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Urban Resilience

A Transformative Approach

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Urban Resilience

A Transformative Approach

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Preface

This book is about urban resilience—how a city survives shocks, such as natural disasters, economic downturns, infrastructure failure, and even complexity overloads. Resilience is not just about recovery. It is also about transformation—the city can redefine itself as a new entity, one which emerges better and stronger after the shock. This book is a unique collection of contributions from mathematical scientists who study general theories of resilient systems and social scientists who try to come up with better urban design in real-world situations. Both approaches are equally important, and they need to be integrated to create resilient urban systems.

Part I of the book gives an overview of the landscape of resilience in general. Resilience has been discussed in various fields such as psychology, ecology, biology, engineering systems, and organizations, to name a few. Resilience is also discussed from many different aspects, including the type of shock, the system which has to be resilient, the phase of concern, and the type of recovery. Part I gives an overview of the field of general resilience and then discusses how these aspects are translated into the urban context.

Resilience is not a static state of a system. It is a process. A city is dynamic and is always changing. Thus, it is natural to organize our book by the phases of this process. Following the well-known plan–do–check cycle in the management literature, the next three parts of the book are organized based on the three major phases of urban resilience: (1) planning, (2) responding, and (3) measuring performance and competency. Each part consists of chapters on theoretical accounts of resilience of a particular phase, followed by chapters on empirical studies on how the phase is executed in real cities.

Part II is concerned with the urban planning phase. Chapter "Urban Economics Model for Land-Use Planning" describes an urban economics model for land-use planning, which can be used for assessing the implications of different scenarios of future urban form. The remaining chapters in this part deal with cities facing specific threats.

Part III discusses the operational aspects of resilience. In particular, what are the possible strategies for responding to a shock when it happens?

Part IV deals with the issue of measuring resilience. Resilience is transformative, and in each transformation, we try to create a stronger, improved city. But first, we have to be able to measure resilience because, as Peter Drucker often quotes, “if you can’t measure it, you can’t improve it.”

This book concludes with Part V, consisting of arguments that cities are dynamic complex urban and regional systems and possible transformations codesigned through an emergent dialog approach would be essential to their sustainability, which can be defined as the capacity to solve problems they face.

The chapters are basically constructed from the papers that were presented at the Global Carbon Project (GCP) workshop held in Okinawa in 2014. Most chapters, especially in Parts II, IV, and V, have been created based on the continuing GCP discussions on the Urban and Regional Carbon Management (URCM) initiative. URCM is a place-based and policy-relevant initiative aimed at promoting sustainable, low-carbon, and climate-resilient urban development (http://www.cger.nies.go.jp/gcp/).

The other project from which this volume has arisen, *Systems Resilience*, is a multi-year, multi-disciplinary project of The Research Organization of Information and Systems, a subsidiary of the Ministry of Education, Culture, Sports, Science, and Technology of the Japanese government. The project was conceived immediately after the Great East Japan Earthquake in 2011. Its mission is to shed a scientific light on the fundamental nature of *resilience*, which can be commonly observed in many different domains such as biological, ecological, engineering and urban systems, as well as economics, and organizations. The team consists of about 20 researchers from diverse fields from biology, mathematics, computer science, cognitive science, and social science.

This book is intended for researchers and students who want to study resilience in the urban context. It is by no means comprehensive, but we tried to convey the sense of the depth and the breadth of the field. This book should also be beneficial to practitioners who want to study the latest developments in the theory and practice of urban resilience. We hope this volume stimulates discussions among people in various disciplines who are interested in making our society a better, more resilient place.

Tsukuba, Japan Yoshiki Yamagata
Chiyodaku, Japan Hiroshi Maruyama
April 2016

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Part I
Systems Resilience, A 30,000 Feet View

Taxonomy and General Strategies for Resilience

Hiroshi Maruyama

Abstract This book is devoted to the latest research results on urban resilience. Resilience thinking is not specific to cities—it has been discussed in much broader disciplines and domains in the literature. In this opening chapter, we argue that research works pursuing the common strategies of system resilience require a language that can help describe the specific contexts in which resilience is applied. We propose here taxonomy for general resilience that consists of three orthogonal dimensions, namely, type of shock, characteristic of the target system, and type of recovery. We show that despite its domain-dependency, there exist resilience strategies that cut across multiple disciplines and domains. We identified 25 such strategies and categorize them by the phase of concern in a resilience cycle and discuss which strategies are best applicable to a system with specific characteristics defined in our taxonomy.

1 Introduction

As our society grows more complex and the environments become less certain, it is increasingly difficult to make our social, economic, and ecological systems sustainable. We have to admit that there are "shocks" that may cause systems to fail, and be prepared to recover from the failure. We call the ability to withstand these shocks and recover from the failure *resilience.*

In many domains there are systems that demonstrated resilience. Long-lived companies such as Toyota and GE have managed to survive against market changes, disruptive technologies, and financial crisis. Tokyo has been devastated twice in the last 150 years, once by the Great Kanto earthquake of 1923 and the second time by the carpet-bombing during the World War II, but it still prospers as one of the world's largest cities. The biological systems on earth have many times been in danger of

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extinction over the past 4 billion years. Yet other systems were not so fortunate. Many companies, cities and communities, and species disappeared.

