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Tomorrow's cities: a framework to assess urban resilience

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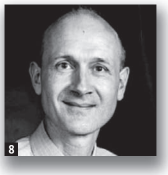
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Urbanisation is one of the great driving forces of the twenty-first century. Cities generate both productivity and creativity, and the benefits offered by high-density living and working contribute to sustainability. Cities comprise multiple components, forming both static and dynamic systems that are interconnected directly and indirectly on a number of levels. Bringing together large numbers of people within a complex system can lead to vulnerability from a wide range of hazards, threats and trends. The key to reducing this vulnerability is the identification of critical systems and determination of the implications of their failure and their interconnectivities with other systems. One emerging approach to these challenges focuses on building resilience – defined here as the degree to which a system can continue to function effectively in a changing environment. This paper puts forward a framework designed to help engineers, planners and designers to support cities in understanding the hazards, threats and trends that can make them vulnerable, and identify focus areas for building resilience into the systems, which allow it to function and prosper. Four case studies of cities whose resilience was tested by recent extreme weather events are presented, seeking to demonstrate the application of the proposed framework.

1. Introduction

In addition to urbanisation trends, which mean for the first time that more than 50% of people live in urban environments globally, the climate is changing. While both trends are being recognised and projected, the inherent uncertainty of their impacts is putting immense pressure on cities and their critical role in sustaining the lives and livelihoods of their citizens, their economies and environments (da Silva *et al.*, 2010).

For engineers, planners and designers an increasingly uncertain world presents challenges for traditional modes of predicting risk based on historical data, and reducing exposure to natural hazards by designing land use and defences to 'keep nature out'. While it is possible to make infrastructure projects themselves more durable in the face of projected changes in climate, considered en masse these investments can collectively decrease (Brown and Kernaghan, 2011) the ability of interconnected urban environments to function and meet livelihood outcomes in the face of such uncertainty.

In order to tackle these challenges at the city scale, organisations including the World Bank, Rockefeller Foundation, City of London, the C40 Cities and the Institution of Civil Engineers are increasingly shifting to resilience-based approaches, recognising the need for adaptable strategies and processes to address a multitude of uncertainties relating to climate, the economy and demography. This means finding ways to prepare for an uncertain range of hazards and threats, and increasing the ability of urban systems to cope with the resulting shocks and stresses.

Research undertaken into what makes a city resilient found that existing frameworks only consider specific trends or hazards such as climate change – for example, Tyndall Centre's integrated assessment methodology for climate change in cities (Dawson *et al.*, 2009) and the urban resilience framework (da Silva *et al.*, 2010); a specific location – for example, Thames Estuary 2100 (McBain *et al.*, 2010) and Resilient Sheffield (Arup, 2011a); or functional vulnerabilities – for example, Economy and Environment Program for Southeast Asia (EEPSEA) adaptive capacity and vulnerability frameworks (Yusuf and Francisco, 2009) and Climate Resilient Ningbo (Arup, 2011b). A new framework was needed to enable engineers, planners and designers to think about city resilience in totality, and assist with the challenge of communicating these complex issues to a wider audience.

This paper seeks to demonstrate the application of the framework through the analysis of four recent urban extreme weather events. The paper examines how the resilience of the four cities was tested, and what can be done to build resilience in these and other cities facing similar threats, hazards or trends. For clarity, the purpose of the framework is to propose an approach to building in resilience, and is not intended to be a fully developed tool.

2. The proposed framework

2.1 Defining urban resilience

Recognising that 'resilience' is an increasingly common term, but is rarely defined in context (Davoudi, 2012; O'Hare and White, 2013; Shaw, 2012; Wilkinson, 2012), the research first sought to establish a working definition of resilience in order to understand what gives rise to resilience in an urban environment.

The concept of resilience was first discussed in relation to science and engineering in the 1970s (Plodinec, 2009), with early definitions being applied to the fields of ecology, physics and psychology. While definitions differ, there are similarities across disciplines. Many refer to the ability to resist shock, the need for flexibility to absorb shocks without compromising function, or the speed with which the system can 'bounce back', that is, regain effective functionality or return to an equilibrium state if the shock has caused disruption or disturbance. Davoudi (2012) calls this 'engineering resilience'. More recent publications (Davoudi, 2012; Roberts, 2009; Shaw, 2012) advocate a definition that incorporates the ability to 'bounce forward', transform or adapt to a new stable state as more appropriate in a planning context that needs to consider complex interconnected sociospatial systems. Davoudi (2012) calls this 'ecological resilience'.

Building on a review of past work by Arup (2009), the following definition was adopted for this study

> The degree to which a system can continue to function effectively in a changing environment.

To function effectively, the city system and component systems need to have certain characteristics (Table 1), while the changing environment refers to short- and long-term change, that is, both shocks and stresses, which may be caused by a wide range of hazards, threats and trends. This definition recognises that the urban environment is intrinsically changeable and allows for the city system to transform in order to function effectively in the face of uncertainty.

Using this definition as a starting point, the research identified the following five fundamental elements that would form the basis of the proposed resilient cities framework

- systems and interconnectivity
- breaking down the system – for analysis and action
- hazards, threats and trends
- characteristics of resilience
- responses: building in resilience.

Figure 1 is a graphic representation of this approach, and highlights the necessary issues and themes that need to be considered at any stage in the cycle of planning, preparing and responding to uncertain shocks and stresses in an urban context. The key elements illustrated by Figure 1 are discussed in further detail in Sections 2.2–2.5.

