change, and then urban digital infrastructure interventions which are increasingly used not just to underpin climate change but urban capacity more generally. These analyses show both types of intervention to largely strengthen community resilience, but also to weaken some aspects.

The paper demonstrates the viability of the developed resilience model to both understand and evaluate urban community interventions, and it offers some evidence that this provides a broader and deeper understanding of those interventions than other perspectives can offer. Future developments should involve greater engagement with practice, including use in planning and evaluation, and the potential to develop some form of resilience index or benchmark.

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A. Introduction

The issue of cities and climate change is viewed from a number of perspectives. These may often co-exist in any given initiative or programme but they are worth disentangling. Arguably dominant has been the mitigation perspective, reflecting the views of the global North (Bulkeley & Betsill 2003). This sees cities as most likely responsible for 60-70% of global greenhouse gas emissions, and thus focuses on mitigation measures as the core response (UN-HABITAT 2011). Yet the mitigation perspective is arguably of limited relevance to developing country cities: the poorer the urban population, the smaller the carbon footprint (Dodman 2009, Hertwich & Peters 2009) with the poorest 49 countries of the world representing 14% of its population but 0.5% of its carbon emissions (UN-OHRLLS 2010).

More relevant, then, to cities in developing countries is the adaptation perspective. This recognises that cities are already being affected by climate change and that it is low-income urban communities in developing countries which are on the "front line" of climate change (Rosenzweig et al. 2011, World Bank 2012). Climate change – or, more accurately, climate events that are being exacerbated by climate change – is already a lived reality for these communities. Records are already reporting that these communities are subject to changes in climate-related extremes: more frequent and intense storms, flooding, heat/cold waves, and drought; and changes in climate-related averages: higher temperatures and rainfall, and sea-level rise with saline intrusion (Satterthwaite et al. 2009, UN-HABITAT 2011). These events have three effects (*ibid.*):

- They directly harm lives: causing death and serious injury from physical impact, heat effects, and drowning.
- They damage the foundations for livelihoods: at a micro-level, destroying or damaging livelihood assets (sources of income, community relations, land, housing, equipment, etc.); and at a meso-level, destroying or damaging urban livelihood infrastructure (buildings, transport, energy, communications, water/sanitation and other ecosystem services).
- They exacerbate existing vulnerabilities: climate change has a multiplier effect on urban vulnerabilities including poor health, low water and air quality, food insecurity, poverty, and social exclusion.

The mitigation and adaptation perspectives have dominated the discourse on cities and climate change, but they have still left some space for additions and variations. One example would be the 'smart cities' perspective which sees information and communication technologies (ICTs) to be the foundation for a mitigation response (ITU 2013). But our focus here will be the resilience perspective. This has attracted various labels: 'urban resilience', 'resilient cities' and 'cities of resilience'. It is the focus for increasing activity:

- In the global North e.g. Local Resilience Forums in the UK (Cabinet Office 2011), and the EU's Transitioning Towards Urban Resilience and Sustainability project (TURAS 2013).

- In the global South e.g. the formation of the Asian Cities Climate Change Resilience Network (ACCRN 2013), and UNISDR's Making Cities Resilient campaign (UNISDR 2013)
- Globally e.g. Rockefeller Foundation's (2013) 100 Resilient Cities challenge.

Resilience means the ability to withstand and recover from short-terms shocks, and to adapt to long-term trends. It can be seen, in part, to respond to two implicit difficulties with the adaptation perspective: the difficulty of identifying the climate change component within the weather events that affect urban areas; and the difficulty of disentangling climate issues from other vulnerabilities within the lives of the poor. Resilience addresses these because it looks at neither the causes nor the effects of climate change or any other shocks/trends. Instead, it focuses on the generic properties of a system – which could be a city, district, community, household or individual – to address any shock or trend. Resilience therefore at once encompasses but also transcends the issue of climate change for low-income urban communities.

There is, therefore, a literature on cities and resilience. The main threats that have triggered this literature are terrorism (Coaffee 2009), non-climate natural disasters such as earthquakes (Comfort 1994), and climate events (Whittle et al. 2010) including climate change in particular (Leichenko 2011). Given the non-specificity of resilience, much of the literature has dealt with generic threats to urban environments (Godschalk 2003, Ernstson et al. 2010). However, resilience itself is not often conceptualised in any depth.

In some cases, resilience is more written around than written about. This may include use without even definition (e.g. Crichton 2007) but more often resilience is used as a largely taken-for-granted catalyst or metaphor or stepping stone that leaves the focus of the literature mainly elsewhere. For example, Coaffee (2007) analyses not resilience itself but the urban governance responses that an interest in resilience trigger; while Prasad et al. (2009) and Ahern (2011) similarly identify strategies for building resilience via only a brief definition of the core term. Ernstson et al. (2010) take resilience based in systems theory and then use that as the basis for their investigation of urbanisation. Pickett et al. (2004) take this line to its conclusion by studying resilience not as a real property but as a metaphor that provides insights into the urban planning process.

Where resilience is engaged with more directly in the literature, then sometimes the depth of engagement may be restricted to defining the component parts of the definition (Whittle et al. 2010), identifying the socio-technical nature of resilience (Godschalk 2003), or broadening to explain categories of resilience: e.g. physical, social, economic, institutional and natural (Razafindrabe et al. 2009); or social, economic, institutional, infrastructural and community (Jha et al. 2013). These remain broad-brush approaches and may be contrasted with literature that offers a few specific factors that are seen as related to resilience, e.g. a diversified economy, planning, and people (Campanella 2006); or wealth, institutional stability, reliable public infrastructure, global interconnectivity, and natural resource dependence (Tanner et al. 2009). Even the relatively few examples of specificity are challenged

by limited overlap and agreement, perhaps because urban resilience is being approached from different foundations including ecological, hazards/risk, economic, and governance/institutions (Leichenko 2011).

We therefore identify a knowledge gap; a requirement for a more thorough conceptualisation of resilience as applicable to low-income urban communities. Only by understanding resilience properly can we effectively make use of it as a concept: for design of future initiatives, for implementation of current initiatives, and for evaluation of past initiatives. This, therefore, is our aim for this paper: to present a well-conceptualised model of resilience that will be of utility to those involved in helping low-income urban communities address climate change.

In Section B, we undertake this presentation, building a model of systemic resilience from the literature on resilience but also from the literature on vulnerabilities, livelihoods and adaptation. In Sections C and D, we then test this model by using it to analyse two sets of urban interventions. The first set are directly related to climate change; focusing on adaptation for the reasons given above. The second set cover digital infrastructure because of the general acceptance that ICTs will form a key component for most future climate change interventions (Hasan & Kazlauskas 2009, Ospina & Heeks 2010). In the final section, the paper reviews emergent pros and cons of the resilience perspective, and draws some conclusions for policy and practice.