What are the differences between successful systems and unsuccessful systems? Are the successful ones simply lucky, or are there any fundamental characteristics that underlie their success? The goal of this chapter is to categorize different characteristics of resiliency and organize as structured knowledge for designing and operating resilient systems. Our approach is to collect cases of resilient systems in various domains, categorize them taxonomically, and extract common features and strategies from among them.

In this chapter, we first discuss the taxonomy that we have built so far in Sect. 2. Section 3 is devoted to the 25 strategies that we have identified. Section 4 reviews the rest of the book with the references to the taxonomy and strategies.

2 Taxonomy of Resilience

The concept of resilience has been known in psychology (e.g., Coutuj 2002) and ecology (e.g., Holling 1973) for a long time. More recently, the concept is applied to other areas such as engineering systems (ACM 2012), organizations (Gilbert et al. 2012), and societies (Longstaff et al. 2010). In biology, the essentially same concept is known as biological robustness (Kitano 2004). In reviewing the literature, we came up with at least three "dimensions" to categorize resilience. They are: (1) type of shock; (2) target system; and (3) type of recovery. In the following we elaborate upon them.

2.1 Type of Shock

The first dimension is the type of shock that the system has to deal with. There are several different aspects of the types of shock.

1. **Cause** (**natural or intentional**). The shock could be a natural phenomenon such as flood (Chapters "Urban Economics Model for Land-Use Planning" and "Land-Use Planning for Depopulating and Aging Society in Japan"), heatwave (Chapter "Modeling Urban Heatwave Risk in Adelaide, South Australia"), and earthquake and tsunami, or an intentional attack such as terrorism and a cyber-attack. Natural causes tend to occur randomly according to a statistical distribution and no human-control can prevent them from happening, while intentional attacks are less random because the attacker tries to take advantage of the knowledge regarding the vulnerability of the system and attack the weakest points. This distinction entails the concept of *degree of controllability*—for intentional attacks, the probability of attacks could be decreased by discouraging potential attackers to mount an attack. From the controllability point

of view, there are shocks in-between; global warming and associated natural hazard (e.g., extreme weather and sea-level rising) are an example where human decisions can affect the probability of the shock. Pandemic (Chapter "Disease Outbreaks: Critical Biological Factors and Control Strategies") is another example where better public hygiene can decrease the chance of outbreak.

2. **Frequency and magnitude**. Smaller shocks, such as motor vehicle accidents, are quite frequent and it is natural to be ready for them (e.g., by taking out insurance). Other shocks such as an earthquake of magnitude 8 are relatively rare but people may expect such an event at least once in their lifetime (e.g., in 2011 the people in Tohoku area in Japan experienced an M9 earthquake). Preparing for them is necessary but costly. There are also extremely rare events, such as a large meteor impact, comparable to the one that is considered to have caused the extinction of dinosaurs. For such extreme cases, ignoring them may be a viable option (Takeuchi 2010).
3. **Level of anticipation**. Some shocks could be predicted relatively accurately. For example, the exact timing and location of the landfall of a typhoon can be predicted two or three days in advance. Providing advanced warning and taking appropriate actions (e.g., evacuating from the coastline) are an effective countermeasure for such predictable events. Other shocks, such as large earthquakes, are less predictable (at least for their exact timing, location, and magnitude) and have to be dealt with differently.
4. **Time scale.** Some shocks are instantaneous (e.g., a lightning), while others are chronic and take a long time from start to finish (e.g., global warming and aging society).[1] For events of slow-occurrence, detecting and responding to them is a viable option.
5. **Source** (**internal or external**). Many shocks come from the outside of the system but sometimes systems collapse by themselves because of their internal complexity. For example, the financial crisis in 2008 is considered to be caused by inappropriate assumptions regarding the independence of the default probability of credits. Bak et al. (1987) showed with their famous "sand-pile model" that a system that gradually increases its complexity can collapse catastrophically. Casti argues that any ever-growing complex system is destined to a collapse (Casti 2012).

2.2 Target System

The literature in resilience deals with various systems.

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[1] Chronic shocks are sometime called *stresses* or *progressive risks* (see Chapter "Perception-based Resilience: Accounting for Human Perception in Resilience Thinking With Its Theoretic and Model Bases").