2.2 Systems and interconnectivity

Cities are complex and rely on a large number of interdependent and interconnected systems. For example, a flood may affect a water supply and sanitation system, which may impact on human health, in turn increasing pressure on the healthcare system. The importance of considering the interconnectivity of systems was demonstrated by Arup's work on Resilient Sheffield (Arup, 2011a), which assessed the city's various systems to determine the implications of their failure and their interconnectivity with other systems, leading to the identification of options for building resilience. Fifteen urban systems

Characteristic	Evaluation questions
Flexibility	How can the city's processes evolve or be diversified to achieve the same goal?
Redundancy	Should one component of a system fail, is there a replacement component on standby. What are the contingencies for main components failing?
Resourcefulness	What are the alternatives should a component or whole system fail?
Responsiveness	How prepared is the community to re-organise and re-establish function?
Capacity to learn	What is the education plan to mitigate and adapt? What can a community learn from the past situations or elsewhere?

Table 1. Characteristics of resilience

were considered, as shown in Figure 2. These interconnected systems form the central wheel of the proposed framework.

2.3 Breaking down the system for analysis and action

Inspired by the five capitals model advocated by Pickett *et al.* (2004), DFID (1999), Forum for the Future (2011), Bahadur *et al.* (2010) and Pasteur (2011), plus the addition of the more recently advocated political capital (IFRC-Arup, 2011), the city system can also be broken down into six assets that must be maintained and enhanced for a city to prosper. The term 'asset' is used as it implies some value to the systems and elements included within each category. The critical systems that contribute to these assets must be resilient in order for the

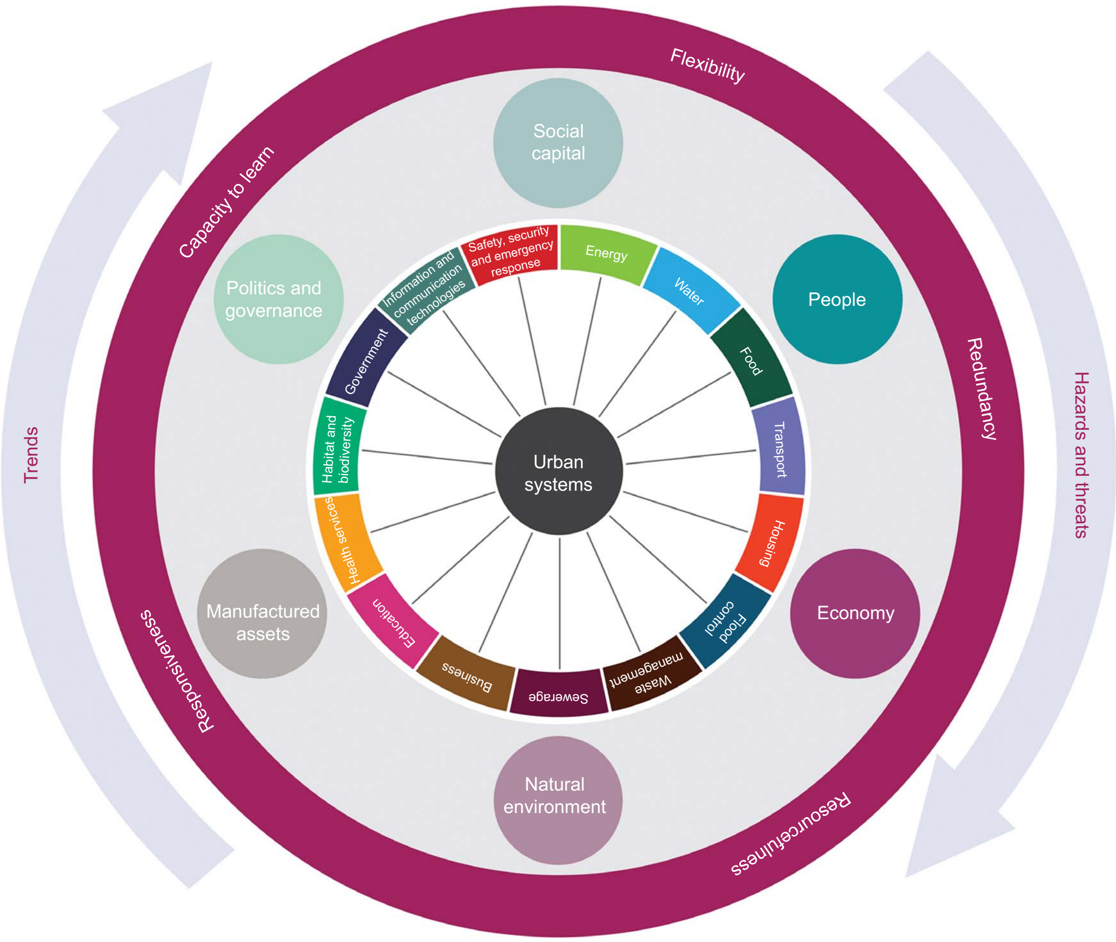

Figure 1. The proposed framework for analysing resilience in cities

Figure 2. Interconnected urban systems (from the Resilient Sheffield study, Arup (2011a))

assets to be maintained and enhanced. Table 2 lists the assets included within the proposed framework.

2.4 Hazards, threats and trends

When defining a set of possible threats and hazards to the city's systems, some are semi-predictable (e.g. seasonal monsoon), but most are uncertain by their very nature. Impacts can result from incremental change or from sudden events. Table 3 shows the categories of hazards, threats and trends to be considered, with examples.

2.5 Characteristics of resilience

The framework is designed to aid identification of the critical systems and their interconnectivity, and consider the vulnerability of these systems to changing environments, be they gradual or instantaneous. The next step is to determine the most appropriate response. In this context, the framework considers the extent to which the critical systems demonstrate five key characteristics of resilience, based on the work of Bahadur *et al.* (2010), McBain *et al.* (2010), O'Rourke (2007), McBean and Rodgers (2010), Barnett and Bai (2007) and da Silva *et al.* (2012), by asking a series of questions (Table 1).