B. Conceptualising Climate Change Adaptation and Resilience

Our starting point for understanding resilience is a systematic and systemic understanding of low-income communities, based around the model shown in Figure 1. Full details of the derivation of this model can be found in Ospina & Heeks (*ibid.*) but, in brief, it was created from the following principles, which draw particularly from the sustainable livelihoods approach and from Sen's capabilities approach:

- That climate change must be understood as one among a number of acute shocks and chronic trends which impact low-income urban communities.
- Climate change and other shocks and trends interact with a set of key vulnerability dimensions such as livelihoods and finance, socio-political conditions, health, habitat and migration, food security, and water supply.
- An urban community can be conceived as a "livelihood system". Actions within the community are determined by the assets available (human, natural, financial, physical, social and informational capitals), by the institutions that shape behaviour, and by the structures that organise those assets and institutions.
- The adaptive capacity of the community to cope with (withstand, recover from, and change in the face of) external shocks and trends, represents a series of livelihood capabilities. However, only a subset of these are converted into actual strategies and actions ("functionings" in Senian terms).
- The overall functionings of the community are diverse but a sub-set represent specific adaptations or adaptive actions that respond to external forces such as

climate change. These actions, in turn, alter the determinants and capabilities of the community.

- The overall actions also drive the outcomes of social, political and economic development seen within the community and beyond.

Vulnerability Context	System Levels	Livelihood System (e.g. Urban Community)		Development Outcomes
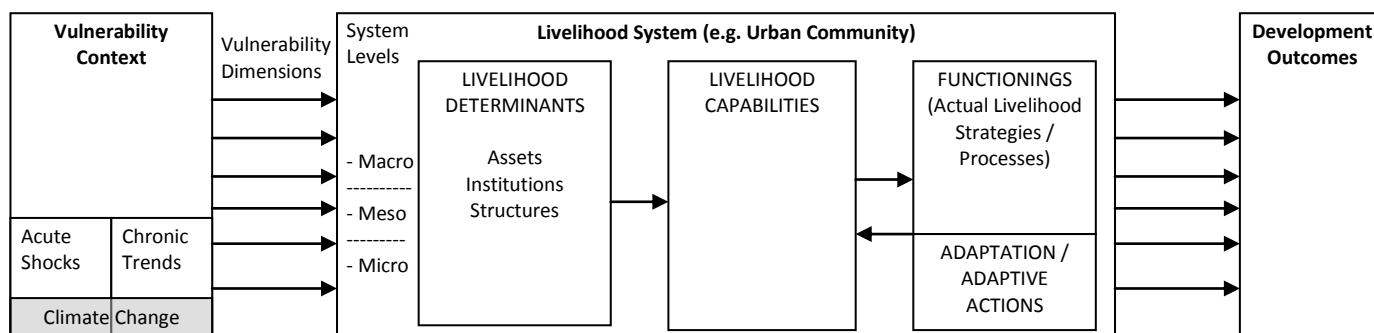
Figure 1: Adaptation to Climate Change: System Components and Processes (adapted from Ospina & Heeks 2010)

Systems can be understood through three main aspects: structure (e.g. components and relations), process (functions), and properties (Laszlo & Krippner 1998, Skyttner 2001, Fisher 2010). Figure 1 shows the structure and process of an urban community, but not its properties. It therefore says nothing directly about resilience since resilience is neither a systemic structure nor a systemic process, but a systemic property (Gallopin 2006). Adaptive capacity of systems such as urban communities derives not simply from the structural elements but also from the properties of those elements in systemic combination (Norris et al. 2008). To progress further, then, we need to understand more about what resilience – as system property – is.

We noted above the limitations of much of the literature dealing with resilience and climate change and/or urban development in practice. But there is a fraction of more conceptual literature of relevance here that recognises resilience as a systemic property. Some of that literature, particularly early work, sought to treat resilience as a monolithic property but more recent work has broken it down into a set of sub-properties. A review of these latter sources suggests that resilience sub-properties can be grouped in two main categories, according to their foundational or enabling contribution to resilience.

B1. Foundational Sub-Properties

Analysis and synthesis of the conceptual resilience-as-property literature (Carpenter et al. 2001, Walker et al. 2004, Folke 2006, Nelson et al. 2007, Plummer & Armitage 2007, Resilience Alliance 2010, Miller et al. 2010, Osbahr et al. 2010) suggests that resilient systems have three core characteristics, referred to here as 'foundational sub-properties'.

The first of these sub-properties – **robustness** – relates mainly to the ability of the system to withstand; that is, to maintain its characteristics and performance in the

face of environmental fluctuations, including shocks (developed from Carlson & Doyle 2002, Janssen & Anderies 2007, Tierney & Bruneau 2007). Generic features of robust systems include reinforcing connections between components and processes, which help spread the effects of any external disturbance, and strengthening individual structures (such as institutions) to avoid their collapse in the face of stressors (Gunderson 2000). In relation to climate change such strengthening would encompass physical preparations such as levees, flood storage basins, greenspaces and tree planting (Gill et al. 2007).

The second foundational sub-property is **self-organisation**, which refers to the system's ability to independently re-arrange its functions and processes in the face of external disturbances, without being forced by the influence of other external drivers (Carpenter et al. 2001). Self-organisation is critical given both the uncertainty of reliance on external systems e.g. during an extreme climate event, and the potential mismatch between external and local system interests. It enables local diagnosis of problems and mobilisation of resources to initiate solutions (Tierney & Bruneau 2007), and relies strongly on the capacity for cooperative decision-making and action within the community; a capacity that will be based significantly on the nature of social networks within the community (Fuchs 2004). The capacity for local collective action will also relate to the nature of local power over structures and resources (such as leadership within the community and representativeness and trust) and psycho-social dimensions (e.g. belief, motivation, hope, perceived self-efficacy) within the community (Brouwer et al. 2007).

The third foundational sub-property of resilience is **learning**: the capacity of the system to generate feedback with which to gain or create knowledge, and build the skills, attitudes and other competences required to innovate and adapt to change. Experimentation, discovery and innovation can all be seen as aspects of both short-term response to shocks and longer-term transformational change (Folke et al. 2010). These may be enhanced by the combination of local knowledge with that sourced from outside the community (Folke et al. 2003).

B2. Enabling Sub-Properties

Further review of conceptual literature suggests the existence of an additional set of sub-properties – redundancy, rapidity, scale, diversity, flexibility, and equality – that enable resilience, and that facilitate the operationalisation of the foundational attributes described above (Godschalk 2003, Folke et al. 2003, Seixas & Berkes 2003, Tompkins & Adger 2004, ADPC 2006, Marshall & Marshall 2007, Callaghan & Colton 2008, Magis 2009, Cuthill et al. 2010).