1. **Domain**. The domain can be biological systems, engineering systems such as aircraft and data centers, financial systems, legal systems (e.g., how criminal laws can effectively handle cases of new crimes that were not anticipated), organizations, and society. Cities are complex combinations of all of above; cities have natural environments with diverse biological systems, civil infrastructure that are engineering systems, economic systems, political systems, and organizational systems—thus, urban resilience can be viewed as an umbrella domain that subsumes many other domains.
2. **Granularity and System Boundary**. To understand a system we need to define a clear boundary of the system. The system can be a single individual (e.g., when we talk about a resilient person), a group of individuals of the same type (e.g., a community), or an ecosystem consisting of multiple types (species). In the urban context, city boundaries are sometimes hard to define. Administrative boundaries of a city may be defined, but the city functions may cross the boundaries.
3. **Autonomous versus Managed**. Some systems such as biological systems are autonomously resilient. Other systems (e.g., organizations) are *managed*, that is, people's decision is essential in planning and operation of the system, and if a shock occurs, in detecting, responding to, and recovering from the shock.
4. **Stakeholders and Objective Function** (**or utility**). Usually the target system has its goals. The goals can be a well-defined metric such as profit of a company. In such a case, resilience and recovery strategies are relatively easy to define. Cities have many stakeholders who have different views on the system goals. For example, some people may put higher priority on economic growth while others value well-being of the communities. Also level of *time discount,* that is, how far into the future the stakeholders are concerned with, varies among stakeholders. Some people may want their cities to prosper for centuries, while others may be concerned with the prosperity within their own life spans.

2.3 Type of Recovery

Once the damage is done, the system needs to recover. This recovery could be a full restoration of the original, or something new. Depending on the level of the changes that are made during the recovery, we identified the following three recovery types.

1. **Structural**. The system is restored to its original structure (by, for example, replacing damaged components). This is usually the case for engineering systems.
2. **Functional**. The system maintains its functionality but the structure may be different. IBM was once a hardware company but after failing to catch up with the downsizing trend of the computer industry in early 1990s they become a

software company. During this transition, though, the company's goals (e.g., making profits and creating stockholders' values) are unchanged.

3. **Transformative**. Sometimes a shock and associated damages to the system can be viewed as a unique opportunity for the system to innovate. The system can even be reborn as a completely new system with a new set of goals and objectives, while certain identities are preserved. The Japanese Empire was almost completely destroyed in 1945 but Japan as a country emerged as a new, democratic society with many of its constituents (people, land, culture, etc.) preserved. The authors of this volume call this type of recovery *transformative*, and this concept is implicitly assumed in the following chapters. In the concluding chapter, Chapter "From Resilience to Transformation via a Regenerative Sustainability Development Path", Holden, Robinson, and Sheppard extensively discuss the concept.

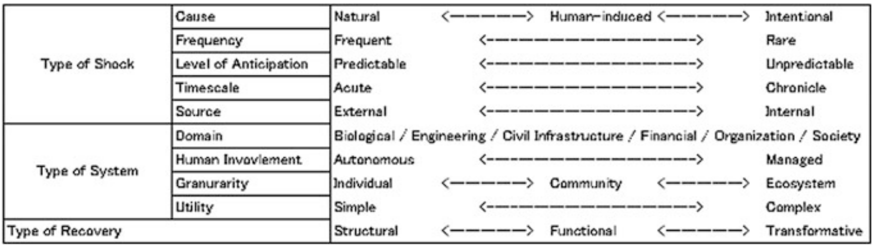
The categorization discussed above is summarized in Table 1 below. This framework of resilience will help understand various aspects of resilience and should facilitate easier communication between stakeholders of a particular system (e.g., a city) as well as between researchers in different fields.

3 Resilience Strategies

3.1 Phase of Concern

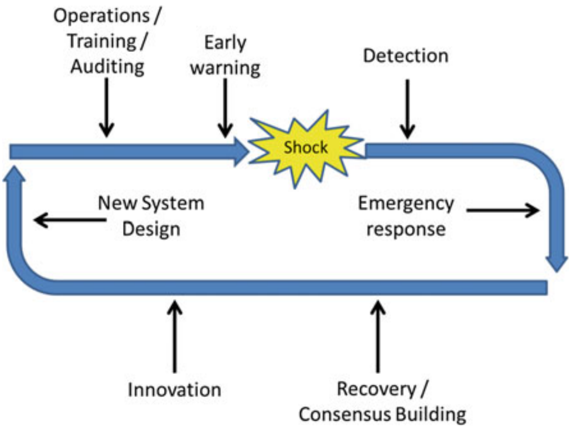
A long-surviving system experiences multiple shocks during its lifetime. Thus, resilience is often discussed in a cycle, and we use the model of resilience cycle as shown in Fig. 1. Different resilience strategies are applied to different phases of this cycle. The system is first *designed*. Some resilience strategies, such as built-in redundancy, are incorporated in this phase. Then the system is put into *operation*. Standard practices for keeping the system in a good condition, such as training and auditing, are concerned during this phase. Once a shock is anticipated, the system may go into the early warning phase where preparations for the upcoming shock are