Assets	Elements
Social capital	Community, culture, religion
People	Health and knowledge
Economy	Employment, wealth
Natural environment	Water, air, ecosystems
Manufactured assets	Housing, transport, energy
Politics and governance	Rules, regulations, political will

Table 2. Asset categories and their elements

Hazards, threats and trends	Examples
Natural	Earthquake, tsunami, typhoon
Health	Pandemic, obesity
Political and security	Terrorism, uprising, war
Economic	Local or global market instability
Demographic	Population increase, ageing population
Infrastructure	Poor sanitation, ageing infrastructure

Table 3. Examples of hazards, threats and trends

2.6 Responses: building in resilience

Having considered the characteristics of resilient urban systems, the final step is to identify suitable ways to respond, that is, specific actions to be taken to build resilience. Increasing, or building resilience into a system, will typically be addressed by one or more of three responses.

- Mitigation: The system will be affected by a particular shock or stress at a level that is able to be mitigated (e.g. a flood protection system stops any impact).
- Adaptation: The system will adapt to a particular shock or stress (e.g. the flood overwhelms the system, but the citizens are prepared and there is little impact).
- Disaster management: The system will be heavily affected by a particular shock or stress, and disaster risk management will be required (e.g. the system is overwhelmed, so disaster response measures are initiated).

In summary, by considering the systems that allow any particular city to function, the characteristics of resilient systems described above, and identifying potential hazards, threats and trends for that particular city, it is possible to identify vulnerabilities that undermine its resilience. On this basis, the proposed framework seeks to go beyond the existing work to define a high-level tool that can be used to identify priority systems and highlight key hazards, threats and trends for any particular city, and hence identify areas for building resilience.

3. Case studies

Weather-related hazards affect the greatest number of people globally, with floods alone resulting in annual losses of US$40 billion in 1998 and 2010 (Jha *et al.*, 2011), and approximately 2 billion people affected between 2000 and 2009 (da Silva, 2012). The case studies chosen to demonstrate the application of the framework are all extreme weather events that resulted in urban flooding in the past few years.

The case studies explore a number of critical system failures that contributed to the extent of the damage and highlight impacts to key assets as identified in the proposed framework. Where failures have been identified, the framework has been used to determine key areas where resilience could be built in.

The human impact of disasters in terms of loss of life and people affected is generally lower in wealthier nations but economic losses are higher in absolute terms as a result of damage to infrastructure (da Silva, 2012). Therefore, two case studies from cities in the developed world and two from cities in the developing world have been selected to allow a comparison of the different impacts and focus for building resilience under different circumstances, as described in Section 4.

3.1 Case study 1: Hurricane Sandy – impacts on New York and New Jersey

Hurricane Sandy made landfall on 29 October 2012, resulting in an estimated US$70 billion worth of damage (i.e. loss to the economy) across eight counties (Freedman, 2013). One hundred and fifty-nine lives were lost, including many who had refused to leave mandatory evacuation zones (Petrecca, 2013). The international re-insurance agency, Swiss Re, found that damage to transit infrastructure in New Jersey alone totalled US$3 billion, with an additional US$3 billion damage to waste, water and sewer systems (Freedman, 2013).

3.1.1 System failures and impacts

In the immediate aftermath of the disaster, the impact on many of the city's manufactured assets meant that communities (and hence social capital) were challenged by a lack of electricity, access to critical services and communication, water and sanitation (Figure 3). The lack of electricity in particular had significant knock-on effects from a health perspective (i.e. impacting people) with a number of hospitals and medical centres evacuated when back-up generators also failed due to flooding. Houses could not be heated, resulting in hypothermia, pneumonia and 'flu, made worse by reduced healthcare facilities to provide treatment.

While the above provides examples related to systems response and interconnectivity post-disaster, the following explores a number of key failures that hindered preparedness and response preceding the event.

The increasing reliance on mobile phones also hindered and/or prevented the evacuation of many who did not have access to a conventional landline telephone. 'Historically, the most common form of emergency notification has been reverse 911. This allows municipalities to send a pre-recorded message to a list of landlines in their community using contact information typically sourced from published telephone white pages listings' (Ellerston, 2013). This highlights the need for the emergency procedures to be modernised to fit with the current information and communication technologies systems.

One of the key issues that exacerbated the impacts of Hurricane Sandy was the failure of the New York City planning system: 'On Staten Island, developers built more than 2,700 mostly residential structures in coastal areas at extreme risk of storm surge flooding between 1980 and 2008, with the approval of city planning and zoning authorities.' (Rudolf *et al.*, 2012). This highlights longer-term challenges in politics and governance.

3.1.2 Building resilience for the future

In order to build resilience moving forward, it will be important for areas like New York and New Jersey to acquire a capacity to learn from events that occurred both in the lead-up to the storm, and in the post-disaster clean-up in order to identify and implement measures to improve resilience to similar future threats. Indeed, the NYS 2100 Commission (2013) notes that Hurricane Sandy resulted in a vastly deeper understanding of New York's current vulnerabilities and makes recommendations across various sectors. They recognise the need to build back better and smarter, quoting Governor Cuomo as saying, 'Many of these systems we know have not worked for many, many years.'

Building physical resilience through the provision of a sea barrier has been considered, but was dismissed due to prohibitively high costs (approximately US$29 billion) (Lee, 2012). This strengthens the argument that resilient responses need to go beyond engineering solutions to consider mitigation, adaptation and disaster risk management across a range of asset types. If hard engineering solutions are cost prohibitive then a broader range of solutions will need to be considered to build capacity and enhance responsiveness. As such, a key focus for these cities must be on good land-use planning, in other words ensuring these cities address redundancy and flexibility within the planning process, while protecting and enhancing the natural environment.