Redundancy is the extent to which components within a system are substitutable; for example, in the event of disruption or degradation. One part of this can be asset diversity, but this is not simply an issue of scale but the ability to access assets that are both in some sense 'surplus' and interchangeable. Redundancy may also involve the overlap of processes, capacities and response pathways that allow for partial failure within a system without complete collapse (Rockefeller Foundation 2009).

Rapidity means how quickly assets can be accessed or mobilised to achieve goals in an efficient manner (Norris et al. 2008), and is key to ensure the system's ability to identify the emergence of problems and decide and implement a course of action in a timely manner. This will have a particular value in responding to acute climate-related disturbances and will relate to a variety of assets but especially information and finance.

Scale refers to the breadth of assets and structures a system can access in order to effectively overcome or bounce back from or adapt to the effects of disturbances (Folke et al. 2010). It involves, for example, access to structures beyond the immediate community level which enable access to resources that may not otherwise be available. These structures may be informal social networks or formal institutions such as extended markets or state organisations, which are shown to be important in climate responses (Few et al. 2006).

Diversity is the availability of a variety of assets, institutions and institutional functions that enable a range of response options (e.g. in terms of livelihoods, land use, adaptive infrastructure choices, etc) (Folke et al. 2005, Hopkins 2009). It also encompasses diversity of knowledge and reference frames (Galaz et al. 2008). This reduces the potential fragility of a 'monoculture' response to external stressors, helping the absorption of disturbance, spreading of risk, and stimulus of competitive reorganisation and renewal (Folke et al. 2003, Nelson et al. 2007, Rockefeller Foundation 2009, Ifejika Speranza 2010, Clements et al. 2010). Diversity of system elements also "provides the basis for innovation, learning and adaptation to slower, ongoing change" (Biggs et al. 2012: 425).

Closely linked to diversity and combined into a single sub-property for the purposes of what follows, ***flexibility*** refers to the ability of a system to undertake different sets of actions with the determinants at its disposal, better enabling it to address problems and utilise opportunities arising from external change (Folke 2006). Flexibility partly relates to the ability of system elements to be recombined in different ways, but also to the existence of knowledge (e.g. from wider networks) that can suggest those different combinations and courses of action; and to an adaptability of decision-making processes to allow alternatives to be considered.

Equality is the extent to which the system affords equal access to rights, resources and opportunities to its members, given evidence that more unequal systems are less resilient and less able to adapt (Adger 2001, Magis 2009). At one level, this is about the distribution of access to resources and institutions, but it is also about the nature of decision-making: whether this is able to produce shared goals by being participative and transparent (Tompkins & Adger 2004).

B3. Conceptualising Community Resilience

Based on the review above, we can now summarise resilience as a series of foundational and enabling sub-properties with definitions and key markers as shown in Table 1 (Ospina 2013).

Resilience Sub-Property	Definition	Key Markers/Characteristics
FOUNDATIONAL SUB-PROPERTIES		
Robustness	• Ability of the system to maintain its characteristics and performance in the face of environmental shocks and fluctuations.	• Physical Preparedness • Institutional Capacity • Multi-level Governance and Networking
Self-Organisation	• Ability of the system to independently re-arrange its functions and processes in the face of an external disturbance, without being forced by the influence of other external drivers.	• Collaboration/Consensus-building and Participation • Social Networks • Local Leadership and Trust
Learning	• Capacity of the system to generate feedback with which to gain or create knowledge, and strengthen skills and capacities. Learning processes are closely linked to the system's ability to experiment, discover and innovate.	• Capacity Building • New and Traditional Knowledge • Reflective Thinking
ENABLING SUB-PROPERTIES		
Redundancy	• Extent to which components within a system are substitutable; for example, in the event of disruption or degradation.	• Resource Spareness • Functional Overlaps and Interdependency • Resource Substitutability
Rapidity	• Speed at which assets can be accessed or mobilised to achieve goals in an efficient manner.	• Rapid Resource Access • Rapid Resource Assessment/ Coordination • Rapid Resource Mobilisation
Scale	• Breadth of assets and structures a system can access in order to effectively overcome or bounce back from or adapt to the effects of disturbances.	• Multi-level Networks • Resource Access and (intra/inter) Partnerships • Cross-level Interactions
Diversity & Flexibility	• Ability of the system to undertake different courses of actions with the determinants at its disposal, while enabling them to innovate and utilise the opportunities that may arise from change.	• Different Courses of Action/Emerging Opportunities • Adaptable Decision-making • Innovation Backbone
Equality	• Extent to which the system provides equal access to rights, resources and opportunities to its members.	• Strengthened Competencies/ Gaps' Reduction • Inclusiveness • Openness and Accountability

Table 1: Resilience Sub-Properties: Summary of Definitions and Key Markers (Ospina 2013)

These resilience sub-properties constitute dynamic, interrelated, and imbricated attributes that interact with available assets, institutions, structures and capabilities (system components) in a livelihood system, and ultimately enable adaptation as realised functionings (system processes). The realised adaptations contribute to achievement of development outcomes, including feedback into the capacity of the system to withstand or adapt to future disturbances and climate-related uncertainties. These connections form the resilience model that is reflected in Figure 2.
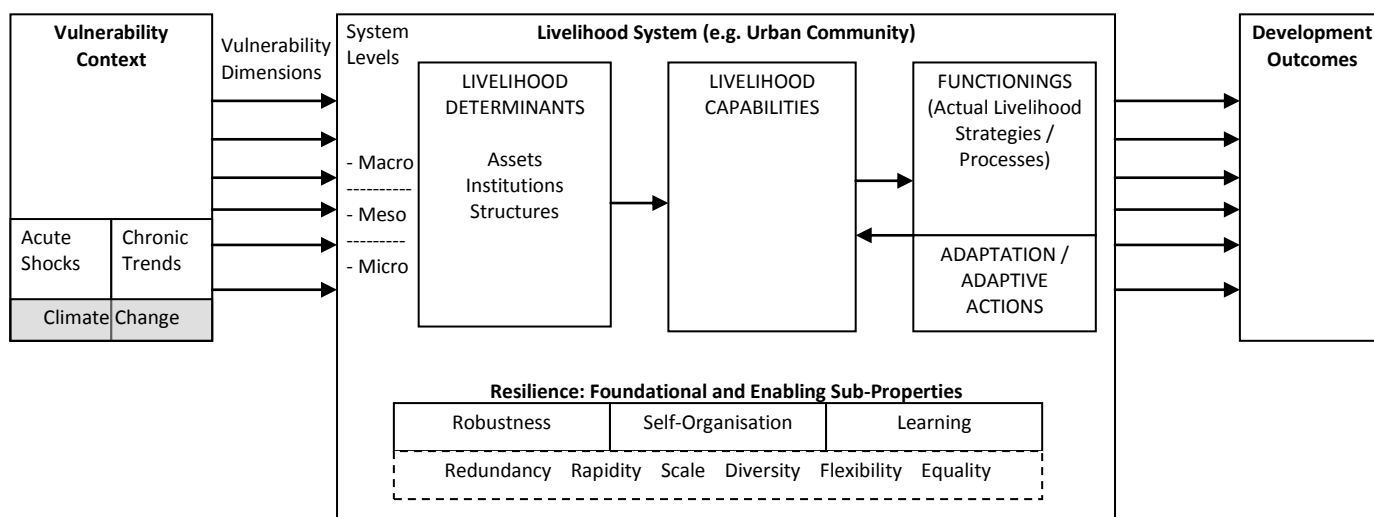
Figure 2: Adaptation to Climate Change: Resilience as a System Property (adapted from Ospina & Heeks 2010)