Table 1 Resilience taxonomy



Type of Shock	Cause	Natural <------> Human-induced <------> Intentional
	Frequency	Frequent <------------------> Rare
	Level of Anticipation	Predictable <------------------> Unpredictable
	Timescale	Acute <------------------> Chronicle
	Source	External <------------------> Internal
Type of System	Domain	Biological / Engineering / Civil Infrastructure / Financial / Organization / Society
	Human Invovlement	Autonomous <------------------> Managed
	Granurarity	Individual <------> Community <------> Ecosystem
	Utility	Simple <------------------> Complex
Type of Recovery		Structural <------> Functional <------> Transformative

Fig. 1 Resilience cycle



performed. The shock needs to be detected, and the emergency response phase kicks in. Depending on the time scale of the shock, these detection and emergency response phases may happen very quickly (e.g., 72 h in disaster recovery) or may take longer. After the damage has been brought under control, the system moves into the *recovery* phase. If the system has a complex utility function, consensus on the priority of many recovery options needs to be reached. Shocks are usually thought as something undesirable. In some situations, however, shocks and associated damage to the system present a unique opportunity to *innovate* the system, which leads to a new system design for the next cycle.

3.2 Design-Time Strategies

3.2.1 Redundancy

Redundancy is a frequently-used resilience strategy seen in many domains.

Biological systems are known to have a large redundancy. For example, E. Coli has approximately 4,300 genes, each of which has its unique function, but almost 4,000 of them are known to be redundant—that is, knocking out one of them will not hamper its ability to reproduce (Baba et al. 2006). Three-spine stickleback is fresh-water fish that had lost their armor plates when they migrated to fresh water from sea water about 10,000 years ago. A sample caught in Lake Washington in 1957 had no armor plates as in Fig. 2a but more recent samples have armor plates (see Fig. 2b). One theory to explain this change is that they regained armor plates because of the predation pressure by trout whose population had increased during this period due to the increase of the water transparency in the lake. The genotype of the armor plates was dormant (and thus, redundant) during the peaceful years but became active when the necessity arose (Kitano et al. 2008).

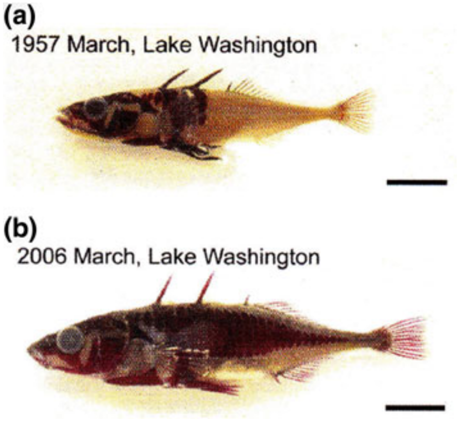


Fig. 2 Adaptation of three-spine sticklebacks. **a** Three-spine stickleback captured in 1957. **b** Three-spine stickleback captured in 2006 has armor plates

In engineering systems, it is a common strategy to have backup systems to make them more reliable. For example, mission-critical storage systems use RAID (Redundant Arrays of Inexpensive Disks) so that the system can continue to function even though one or more disks fail (Katz et al. 1988). Before The Great East Japan Earthquake on March 11th, 2011, the nuclear power had accounted for about 30 % of all the electricity supply in Japan. Within 14 months after the earthquake, every one of Japan's 50 nuclear power stations went into maintenance cycles and remained nonoperational until a few of them resumed a few months later. Although Japan has lost almost a third of its electric generation capacity, Japan has never experienced major blackout during this period. This can be attributed to the centralized and monopolized system of Japanese electric industry. One of their top priorities resides in the stable supply of electricity, and for that purpose Japanese electricity systems have had a huge excessive capacity.

The auto industry was also affected by the earthquake because their extremely complex supply chains depend on a large number of suppliers located in the Tohoku area. Despite the unprecedented scale of damage they suffered, every major auto company in Japan survived the crisis. One of the reasons of their survival was their monetary reserve that could compensate the temporary loss of the revenue. Electricity and money can be considered to be universal resource, and having extra universal resource in reserve is a good strategy for preparing unseen threats.

When the United States was attacked by the terrorists on September 11th, 2001, the police departments, the fire departments, and the secret service had difficulty in communication and coordination due to the lack of interoperability between their communication equipment. Interoperability enables one component to function as a back-up of another. Thus, interoperability is a form of redundancy in this context.