Overall, enhancing politics and governance in these cities is a key factor in building resilience. The NYS 2100 Commission (2013) acknowledges that 'inexpensive policy changes will be as critical as the financial investments we make' and 'improving our institutional coordination, public communication, and rapid decision making abilities will make us better able to recover from the catastrophic effects of natural disasters'.

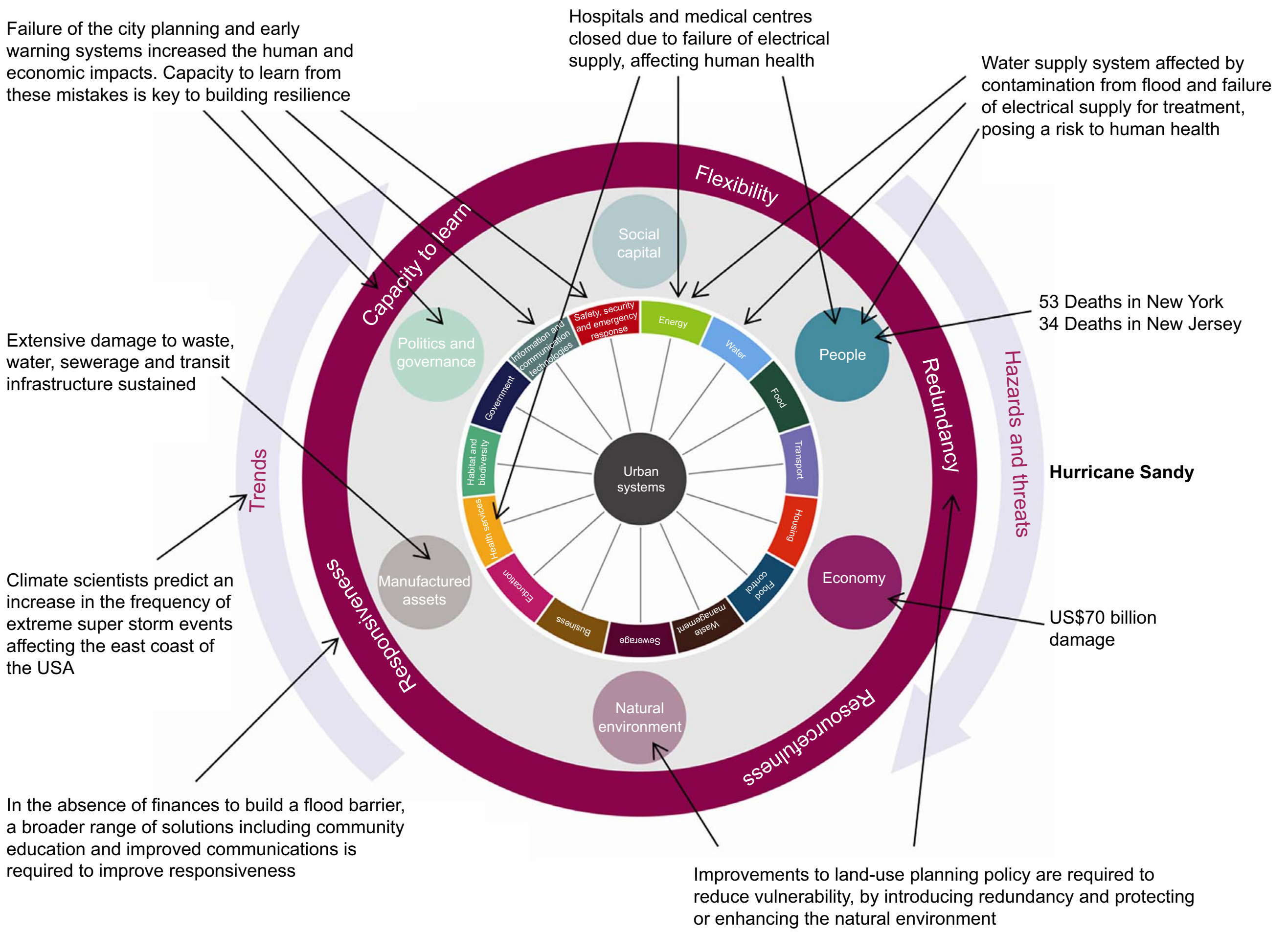

Figure 3. Hurricane Sandy: system failures, impacts and ways to build resilience

3.2 Case study 2: ex-tropical cyclone Oswald – impacts on Brisbane (Mt Crosby water treatment plant)

The city of Brisbane, in the south-east of the state of Queensland, has a population of approximately 1 million people. In late January 2013, ex-tropical cyclone Oswald passed over the Australian states of Queensland and New South Wales, causing approximately A\$2·4 billion (US\$2·3 billion) worth of damage (Steffen, 2013). As a result of flooding associated with ex-tropical cyclone Oswald close to 60 000 people faced the threat of no water due to the shutdown of the Mt Crosby water treatment plant. Seven suburbs across the city were placed on high alert, with Brisbane City Council stockpiling 40 000 one-litre bottles of water and water trucks being placed on standby in the event of the taps running dry. Water restrictions were enforced across the whole city, with residents asked to limit water to drinking, cooking, cleaning and bathing.

3.2.1 System failures and impacts

The water shortage was an unexpected consequence of heavy rainfall. With soil washed into the water supply as a result of the heavy rain, water flowing into the treatment plant registered levels of turbidity so high that the plant was no longer able to treat the incoming supply effectively (Thompson, 2013).

In terms of the impact on the city's assets, the water shortage presented a number of knock-on effects to Brisbane's people and economy (Figure 4). One major hospital suspended elective surgery and diverted major trauma cases as a result of the water shortages. The impact that the threat of water shortages had on local businesses such as childcare centres was identified in the local press (The Courier Mail, 2013a).