To summarise, the analysis of systemic adaptation is concerned with the relationships between components, properties, processes and outcomes in a given system (Nelson et al. 2007), as reflected in Figure 2. Here, external shocks or trends within a particular context (such as those related to climate change) act as a stimulus that requires a response. The capacity of the system – in this case an urban community – to respond through adaptation can be understood in two ways. First, as a set of structuro-functional components. Second, as a set of (sub-)properties. Together these interact to create the adaptive capacity of the system/community, which can be thought of as the system's capabilities – what it is able to be and to do – in making a response to acute or chronic external stressors. Therefore, resilience interacts with assets and other components to shape the trajectory of functioning and adaptation (Norris et al. 2008).

Having laid out the conceptual basis for community resilience, we will now use this framework to analyse the relationship to resilience of two different types of intervention – climate change and digital infrastructure initiatives – both of which are seen as central to creating the "smart, sustainable cities" of the future (ITU 2013).

C. Analysing Urban Climate Change Interventions Through a Resilience Lens

Sources in the field have documented a range of (anticipatory and reactive) interventions to climate change impacts on cities which aim to strengthen the adaptive capacity of urban communities (e.g. Alam & Rabbani 2007, Tanner et al. 2009, UN-HABITAT 2013). Interventions include physical measures of flood protection and infrastructure hardening against extreme weather events, seawalls to reduce the impact of sea level rise, improved housing quality to ensure resistance to storm events, improved enforcement of building development and land use regulations, relocation of vulnerable populations to new settlement areas, disaster planning and early warning mechanisms, and awareness raising on emerging health challenges, among others (IHC 2011, World Bank 2011).

The potential and actual impacts of these interventions are often assessed from short term, asset-driven perspectives; focused on identifying measurable impacts of investments led by institutional objectives and external funding agendas. These perspectives may overlook broader and deeper systemic impacts of such interventions. In other words, evaluation to date of urban adaptive interventions tends to neglect the impact on community resilience. (It also tends to neglect potential negative impacts of such interventions.)

The objective of this section is therefore to analyse selected urban climate change interventions through the resilience lens introduced in Section B. The analysis aims to provide a broader, more encompassing view of the impacts (positive and negative) of such interventions on vulnerable urban populations, highlighting aspects that may have been overlooked from traditional perspectives.

C1. Flood Interventions

In response to the extreme flooding that affects urban Bangladesh, at the end of the 1980s the government put into action a flood protection and drainage plan that included enclosing flood embankments, reinforcing concrete walls and installing drainage/flood regulation structures (e.g. sluice and pumping stations), aimed at protecting the most highly-urbanised areas of Dhaka (Alam & Rabbani 2007). Although the measures helped save human lives and property (e.g. during flood events in 1998 and 2004) (*ibid.*), they have also been associated with water-logging or internal drainage congestion during heavy rainfall due to inadequate pumping facilities and lack of proper infrastructure planning.

From a resilience perspective, we can relate these interventions to the following sub-properties:
- *Robustness*: by improving the ability of urban systems to withstand the impact of climatic events, improving the physical preparedness of human settlements to extreme weather, reducing the impact of flooding on critical infrastructure, and

improving the capacity of local institutions to undertake actions in the event of climatic disruptions.

- *Redundancy*: by contributing to the availability of functional overlaps via alternative mechanisms to cope with the effects of flooding.
- *Rapidity*: by contributing to rapid resource mobilisation to prevent or mitigate the impacts of flooding (e.g. via evacuation mechanisms to reduce loss of life).

However, when inadequately executed, flood interventions can weaken *robustness* by increasing the range of external stressors to include, for example, health problems derived from water contamination, sewerage and draining congestion, particularly in urban slums (Ali 2002). They can also affect the availability of spare resources (i.e. *redundancy*), due to the costly maintenance of infrastructure that can divert money and labour from interventions in other/emerging risk areas such as capacity building. Large investments in built infrastructure can also discourage new interventions and resource allocation to emerging and/or projected areas of risk, compromising the *flexibility* of urban areas to address emerging climatic risks.

C2. Urban Agriculture Interventions

In response to reduced land productivity and food insecurity, a number of cities in Africa and Asia have launched urban agriculture projects as part of their adaptation and mitigation efforts (Huq et al. 2005, Satterthwaite 2011). Specific initiatives include the work of the UN Cities and Climate Change Initiative (UN-HABITAT 2013) working in Bobo Dioulasso, Kathmandu and Kesbewa district of Colombo with actions that include conversion of open, vacant areas within the cities to multi-functional land use, rooftop gardening, urban greening, diversification of seed types, vegetable production on raised embankments, and small, semi-commercial home gardens in denser urban areas, among others.

These interventions can contribute to the following resilience sub-properties:
- *Robustness*: by improving the city's preparedness and capacity to face food shortages and other stressors on land productivity (e.g. through locally-grown produce using micro-gardens, and more resistant or productive seed varieties), and by helping protect environmentally-critical urban areas from illegal residential development (Dubbeling et al. 2009).
- *Redundancy*: by supporting the generation of additional financial resources from semi-commercial home gardens and livelihood diversification, and from the increased availability of redundant areas for agriculture.
- *Diversity and Flexibility*: by increasing the diversity of land use within urban communities, of opportunities for income generation, and even for disposal of organic waste; and by signalling innovative use/reconversion of urban areas.

Despite these positive contributions, and the weight of evidence clearly suggesting the benefits of urban agriculture (UA) outweigh the disadvantages, there are some threats to resilience. UA may undermine *robustness* of urban communities by increasing health and environmental (e.g. pollution) stressors (Mougeot 2000). The greater workload imposed by UA falls particularly on women and reduces the

redundancy of any spare labour they might have contributed to other activities (Bryld 2003).