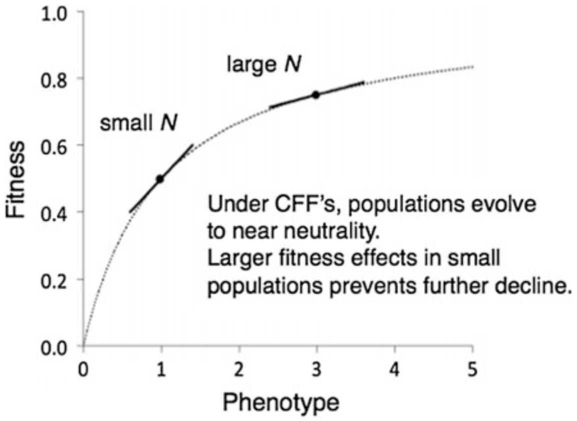
3.2.2 Diversity

Diversity seems to play the central role for biological systems to survive. The first life on earth appeared about 4 billion years ago and since then, the lives were threatened by many shocks—for example, it is estimated that the Permian Triassic extinction event that occurred 251 million years ago eliminated up to 96 % of the marine species at the time. The probable cause of this mass extinction was a sudden environmental change, possibly caused by a meteor impact. Species that were not fit against the new environment could not survive. If every species were such unfit one, no life would have survived. Because of the diversity, fortunately, some of the species were fit against the new environment and they survived.

If higher diversity entails better survivability, an interesting question here is how to increase the diversity. Or, what are intrinsic mechanisms to introduce diversity into a system? We suspect that the law of diminishing returns plays a significant role. Because of natural selection, the population of a fit species generally increases with each generation. If natural selection is the only factor to determine evolution, the fittest species would eventually dominate the entire ecosystem. Without a mechanism that penalizes such domination, the resulting ecosystem would become a very monotonic one.

A gene allele refers to alternative forms of a gene, often leading to no visible difference of phenotypes. Kimura (1968) argued that this neutrality in terms of fitness is the source of gene-level diversity of biological systems. Later Ohta (1992) discovered that pure neutrality could not explain the observations of real world data, and proposed a near-neutral theory. Akashi et al. (2012) studied the data and the mathematical models and hypothesized that a *concave fitness function* as shown in Fig. 3 could explain why we observe so many slightly deleterious mutations in nature. This concave function represents the law of diminishing returns of the cumulative advantages of alleles, because as the species gain in fitness, a contribution of each advantageous mutation to the fitness declines (Fig. 3).

Fig. 3 Concave fitness function (CFF)



Many systems, especially those that appear in the nature, seem to follow the law of diminishing return. For example, human sensitiveness to external stimulus is known to be logarithmic. On the other hand, artificial systems are often linear, and do not follow the law of diminishing returns. A prominent example is our financial system. Although the subjective value of $100 widely varies between rich and poor, the objective value, viz. goods and services one can buy by $100 remain unchanged. This leads to polarization between the rich and the poor, and may make the society more fragile.

Although there is evidence that diversity contributes to the resilience of a system, it is also a costly strategy, especially for engineering systems. The Boeing 777 aircraft has three onboard computers, each of which is designed and manufactured by different vendors. The diversity in design of these computers prevents the aircraft from crashing even if there is a design failure. However, it means that the development cost would be large.

Diversity is not necessarily good for resilience in every situation. The ecosystem of the Antarctic Ocean is known to be very simple—almost every large animal preys upon Antarctic krill, a shrimp-like organism in the sea. One of the theories explaining the lack of diversity in the Antarctic Circle is that having diversity is less advantageous in a very harsh environment. There are more chances to survive if every constituent of the system is optimized for the environment.

To the author's knowledge, there is no well agreed-upon mathematical model to explain the tradeoffs between diversity and other factors such as cost and environmental harshness. Minami et al. are building agent-based models to simulate different strategies (Minami et al. 2013). We are hoping that these simulations will give us clues as to in what situations diversity is most effective in leading to resilient systems.

3.2.3 Decentralized Resource and Management

It is a known practice to avoid a "single-point-of-failure" in reliability engineering. Distributing system resources and decision-making throughout the system eliminates any single point whose failure prevents the system to function. For example, Internet was originally designed by DARPA to withstand nuclear attacks from the former Soviet Union. Most of the Internet functions are managed by local devices such as routers and end-point computers to avoid single-points-of-failure.

3.2.4 Risk Transfer

If the statistical properties of shocks, such as frequency and distribution of expected losses, are relatively well known, having an insurance coverage is a viable option. This is considered as an example of "risk transfer" strategy in the risk management literature.

3.3 Operation-Time Strategies

3.3.1 Training

Exercising periodical training is a good way to maintain the readiness against possible shocks. Training could be either noticed (the details of the simulated shock and the response scenarios are shared by the stakeholders in advance) or unnoticed (the scenario is created by the management but not communicated to the personnel who are responding to the shock). Both forms of training are valuable—even in noticed trainings people always find places that can be improved for future shocks. Unnoticed trainings are more difficult to plan and execute, but gives even higher readiness of the persons in charge.

Inducing controlled shocks to a real system can be viewed as a special form of unnoticed training. Large data centers, such as those of Google and Amazon Web Services, have a practice called "Game Day (ACM 2012)". Once a game day is announced, no operators are allowed to take a vacation and they wait for the shock, although no details of the shock is informed to the operators. Then, the shock-inducing team induces the shock, e.g., unplugging the power cable of a server of a real production system that is providing services to customers. Of course, the overall system is designed so that it is not to be affected by such failures, but the operators need to respond to something that is not known in advance, and this gives them higher level of readiness for future events.