3.2.2 Building resilience for the future

It is important to note that this is not the first time that the Mt Crosby water treatment plant has been close to failure. In 2011

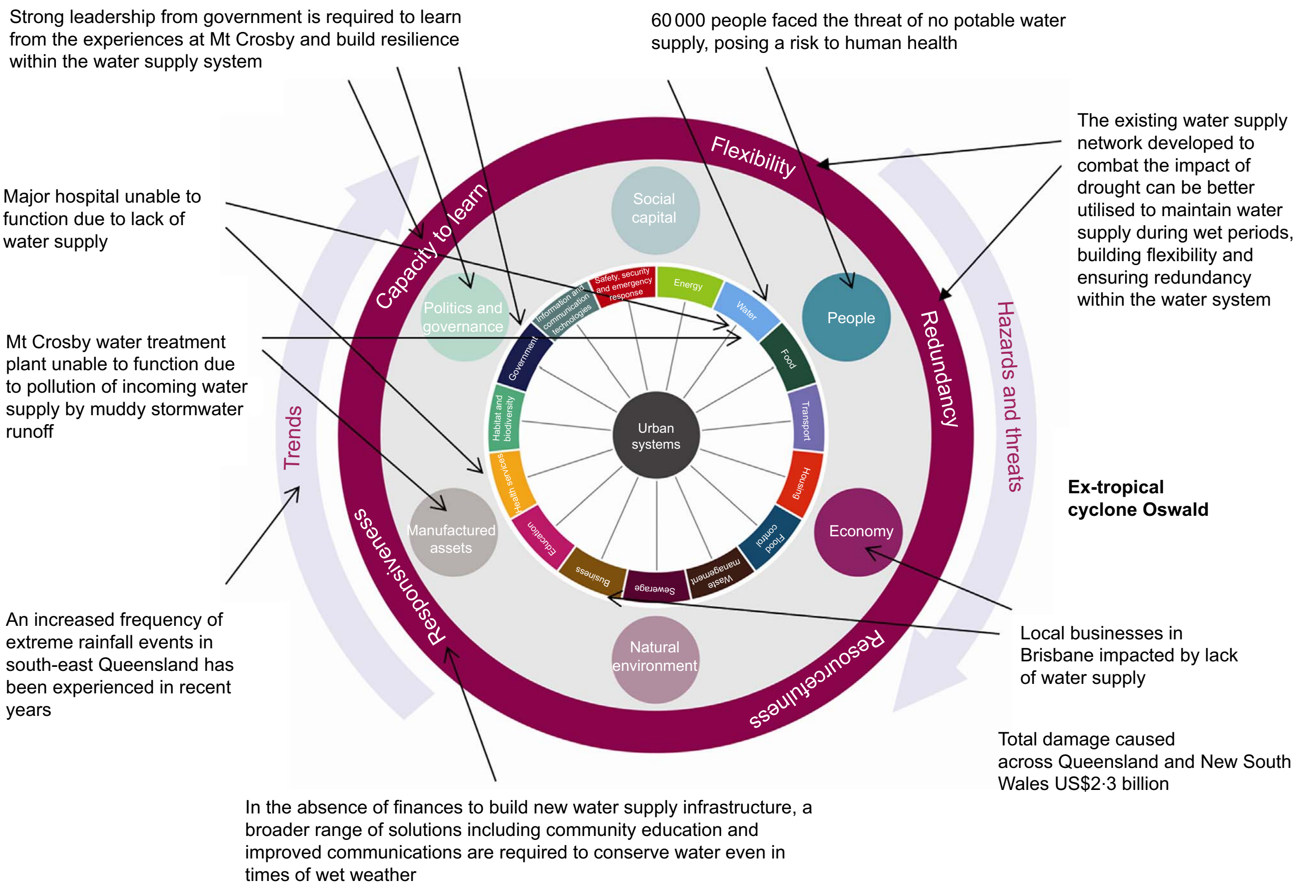

Figure 4. Ex-tropical storm Oswald: system failures, impacts and ways to build resilience

similar problems were caused due to extensive flooding across the state, and the back-up automatic control systems also failed as a result of lightning strike (Lyell, 2011). While a hard engineering solution has been deemed cost prohibitive, and the government has been slow in coming up with alternative solutions (The Courier Mail, 2013b), there are existing options that the city's officials could take to build resilience.

Although recent years have seen south-east Queensland affected by increasing occurrences of intense rainfall events, the past decade has been largely marked by a period of prolonged drought. As a result of the drought, several prevention mechanisms were developed that could be explored to help build resilience to intense rainfall events and their impact on the region's water supply. For example, a number of educational and community awareness programmes were executed to help reduce water consumption when dam levels reached critical levels. The recent bout of wet weather has seen these all but abandoned. The reintroduction of water conservation programmes across the community is one approach that may be sought and aligns well with the characteristics of a resilient approach. There is a need for community adaptation – enhancing their capacity to learn from previous events through increased awareness, education and preparedness.

Further, a 250-km-long water distribution grid has been constructed to help build drought resilience by connecting major water treatment plants including the Tugun desalination plant (Keller, 2013). Better use of this existing infrastructure (resourcefulness) related to the introduction of redundancy and flexibility within the water supply system could greatly assist in securing the region's water resilience in future, albeit this time in response to flooding.

3.3 Case study 3: Bangkok floods 2011

Thailand's worst floods in 50 years were triggered by heavy monsoon rain that began in July 2011. By the time Bangkok was hit towards the end of October 2011, more than one third of the country's provinces had been inundated. Within Thailand, these floods claimed over 800 lives and 13·6 million people were affected (Recent Natural Disasters, 2012). With an estimated US$40 billion of damages, it was also the most expensive hydrological disaster ever registered (Guha-Sapir *et al.*, 2012), and had impacts far beyond Bangkok.