C3. Urban Migration Interventions

India has seen an increased inflow of rural migrants to urban areas, exacerbated by climatic events and trends. This has triggered a response seeking to help support recent migrant groups who may themselves settle in slum areas vulnerable to climate shocks. For example, the Indian NGO Aajeevika Bureau ("Livelihoods Bureau") works with urban migrant populations to provide services such as shelter improvement, ID cards, skills training, job placement, and health insurance, among others (Aajeevika 2013).

Using a resilience lens, these interventions can be linked to the following sub-properties:
- *Self-organisation* by fostering the formation of social networks, collaboration and trust among migrant populations.
- *Learning*: by broadening access to training and educational resources among vulnerable migrant populations, fostering information exchange and improving migrants' confidence and self-perception.
- *Scale*: by connecting migrant communities with higher-level institutions from the NGO and public sectors, and by integrating those communities into broader systems of resource access.
- *Equality*: by building the assets and capabilities both of this marginalised group within the overall low-income urban community, and within this group by targeting those who are typically most excluded.

However, there are also difficulties that can arise with such interventions (Moser 1998, Cattacin 2006). They tend to create or exacerbate dependencies on external funding and sources of support, thus weakening the ability of the urban communities to *self-organise*. They also tend to impose or at least encourage particular mechanisms and approaches that have the effect of diminishing alternatives, thereby reducing the *diversity* within the community.

C4. Community-Based Risk Management Interventions

In Kampala, school students and other community members located in poor flood-prone neighbourhoods have been organised to collect meteorological data – particularly rainfall – on a daily basis (Sliuzas 2012). This is part of a broader flood management initiative that brings together academic, UN and slum dweller organisations and which aims to reduce climate risks by creating a community-based early warning system and by improving land management.

This can be seen to strengthen a number of resilience sub-properties:
- *Learning*: by raising awareness about the climate causes of flooding, the nature of flooding, and the impacts of flooding; and by building other knowledge and skills, the project has enhanced the learning capacity of the community.

- *Scale*: by linking local community members to each other and externally to academic organisations and international stakeholders, the project has improved the breadth of access to assets of the community.
- *Equality*: by incorporating children – traditionally one of the more excluded groups within urban communities – this intervention makes a contribution towards community equality.

While community-based approaches have been widely encouraged and tend to be treated as an unalloyed good, they may also weaken certain aspects of community resilience (Gregory 2002, Bhattamishra & Barrett 2010). They can do this by reducing the *rapidity* of the community in its ability to access data and to make decisions, and by reducing the *diversity* of decision/action pathways unless there is significant external intervention in the risk management processes.

C5. Summarising the Impact of Urban Climate Change Interventions

We have only had space to discuss a few specific interventions here but we can summarise the analysis using the framework shown in Table 2. This demonstrates both the applicability of the resilience model and also the impact that climate change interventions can have on the resilience of low-income urban communities across the whole range of sub-properties.

Resilience Sub-Property	Flood Intervention	Urban Agriculture Intervention	Urban Migration Intervention	Community-Based Risk Management Intervention
Robustness	+ Strengthen physical and institutional capacity of community to cope with extreme weather - Poor planning can increase external stressors e.g. health problems	+ Improve physical preparedness against food shortages and illegal land development - Increase health/environmental stressors		
Self-Organisation			+ Build networks and trust within community - Increase external dependencies	
Learning			+ Build skills, knowledge, confidence and interactive relations	+ Build skills and knowledge related to climate events and impacts
Redundancy	+ Develop functional overlaps via alternative flood response mechanisms - Can divert resources from other investments	+ Develop spare financial resources and unused land - Reduce potential for spare labour		
Rapidity	+ Improve speed of resource mobilisation during flooding			- Reduce speed of data access and decision-making
Scale			+ Connect communities to external institutions and systems	+ Build connections within and outside community
Diversity & Flexibility	- Can discourage investments that address emerging climate risks	+ Increase diversity of land use and income sources, and signal urban innovation	- Focus on single courses of action	- May reduce diversity of decision/action pathways
Equality			+ Build capacities of marginalised groups within and between urban communities	+ Incorporate children into intervention

Table 2: Impact of Selected Climate Change Interventions on Urban Community Resilience

Key: Strengthening (+) / Weakening (-)

D. Analysing Urban Digital Infrastructure Interventions Through a Resilience Lens

As was done for the urban climate change interventions, this section now takes the resilience framework and uses it as a lens for the re-analysis of urban ICT projects: attempts to deepen the digital infrastructure of urban communities. In order to more fully examine the utility of the framework, we will use a slightly different approach here: rather than analysing interventions one-by-one we will, instead, analyse each of the sub-properties in turn while still recognising that – given space constraints – what is achieved here can only be illustrative rather than comprehensive.

D1. ICTs Strengthening Foundational Sub-Properties

ICTs and Robustness

ICTs can help strengthen the physical preparedness of communities by helping those communities optimise the location of physical defences. For example, in a number of cities, geographic information systems (GIS) have been used to plot flood plains and watercourses, enabling the improved planning of maintenance and installation of storm drains (Kluck et al. 2010). ICTs can also strengthen institutions needed for the system to withstand the occurrence of climatic events. This can occur by developing the capacity of individual institutions: for example of local government to deliver services or to make good decisions (Schuppan 2009). But it can also occur by drawing institutions together into networks and partnerships that expand urban governance capacity, creating so-called 'smart city' or 'e-city' governance models (Paskaleva 2009), or by placing local institutions as one actor within multi-level networks that are global in scale (Sun et al. 2010).

ICTs and Self-Organisation

Self-organisation of low-income urban communities requires that they have internal, independent capacity to take decisions and actions, something conceivable in terms of the information chain (see Figure 3).
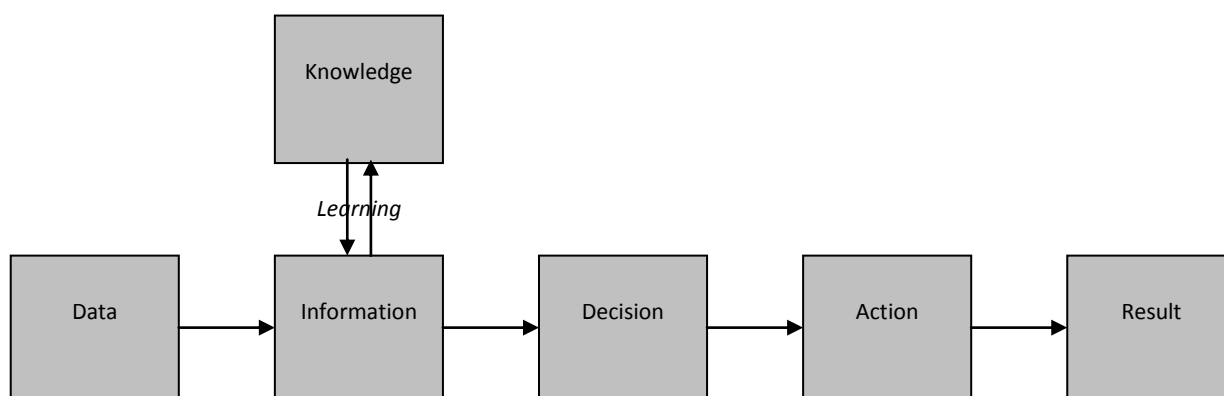
Figure 3: The Information Chain (adapted from Heeks & Kanashiro 2009)