3.3.2 Adaptation (Management Cycle)

A system is designed according to the assumption on the environmental parameters that the system is supposed to operate in. These environmental parameters, however, change over time, and the system administrators have to adapt accordingly. This adaptation is achieved usually by a management cycle, for example, a PDCA (Plan-Do-Check-Action) cycle.

3.3.3 Efficiency/Stockpiling Resources

When a shock occurs, the system likely runs at a lower performance than normal. This means that the system may depend on its own resources in reserve. The more resources in the reserve, the longer the system can survive before regaining the normal operating performance. Running at a higher efficiency in normal operations and stockpiling more resources while in normal operation helps this.

3.3.4 Controlling Human-Induces Causes

If the shock is human-induced, suppressing the cause is another option. Reducing greenhouse gas emission to decrease the risk of global warming is an example. If the shock is an intentional attack, deterrence strategies such as demonstrating the ability of counterattack is also a viable option.

3.4 Early-Warning-Time Strategies

3.4.1 Prediction

Accurate anticipation of large rare events is extremely hard, and it generally requires a lot of intelligence and computation. There are three different approaches to anticipation; prediction, scenario planning, and simulation.

Silver (2013) extensively discussed why predictions are so difficult. Some predictions, such as weather forecast, can be done solely based on the past statistical data, but the best predictions are usually based on combinations of a large amount of high-quality data on the past phenomena and the wisdom of human experts in the domain. More generally, Scheffer et al. (2009) suggested that for any dynamical systems there could be early-warning signals that indicate the system is near a tipping point.

3.4.2 Early Action

If we anticipate a large-scale event, we can prepare for it. WHO defines six phrases of pandemic alert. When avian flue H5N1 pandemic was a major threat in 2009, the global society at large responded based on the phase 4–6 declarations by WHO. As another example, Japan Meteorological Agency issues warnings on large-scale natural events such as typhoons, volcanic activities, and tsunami.

3.5 Emergency-Response-Time Strategies

3.5.1 Detection

A shock needs to be detected before it is responded to. Detection is critical in two situations. One is that there is a time window to react within which timely responses would minimize potential damages. When 2011 earthquake happened, the detection sensors located at the coast lines by East Japan Railway Company could successfully lowered the speed of all the Shinkansen trains running at the time before the main ground waves of the earthquake reached to the railway tracks. No casualties or injuries were reported.

The other is when detection is hard, especially when an adversary deliberately conceals an attack. In the Carbanak cyber-attack on financial institutions in 2014, there is evidence indicating that in most cases the network was compromised for between two to four months, during which the total financial losses are estimated as high as 1 billion US dollars across 100 financial institutions.[2]

3.5.2 Situational Awareness and Damage Control

When a shock is detected, the first things to do are to collect information from various sources and draw a picture of what is happening. If the damages are still expanding, and they are often so, they need to be controlled.

Modern systems are very complex and their parts are interconnected. This means that damage inflicted to one part of the system may spread over to other healthy parts of the system unless the damages are properly controlled. A common technique for damage control is *isolation*. For example, if a datacenter manager detects computer virus activities in one machine, he/she may decide to disconnect the machine from the rest of the network, even if this means disruption of running services. When a carrier of new influenza that may potentially cause a large pandemic is discovered, governments may decide to shutdown land and air traffic in order to preventing rapid spread of the virus.

Another form of isolation that is called *retarding* is to reduce the speed or the bandwidth of interactions instead of completely shutting them down. This strategy buys precious time to react if the speed of damage spreading is too fast. Retarding may be effective especially system components are connected via digital network.

3.5.3 Policy Switching

Nasim Taleb discussed in his book *Black Swan* (2007) that common statistics based on Gaussian distribution, mean values, and standard deviations etc. do not work for extreme events because these extreme events do not follow the familiar probability distributions. Many extreme events, such as earthquakes, are known to follow a power-law distribution, and depending on the parameter, a power-law distribution may not have a finite average value or a finite standard deviation. This means that we cannot rely on insurance because insurance is based on the estimated average loss across multiple incidents.

A similar discussion goes to how high the sea walls must have been to prevent the damage caused by the 2011 tsunami. The Fukushima nuclear power plant disaster could have been prevented if the sea wall were 15 m high instead of 5.7 m.

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[2] See https://securelist.com/files/2015/02/Carbanak_APT_eng.pdf.

However, in the record the Meiji Sanriku Tsunami reached as high as 40 m in some places. It is not practical to build such a high sea wall.

Statistician Takeuchi (2010) argued that, for such extreme and rare events, it would be better to ignore these risks in the normal life. If you are lucky, you will never be a victim of such a disaster in your lifetime. You can live a happy life without too much worrying about the worst. On the other hand, if such a disaster does happen, the society has to change its mode and get ready to help each other. Under these extreme circumstances, the social norm has to inevitably change, and the people need to accept the reality and try to recover.