3.3.1 System failures and impacts

Large areas of the northern suburbs of Bangkok were flooded, leading to factories being closed down and the loss of thousands of jobs, with impacts on the city's manufactured assets, economy and social capital (Figure 5).

Bangkok represents 41% of Thailand's gross domestic product. The cost to the city alone was US$4·65 billion. Business and global supply chains were severely affected by the factory closures: car production slowed in several countries and the price of hard drive production rose by 10% as a result of factories being overcome by the floodwaters (Thailand produces a quarter of the world's hard drives). Multinationals such as Toyota, Honda and Sony suffered significant losses: Toyota was forced to cancel overtime at its Japanese plants, Honda's North American plants had to halve production due to a shortage of parts, and Sony announced that several product launches had to be postponed. Overall, the impact on the global economy was a 2·5% slowdown in industrial production (da Silva, 2012). However, measures taken to combat the impact on the local economy allowed Thailand's automotive industry itself to bounce back the following year and regain its place as Asia's top car producer. Losses were limited by insurance and incentives made to bring in post-flood investment.

Failure of the planning system has led to a lack of balance between manufactured assets and the natural environment.

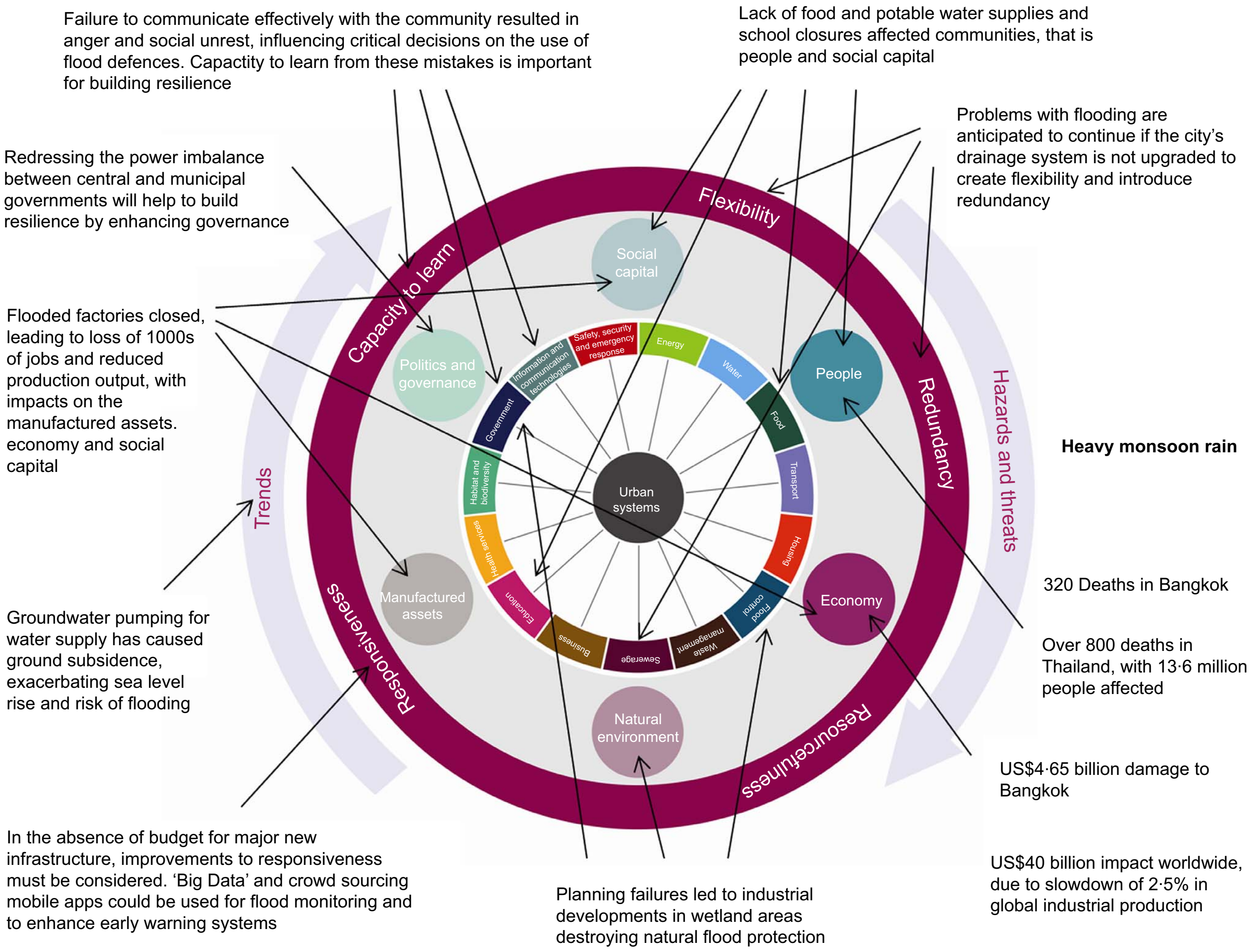

Figure 5. Bangkok floods 2011: system failures, impacts and ways to build resilience

Suburban industrial parks were developed on what used to be rice paddies and wetlands, which may have attenuated the floods hitting the city had they not been extensively developed. The Asian Development Bank advises that cities should embrace ecosystem solutions such as preserving urban wetlands and mangroves as well as improving waterways and pumping capacity (Stulz, 2012).

Bangkok's governor, who initially tried to protect the business community of central Bangkok by keeping flood barriers down, eventually bowed to residents' pressure (i.e. undermining the asset of strong politics and governance) and a sluice gate was opened in the east of the city allowing another key industrial estate to flood (Guha-Sapir *et al.*, 2012). In addition to these tensions, communities, and hence people and social capital, were affected as many schools had to postpone the start of the new term, and supplies of canned food and bottled water ran low as panic buying took hold (Guha-Sapir *et al.*, 2012).