A first step will be provision of appropriate data and information for decision-making processes. ICTs of course have a key role here. Most often, digital information about, say, climate events or climate change will come from outside the community (Ospina 2011, World Bank 2012). This does not per se install external drivers that may divert and undermine self-organisation, but of greater fit with self-organisation will be ICT use to generate data within communities themselves; an option which is increasing with greater availability of mobile phones. These have been used to report on-the-ground data during urban disasters or in relation to WaSH (water, sanitation, and hygiene) services, though as with all ICT systems there is still a reliance on external sources for hardware, software and telecommunications (Hutchings et al. 2012, World Bank 2012).

Digital tools such as public participatory GIS (in some cases with linked decision support systems) are increasingly used to help communities make decisions (Bugs 2012). This support for self-organisation via ICTs increases dramatically if we extend the scope of 'self' to also cover local government. Although lagging behind the extent of use in the global North, use of ICTs in local governments in Latin America, Africa and Asia is expanding fast, and assisting with data gathering, processing and decision making of relevance to climate change (e.g. Revi et al. 2006, World Bank 2012).

The 'action' component of the information chain is less associated with ICTs but the capacity for all elements of the chain – creating information, making decisions, taking actions – can be impacted by new technology. Some of these capacities, such as learning or general provision of resources, will be discussed in relation to other sub-properties. However, Table 1 specifically identifies social networks, leadership and trust.

ICTs can be seen to foster robustness by supporting social relations and social networks that reach outside the urban community; for example links to relatives based in rural areas (Skuse & Cousins 2008, Morawczynski 2009). But mobile phones also strengthen the social networks within urban communities, enhancing their ability to self-organise responses to external disturbances within those communities. They do this by enhancing communication within these networks, and thus building trust and social capital within the individual bonds of the network (Duncombe 2006). Experience in urban communities of using other ICTs such as online discussion forums has been more mixed, but there are signs that it can increase the density of contact within these communities and enable forms of self-organisation that spill over from the virtual to the real world (Kotus & Hlawka 2010). As might be expected, ICTs have been highly effective in strengthening the capacities of community leaders (e.g. Ogbu & Mihyo 2000, Ben-Attar & Campbell 2013).

ICTs and Learning

The use of ICTs enhances direct acquisition of new ICT- and information-related skills but strengthening this resilience sub-property can be related to more specific climate-oriented learning. The increasing mediation of learning via ICTs means that,

necessarily, low-income communities will increasingly be building their base of information, skills and knowledge through digital technologies (Garrison 2011). The opportunities for learning are expanding as more online educational resources around climate change are developing (e.g. Wilson et al. 2011), though it will be some time before these filter down to engage low-income community members in developing countries.

More accessible have been digital tools such as Web 2.0/social media applications to support processes of collective learning, particularly among institutions working in or with low-income urban communities (GTZ 2008). This can be understood in terms of Kolb's (1984) learning cycle: the sharing of experiences such as changes in the urban environment, group reflection on this evidence, the development of understanding through conceptualisation, and then the translation of these frames into active experimentation within the local area. This has been seen, for example, in the intensive use of ICTs in the Learning and Action Alliances that have supported reflection and built collective knowledge around urban flood risk management (Manojlovic et al. 2013).

D2. ICTs Strengthening Enabling Sub-Properties

ICTs and Redundancy

Redundancy refers to the potential of ICTs to increase availability of resources to such an extent that there is some spare, excess or possible substitutability of assets. One key way in which ICTs can contribute to redundancy is by supporting access to additional financial capital. ICTs – mobile phones especially – have been associated with an outflow of financial remittances from urban to rural areas, but they also enable inflows from richer urban and overseas diaspora social contacts into low-income urban communities (Skuse & Cousins 2008, Bowora & Chazovachii 2010). Although difficult to characterise this as creating 'spare' income, it does move communities in the direction of redundancy in terms of both financial capital and other assets purchased with the money. ICTs – e.g. mobile systems – also offer a channel for income flows that substitute for income that can no longer be produced locally during periods of acute shock, for example reversing standard urban-to-rural flows (Morawczynski & Pickens 2009)

Just as asset redundancy can improve the resilience of urban communities, so does redundancy in institutions and organisations (e.g. markets), which allows a community to continue to operate even in the event of partial failure of some of its components. One example is the broadening of urban job market channels through use of ICTs such as the Babajob system for informal sector employment in India (Heeks 2010a). This has functional overlaps with existing informal networks, thus providing a substitutable, redundant channel for job market operation. Another example is m-commerce – such as the CellBazaar system in Bangladesh – which provides redundancy in retail channels for urban communities, creating substitutable trading links (Zainudeen et al. 2011).

ICTs and Rapidity

A core functionality of ICTs is the increasing speed with which they process and communicate data. They are thus strongly associated with increases in systemic rapidity within urban communities for all information flows, transactions and services that they handle. For example, ICTs enable greater rapidity of access to, and mobilisation of, financial assets via m-finance applications (Duncombe & Boateng 2009). This, in turn, enables greater rapidity of mobilisation of the assets and services purchased with this money.

Similarly, by speeding up the accessibility of data, ICTs speed up the whole information chain (see Figure 3). So, for instance, mobile-based disaster management systems enable more rapid disaster early warning, response and recovery including coordinative decisions and actions (Yap 2011).

ICTs and Scale

By connecting low-income urban communities to distant and/or higher-level institutions, ICTs can improve the scale of assets and structures to which these communities have access. Telemedicine can provide access to the information, knowledge and other capabilities of the wider health system (Blaya et al. 2010). Urban weather forecasting and early warning systems similarly provide connections to wider capitals (informational, human, social, etc) and systems (Shaw 2012). ICTs can also improve the breadth of access to economic structures: tapping poor urban producers into wider markets (see the CellBazaar example mentioned above), or into regional and global supply chains (Munoz & Choi 2010). Most directly, this can improve scale of access to financial assets. As well as linking urban communities to "higher-level" systems, ICTs can also assist by enabling community organisations and enterprises to scale, and by facilitating cross-community interactions and partnerships (Schaffers et al. 2011)

ICTs, Diversity and Flexibility

ICTs typically provide a supplement rather than substitute for pre-existing sub-systems of data processing, communication, transactions and services. As such, they necessarily increase the diversity of any system such as an urban community. But they also significantly increase the potential for diversity of decision-making and action within the community, because they increase the diversity of information flows into the decision-making process (Shachaf 2008, Hampton et al. 2011). This would include providing information on a more diverse range of actions than might otherwise be known, in part through the more diverse social connections that ICTs enable; as already described.