We call this concept *mode switching*. In the normal mode, the system works within the designed realm and the system follows the designed set of policy, for example, pursuing maximum economic efficiency. If an extreme event happens and the system can no longer function as designed, the system switches its operational mode to the emergency mode, in which the system and the people behave based on a different set of policies (e.g., helping others). Maruyama et al. (2013) discussed the mode switching concept in the context of security policy in cace of emergency.

3.5.4 Empowerment of Field Personnel

It is said that “No Battle Plan Survives Contact With the Enemy”. When an emergency situation occurs, often prepared procedures do not work as they are planned. Thus, the field personnel dealing with the situation are forced to improvise. ISO 22320, which describes the best practices for incident responses, state that “structures and processes should permit operational decisions to be taken at the lowest possible level, and coordination and support offered from the highest necessary level (2011)”.

3.6 Recovery-Time Strategies

3.6.1 Optimization of Resource Allocation

When a disaster occurs, often relief goods are not delivered to victims who need them. This is in part due to lack of effective information sharing (disaster relief force has little or wrong information on the needs). Because relief resources (water, food, energy, and personnel) are limited, there should be some coordination of relief activities. One example of helping coordination of resouce allocation is Sahana,[3] an open source software dedicated to disaster management.

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[3] http://sahanafoundation.org/about-us/.

3.6.2 Altruism

There empirical evidences that in disaster situations people tend to be less selfish and try to help others. The Panel Data Research Center at Keio University conducted a survey on tendency of people before and after the Great East Japan Earthquake and reported that 35 % of the respondents reported that their altruistic tendency had been increased after the earthquake while 5 % reported a decrease. From the theoretical point of view, Nowark (2006) argued that in fact natural selection can lead to cooperation.

3.6.3 Boundary Expansion

Even when a system is permanently damaged, if we enlarge our scope to the enclosing system that includes the damaged system as its subsystem, we may be able to achieve resilience of the larger system. In February, 2015, our project hosted a Shonan Meeting, a Dagstuhl-style intensive workshop attended by invited experts, titled “Systems Resilience—Bridging the Gap between Social and Mathematical[4]”. During this meeting, different forms of this “boundary leak” idea appeared in multiple different contexts and were extensively discussed. This suggests that we may have to be flexible in terms of the system boundary, and should always be ready for the fallback plan, that is, to save the larger system in case some subsystems cannot be saved. It was also suggested that these resilience plans have to be prepared at all the levels of potential system boundaries.

3.7 Innovation-Time Strategies

3.7.1 Archiving and Postmortem

If a large shock occurs, it is rare that the system can handled it flawlessly. In many cases there are rooms for improvement. If the system goes back to exactly the same configuration after recovery, it will suffer the same or similar damage when the next shock of the same type happens. To prevent this, the system needs to be improved. At least, the system should be prepared similar shocks, and respond and recover better. Thus, it is important to record the facts; what exactly happened, what the responses were, what the rationale behind decisions were, and what went well and what went wrong. National Diet Library hosts the National Diet Library Great East Japan Earthquake Archive[5] which is the central portal for recording all the

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[4] The report of this workshop is here. http://shonan.nii.ac.jp/shonan/wp-content/uploads/2011/09/No.2015-32.pdf.

[5] http://kn.ndl.go.jp/.

information related to the earthquake. There are a number of studies on analyzing this huge body of data for making future societies more resilient.

3.7.2 R&D Investment

Japanese government's the 4th Science and Technology Basic Plan that had been originally planned to be defined before the 4th term (FY2011-2015) starts, but it was revisited to reflect the fact that the Grate East Japan Earthquake happened and the revised plan puts a high priority on R&D investment on disaster recovery and prevention.

3.7.3 Consensus Building

How to recover from the shock usually requires consensus building among stake holders. After the 2011 earthquake and tsunami, Miyagi prefecture, the largest prefecture in the Tohoku area decided to rebuild a stronger industry base in the damaged area, whereas the people in Iwate prefecture, whose main industry is agriculture and fishery, decided to focus more on wellness of the residents than its economical success. In general, a large perturbation may present an opportunity to scrap and re-build the system from scratch. But first we have to identify the stakeholders and ask for their consensus.

3.8 Meta Strategies

So far we have discussed various resilience strategies. Not all strategies are effective on every resilience context. Some strategies work better than others depending on the situation. We are developing a matrix as shown in Table 2 that helps us to identify effective strategies for given situations.

In general there are tradeoffs among the strategies we discussed. The available resource (e.g., budget) is limited. Should we invest our resource on redundancy, diversity, adaptability, or plans for recovery? Investing too much on redundancy by having n-way backup systems may delay the system update cycle and thus may hamper the adaptability for the business environment. What combination of resilience strategies is optimum under a given condition is one of the questions that we would like to answer in our future efforts.