3.3.2 Building resilience for the future

The combination of ground subsidence and projected sea level rise in Bangkok has created an outlook so bleak that one proposal that had been tabled to parliament was to relocate the capital (C40 Cities, 2011). To relocate a community is the least easily accepted course of action, one that politicians are most reluctant to contemplate, and yet in relation to coastal floods may ultimately be the only truly resilient approach.

Considering other ways to improve the existing city's resilience to flooding, according to *The Economist* (2013), with such a tight municipal budget and limited local political control, problems are likely to persevere unless sewers and critical infrastructure are upgraded, creating more flexibility and introducing redundancy into the city's drainage and flood management systems. The governor of Bangkok controls a mere US$2 billion budget handed down from central government and only one sixth of this is earmarked for capital investment (The Economist, 2013). To redress the political imbalance requires long-term leadership and a capacity to learn from past failures – for example, the mixed messages that created social unrest.

Given the lack of budget for hard engineering solutions and the cost, timescale and political difficulties associated with relocating the entire city, Bangkok also needs to look at ways to improve responsiveness for the next flooding event, building on lessons learned from the 2011 floods. Social media may well play an important part in future resilience, considered in terms of resourcefulness – for example, the United Nations (UN) funded research in Bangkok whereby a 'crowd sourcing' mobile app allows real-time flood monitoring by local people (Yeomans, 2012).

3.4 Case study 4: tropical storm Washi – impacts on Iligan City and Cagayan de Oro, Mindanao Island, Philippines

On 16 December 2011 tropical storm Washi (known locally as Sendong) hit Mindanao Island in the south of the Philippines. Overnight between 16 and 17 December 142 mm of rain fell on the island, causing the River Mandulog to burst its banks, and triggering flash floods and landslides in coastal communities. Iligan City and Cagayan de Oro were the worst affected communities, with people taking refuge from the floods on the roofs of their homes swept away as landslides demolished their houses. Over 720 000 people were affected and more than 1000 lost their lives – a major setback for social capital (Ramos, 2012).

In the aftermath of the disaster relief operation the financial cost of damages caused by the flooding was estimated at US$47 million (comprising agriculture US$7 million; infrastructure US$31 million; private properties US$9 million) – a significant impact on the economy of these developing cities. The majority of the costs were attributed to damage to manufactured capital (Figure 6) such as roads and bridges (NDRRMC, 2011).

3.4.1 System failures and impacts

In the days following the floods it was found that 31 local healthcare facilities had been damaged, with stagnant flood water. The lack of potable water and inadequate sanitation exposed the surviving population to the risk of epidemics, in particular diarrhoeal diseases.

An inquiry was quickly launched because the number of victims of the storm was much higher than would have ordinarily been expected. Among the initial findings (Lagmay, 2012) was that although the landslides were ultimately caused by the exceptionally heavy rain, legal and/or illegal logging (damage to the natural environment resulting from weak politics and governance) exacerbated the situation (Meruenas, 2011). It was also found that in spite of various advisories from local and national government, no pre-emptive evacuations occurred in the threatened coastal communities. Mindanao is rarely hit by storms, compared to other Philippine islands more frequently battered by tropical storms and typhoons. As such, cities on Mindanao were not prepared to respond.

3.4.2 Building resilience for the future

A capacity to learn from the failures that exacerbated the impacts of Washi will prove crucial in building the resilience of these cities to similar threats in the future. Indeed, this was acknowledged by President Aquino, who issued guidance to local governments through the National Disaster Risk Reduction and Management Council (NDRRMC) on how to prevent any loss of life on a similar scale in the future (Official Gazette, 2011). The measures that he outlined were to