Initial generations of ICTs were associated with inflexibility and the idea that they set procedures and systems in "electronic concrete" (Heeks 1999). However, more recent ICTs are much more flexible – not only incorporating an ever-wider range of functionalities but also more-readily enabling users to themselves re-purpose the technology. This means that ICTs can facilitate greater flexibility within social and

economic development components of urban communities (Forcheri & Molfino 2000, Ritchie & Brindley 2005). They can also form the foundation for new, collaborative forms of urban innovation, particularly social innovations (Deakin & Allwinkle 2007).

ICTs and Equality

The 21st century's "mobile revolution" has brought almost all members of low-income urban communities within reach of digital communications, with the majority of the population owning a mobile and with access to mobile telephony being close to ubiquitous (Ling & Horst 2011, Wesolowski et al. 2012). This has been a significant equaliser and its impact on equality will continue to expand as an increasing range of services becomes available via mobile phone. Alongside examples already cited around use of m-money, this extends to the development of skills via m-learning (e.g. Zolfo et al. 2010) and to the political sphere.

The spread of ICTs has seen improvements in access to government services provided online via PC and mobile (Scholl 2010), but the impact of ICTs has gone beyond this to foster greater inclusion in political processes. For example, in Uganda, mobile phones and social media (e.g. Facebook and Twitter) have been widely used for campaigning and civil activism that can draw low-income groups into political activity (CIPESA 2012). ICTs can also open up governance in other ways: improving "transparency and accountability in the delivery of social services" (World Bank 2004: 5) by allowing urban citizens to monitor public processes, and supporting the participation of citizens in urban planning decisions, for example through use of PPGIS (public participation geographic information systems) (Bugs et al. 2010). In this way, ICTs help level the playing field of political power, shifting power somewhat from traditional institutions to the community.

D3. ICTs Weakening Resilience

It is, therefore, possible to identify many ways in which ICTs are strengthening resilience in urban areas. However, the ever-greater penetration of ICTs into the lives of low-income urban communities should not be read simply as positive in resilience terms, since ICTs may also weaken resilience sub-properties. We give two brief illustrations here.

ICTs form a global digital infrastructure which encourages and enables local communities to become part of global digital networks in economic, political, social and cultural spheres. As noted above, this strengthens robustness and scale and it is not necessarily at odds with self-organisation . . . but it can be if local capacities and systems atrophy in the face of external connections. Where, for example, ICTs support global supply chains at the expense of local ones (Audirac 2005). This can create a dependency on wider connectivity that can undermine the ability to organise and act locally and independently.

All new technologies are almost inherently levers of inequality because of their uneven patterns of adoption and use: in other words that those with initially higher

resource endowments make faster, better use of new technologies thus increasing the endowment gap to those with initially lower endowments (Heeks & Kenny 2002). The picture with ICTs is not simple, with gaps closing over time: e.g. in terms of gender inequalities in access to ICTs (Brannstrom 2012). But gaps evolve – from a divide of access to an emerging gap of skills for effective use, and from a divide of older generation to an emerging gap of newer generation technologies (Heeks 2010b, van Deursen & van Dijk 2010). Thus ICTs are simultaneously strengthening and weakening aspects of equality.

E. Conclusions and Recommendations

Resilience is key to the future of low-income urban communities in developing countries. If they are not resilient, they will increasingly fail in face of the growth in external stressors, not least the expanding impact of climate change. Because this is widely-recognised, there has been ongoing interest in urban resilience for many years. Resilience-targeting actions have also been on the rise but both interest and actions are likely to have been held back by a conceptualisation of resilience to date that has simultaneously been too broad and too shallow. Debate has fragmented around multiple definitions, and has stuttered due to the lack of an all-embracing framework.

In this paper, we have developed a fairly clear but also comprehensive framework for understanding resilience as a system property, with a low-income urban community being one such system. We have further shown how this resilience framework could be used to analyse the contribution of two types of urban intervention: climate change- and digital infrastructure-related. This has had important limitations: it has been a post-hoc reinterpretation of evidence based on a relatively few cases, not all of which relate to developing country low-income urban settings. There is a consequential need for further work applying the model in greater depth and *durante hoc*. We hope, though, that the paper has shown the resilience model can work as an analytical framework, and can form the basis for evaluation of urban interventions.

Beyond this proof of concept, the paper has demonstrated the analytical flexibility of the resilience model in allowing different approaches to analysis: one emphasising depth, the other breadth. Section C showed how individual urban interventions can be assessed in terms of their relation to resilience, examining the way in which these interventions can strengthen and weaken the resilience of urban communities. Section D showed how an aggregate and cross-cutting evaluation of interventions can be undertaken from a resilience perspective, providing an overall sense of the impact on resilience of a particular strategy or suite of related interventions. Again, it was seen that interventions can both increase and decrease community resilience. The framework therefore helps understand both the pros and cons of any intervention.

But none of these approaches directly answers the "so what?" question, addressing the much more difficult issue of what new, additional insights a resilience perspective offers compared to others. This has two aspects. First, and easier to identify, understanding urban communities as systems – as shown in Figures 1 and 2 – prevents community members, practitioners, strategists and others from missing key issues, and helps them to understand how climate change and other stressors have an impact and can be responded to. This is akin to recognising the value of the sustainable livelihoods framework in development research and practice, and delivers on the ability of our model to transcend the specifics of climate change and to recognise it as one among a number of stressors and vulnerabilities.

Second, is the question of the specific contribution of resilience: the value addition in moving from Figure 1 to Figure 2, and in moving from a focus on structure and function to a focus on properties. The comprehensive nature of the framework may be of value here, nor should one dismiss the stimulus value of a novel approach and terminology. By investigating properties, a resilience approach also ensures that interventions do address the foundations, the core of what communities require in order to survive and prosper in the 21st century. So the – not yet fully-proven – potential of resilience is that it includes important aspects that other approaches may miss, and that it is better at targeting more important issues and priorities. It refocuses attention from the short-term to the long-term, and adds both breadth and depth to our planning, implementation and evaluation.

More evidence about that potential can emerge from conceptual work, applying the framework to further cases. But it may be more likely to arise from its application to practice, something which – as discussed next – will also require further work.

E1. Developments for Practice

The resilience framework already has practical uses – as exemplified in this paper – in evaluating *pre-*, *durante-* and *post-hoc* urban interventions; not merely helping to understand them but also prompting revisions that will deepen the development of community resilience. This could use either the in-depth method of Section C or the cross-cutting method of Section D. Other analytical methods are also possible: for example, Appendix A provides a template that could be used to plan interventions aiming to address specific climate threats. By identifying initiatives for each cell in a row, planners can ensure that all aspects of resilience are strengthened in response to the particular climate threat.

Further developments in use of the resilience framework to address the needs of urban communities would include moving from general markers of each resilience sub-property, to specific indicators which could be measured either using rating scales or more objectively. Urban resilience indexes do already exist – for example the Disaster Resilience Index (Cutter et al. 2010) or the Resilience Capacity Index (BRR 2013). However, both have only been applied to US cities and they rely on conventional measures largely available within the public domain. They therefore touch on some aspects of some of the resilience sub-properties such as the human and institutional capacity markers of robustness and learning, the gap marker of

equality, and perhaps some element of scale. But the major part of resilience is left untouched as the focus is largely on components and functions rather than properties. UN-HABITAT's City Resilience Profiling Programme is underway at the time of writing and seeks to bring metrics to bear on the issue of urban resilience. Details of the underlying urban systems model are relatively sketchy but again it relates to components and functions of city systems, not to properties (Lewis 2013).

There thus remains a space to create a true resilience index which recognises resilience as a property of urban communities viewed as systems. This suffers in comparison to the indexes mentioned above because of the greater distance between its requirements and currently-available data. This greater cost of data gathering can be partly mitigated by relying on rating scales, and is balanced by the greater benefit of truly measuring resilience. It could be used to create comparative radar charts of resilience, as hypothetically illustrated in Figure 4.
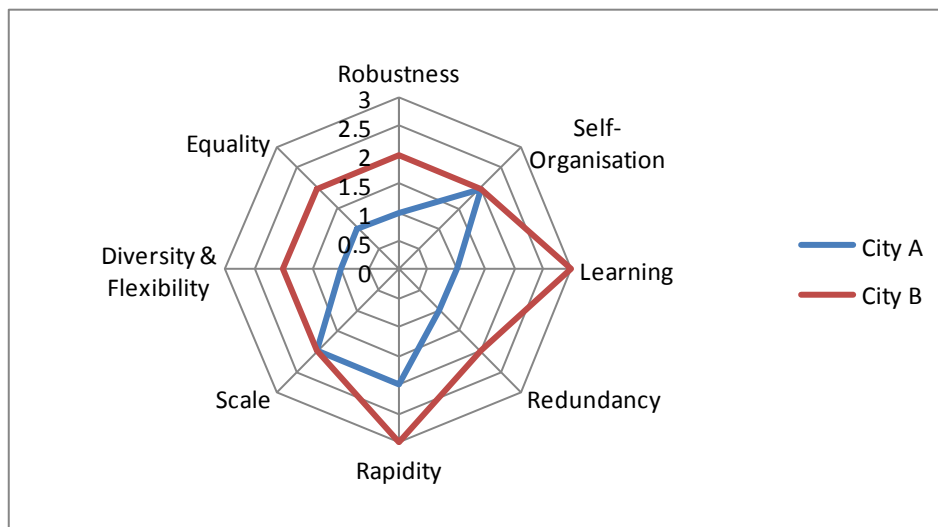
Figure 4: Sample Radar Charts of Urban Resilience

The opportunities for comparison and benchmarking mean this has much to recommend it, but it will be difficult to implement. More likely is that the framework would be used on a more community-specific basis, getting community representatives to discuss the sub-properties and their meaning, relevance, priority, etc for their particular community; integrating the framework with tested approaches such as Community Resilience Labs (Reos 2013). This and the other elements mentioned above set a future agenda for research and practice around urban resilience.

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Appendix A: Template for Planning Resilience-Enhancing Interventions to Address Particular Climate Threats

Resilience Sub-properties/ Markers:	FOUNDATIONAL Sub-Properties			ENABLING Sub-Properties				
	Robustness	Self-Organisation	Learning	Redundancy	Rapidity	Scale	Flexibility/ Diversity	Equality
Examples of Climate Change Impacts and Interventions (Short and Long Term):	• Physical Preparedness • Institutional Capacity • Multi-level Governance	• Collaboration and Participation • Social Networks • Local Leadership/Trust	• Capacity Building • New/Traditional Knowledge • Reflective Thinking	• Resource Spareness • Functional Overlaps • Resource Substitutability	• Swift Resource Access, • Assessment • Mobilisation	• Multi-level networks • Cross-level Resource Access/ Partnerships • Interactions	• Different Courses of Action/Opportunities • Adaptable Decision-making • Innovation	• Strengthened competencies/ Gap reduction • Inclusiveness • Openness and Accountability
1. Increased storm activity in coastal areas, with direct impacts on low-lying settlements, settlements on steep slopes and ravines								
ST: Improve EWS, evacuation systems, emergency distribution of food/aid for recovery, low-cost infrastructure upgrading. **LT:** Strengthen infrastructure, flood protection measures (e.g. earthen embankment, raised roads and floodwalls, sluice gates, pumping stations).								
2. Rising sea levels, with direct impacts on low-lying settlements								
ST: Sandbagging, stop-gap measures for immediate protection of vulnerable areas **LT:** Seawalls and landfills,								

upgrading of infrastructure to adapt to higher water tables, salt-water infiltration, etc. Settlement Relocation, enforcement of land use regulations.							
3. Increased temperature, with direct impacts on all urban residents							
ST/LT: Tree planting and measures to reduce urban heat island effects, raise awareness on health-related effects/ prevention. **LT:** Improve natural cooling system of construction, improve building standards for new construction, public health measures to address changing disease vectors.							
4. Increased air pollution, with direct and indirect impacts on all urban residents, specially those inhabiting areas near polluting industry/transportation							
ST: Controlling motor vehicle use, increase use of mass transit systems, control, indoor recreational facilities for extreme pollution days, raise awareness on health-related effects/prevention. **LT:** Adoption of more stringent emission standards/regulations, expansion of mass transit systems, improved							

construction/ventilation systems								
5. Reduced productivity of land, with effects on the food security of growing urban populations								
ST/LT: Adoption of urban agriculture practices, measures to address the needs of new urban migrants/rural-urban migration in appropriate parts of the city/construction designs.								
6. Increased water stress, with direct and indirect effects on urban residents								
ST/LT: Investment to improve water and sewage services, expansion of rainwater storage, wastewater reuse, water-use efficiency by recycling, economic incentives (e.g. metering, pricing) awareness raising)								