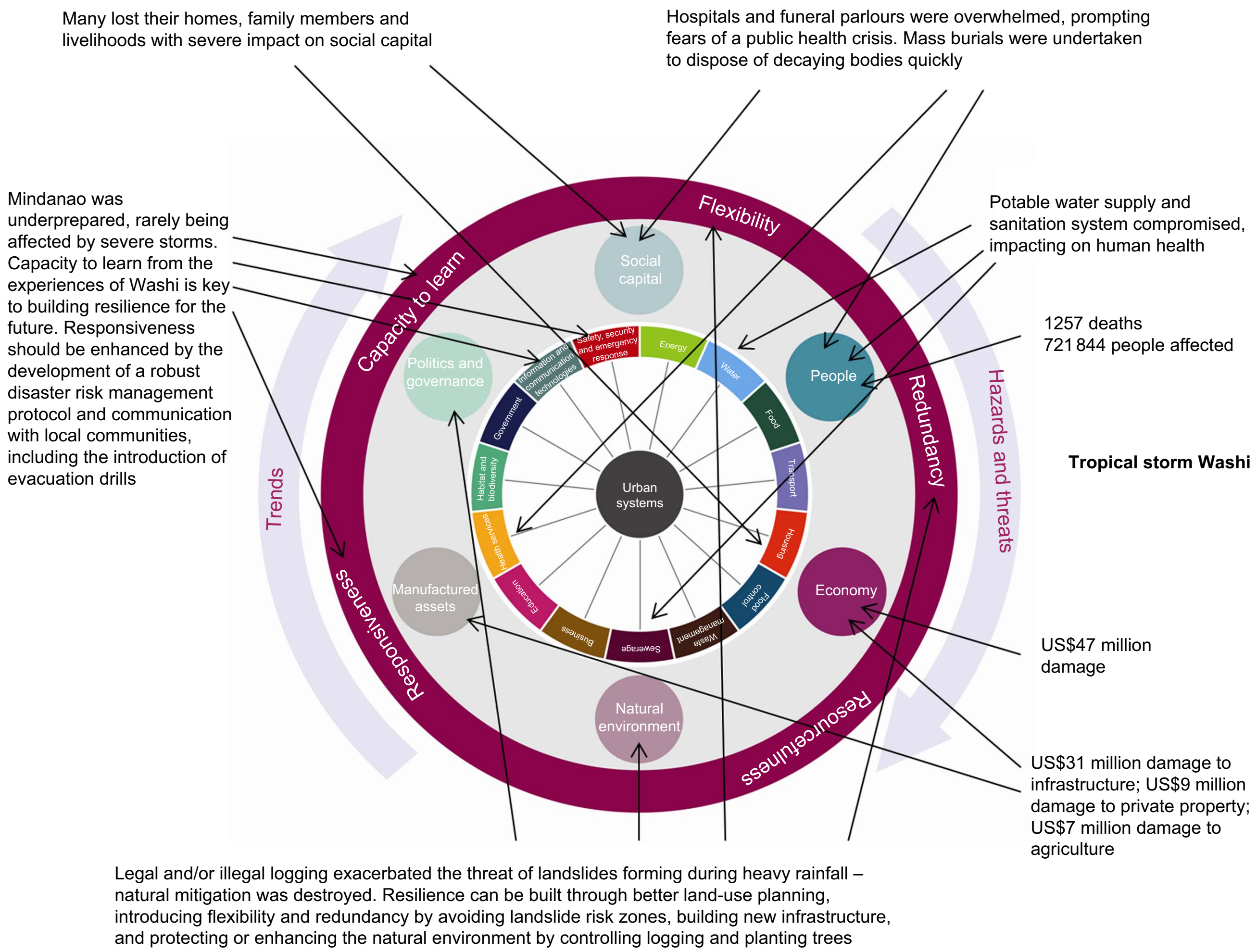

Figure 6. Tropical storm Washi: system failures, impacts and ways to build resilience

- consider long-term mitigation measures to address siltation of rivers and the impacts of mining and deforestation
- identify high-risk areas for human settlements and developments and to ensure that families living in these areas are relocated to safe habitation
- transfer military assets before the 3-day warning whenever a typhoon is expected to impact communities at risk
- review disaster management protocols to include maintenance and transportation costs of these assets
- address the need to develop a crisis manual for natural disasters
- improve the early warning system.

In addition to the recommendations of the NDRRMC, Lagmay (2012) stressed the need for effective communication of geo-hazards and for communities to know what to do when threatened by a natural hazard. He recommended that the barangays (administrative wards within the cities) organised drills for evacuations and disaster management. These suggested actions help to build in resilience by introducing redundancy and/or flexibility by better land-use planning, building new infrastructure and protection or enhancing natural infrastructure, and enhancing the responsiveness of these cities to future events.

4. Comparison of case studies

The economic impacts (economy) of Hurricane Sandy, affecting the east coast of the USA (US$70 billion), were much higher than for super storm Washi (US$47 million), impacting the island of Mindanao, Philippines. Consequences on infrastructure or manufactured capital were the most significant in both cases; however, the value of the infrastructure in monetary terms was much greater in the USA.

The economic impacts of the 2011 Bangkok floods were some of the highest on record (US$40 billion globally). This case study demonstrates the impacts of local extreme weather events on globally interconnected systems, particularly in cities like Bangkok with emerging economies whose manufacturing industries are relied upon worldwide. Events with high economic impact also have further global impact in terms of the cost to the global insurance and re-insurance markets. Resilience to extreme weather events is not just a local issue, but one faced by global systems.

All four case studies highlighted the problems of lack of finance to build resilience by investing in physical mitigation measures such as flood barriers and drainage upgrades. This demonstrates that resilient responses in both developed and developing cities need to go beyond hard engineering solutions to consider different modes of mitigation, adaptation and disaster risk management to reduce their vulnerability.

Key lessons learned from the events of Hurricane Sandy, super storm Washi and the Bangkok floods highlight the need to improve responsiveness by enhancing early warning and communication systems and the effectiveness of evacuation procedures through public education. These three case studies also highlight the importance of better planning as a mode of mitigation, demonstrating that similar mistakes in land-use planning have been made all over the world, such as building within the flood or landslide risk zones. Resilience can be built into new urban developments by learning from these mistakes (capacity to learn), and planning to protect or enhance the natural environment such as wetlands and forests, which act as flood and landslide protection – a soft 'mitigation' solution.

Finally, all four of the case studies demonstrate the importance of good politics and governance in building resilience, even in the absence of money to invest in hard engineering solutions. Governments have the power to mitigate by improving land-use planning, preventing the depletion of the natural environment and investing what finances they do have in the most appropriate measures to build resilience, which must include preparing the communities they serve to adapt and respond to threats such as those posed by extreme weather events, as per the examples presented in this paper.

5. Conclusion

Trends in urbanisation and climate change mean that the world's cities are facing unprecedented uncertainty, which has the potential to undermine their ability to sustain the lives and livelihoods of their citizens. For professionals in the built environment, this situation presents challenges to traditional practice.

This paper has proposed a framework to help engineers, planners and designers think about city resilience in its totality, and assist with the challenge of communicating these complex issues to a wider audience. The framework draws on an asset model of the city, to aid the identification of: priority city systems and their interactions and interdependencies; key threats to the resilience of any particular city; and ways to build resilience. It should be stressed that the framework is proposed as an entry point to understand the issues and begin to consider how to respond.

The framework was used to examine how the cities affected function as complex systems comprising a multitude of interconnected systems. Failure of these systems undermines the assets that allow the city to function and prosper. By examining system failures, ways of building resilience into these systems for the future were identified.

Using the proposed framework, lessons can be learned from these case studies to help other cities around the world consider how they can build resilience to a wide range of hazards, threats and trends.

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