Table 2 Taxonomy-strategy matrix

Resilience Strategy				Increased Margin	Backup	Interoperability / Modularity	Diversity Control by Index	Portfolio Management	Diminishing Return	Distributed / Decentralized System	Risk Transfer / Insurance	Training	Controlled Shocks	Management Cycles	Maximizing Efficiency	Control Human-Induced Causes	Prediction of Shocks	Early Warning Systems	Situational Awareness	Damage Control	Policy Switch	Empowerment of Field Personnel	Optimization of Resources	Altruism	Boundary Expantion	Postmotem	R&D Investment	Consensus Building
Phase in Resilience Cycle				Redundancy			Diversity																					
				Design Time								Normal Operation					Early Warning		Emergency				Recovery			Innovation		
Resilience Taxonomy	Type of Shock	Natural vs Intentional	Natural Disaster	◎						◎		◎						○	◎	◎	◎	◎	◎	◎	◎		○	◎
			Human-Induced	○						○			○	◎		◎	◎	◎	◎	◎			○		○	◎	○	○
			Intentional Attack			○	○			○		○	◎			◎		◎	◎	◎				–		○		
		Frequency	Often	◎	◎	○					◎	○		◎	◎				◎	○	○					○		
			Low Frequency	○	○	◎	○	○	○	○		◎	○					○	◎	○		○	○	○	○		○	○
			Rare				◎	◎	◎	◎			◎						◎	○					◎		◎	◎
		Predictability	Predictable									○					◎	◎	◎	◎	◎							
			Unpredictable	◎	◎				◎								–	–	◎	◎	○							
		Duration	Accute									○							◎	◎	○					○		
			Chronicle											◎		◎		◎	◎	○	–		○				○	
		Internality	External Cause							○		○	○						◎	○	○	○		○				
			Internal Cause										◎	◎		◎			◎	○						○	○	
	Target System	Domain	Biological / Ecological						◎				◎	–					–	–	–							—
			Engineering	◎	◎	◎		○		◎	○	◎					○	○	◎	◎	◎		○				○	
			Civil Infrastructure	◎	◎			○		◎		◎		○	◎				◎	◎	○	○	○				○	
			Financial					◎		○					◎				◎	◎								
			Organizational				◎				○	○	○	◎	◎	○			◎	◎	◎	◎	◎		○			
			Societal						○			◎			○	◎			◎	◎	○	×	○	◎	◎			◎
		Autonomy	Autonomous		○				◎	○									◎	◎								
			Managed				◎					○	○	◎	○	○		○	◎	◎	◎	○	○				○	
		Granularity	Invidiual																◎	○								
			Group of Same Type									○	○	○	○	○			◎	○	◎	◎		◎	○			
			Ecosystem				◎					○	○	○		○			◎	○	○	○		○	◎			◎
		Objective Function	Simple								○			○	◎	○			◎	○	◎	◎	◎				○	
			Complex											○		○			◎	○	○	○		◎	◎			◎
	Recovery Type		Structural	◎	◎	◎				◎									◎	○	○	○	◎			○		—
			Functional			◎	◎	◎		◎									◎	○	○	○	◎			○	○	
			Adaptive				◎	◎	◎										○	○		○		◎	◎	○	○	◎

In the table, ◎ indicates the strategy strongly applicable to the type, while ○ is relevant dependent on the context and a dash is for that the strategy does not work for the situation. No mark means it is neutral

4 Resilience Taxonomy and Strategy in Urban Context

How the taxonomy and the catalogue of general strategies apply in the urban resilience context? Here, we briefly review the following chapters by making references to the taxonomy and strategies identified above. Chapter "Urban Economics Model for Land-Use Planning" by Yamagata addresses flood risks (which may be indirectly caused by global warming) in the Tokyo Metropolitan area. His strategy for resilience is to reduce exposures (estimated losses) by means of land-use planning that combines economic benefit. Murakami, Benger, and Yamagata discuss in Chapter "Modeling Urban Heatwave Risk in Adelaide, South Australia" focus on heatwave risks, particularly on elderly population (vulnerability) in Adelaide, Australia. Their mitigation strategy is also exposure reduction via land-use planning, in this case, by "greening," such as providing forest, parks, and water mass. Chapter "Flood Risk Management in Cities" by Murakami is again on flood risks, countermeasure being also exposure reduction but in this case it is done by encouraging people to move less hazardous areas, through carefully manipulating land prices. Murayama's chapter, Chapter "Land Use Planning for Depopulating and Aging Society in Japan", studies different situations in three cities (Yokosuka, Shizuoka, and Suzuka, all in Japan) against different types of shocks, including long-lasting stresses such as depopulation and aging society, and natural hazards such as earthquake and tsunami. His approach exemplifies a combination of multiple strategies, such as keeping high community efficiency, reducing exposures to natural hazards, and focusing on the well-being of stakeholders.

While Part I of the book focuses mainly on strategies on planning, much of the discussions in Part II are around how to respond to shocks. Chapter "Resilient Community Clustering: A Graph Theoretical Approach" by Legaspi, et al. studies how people responds to shocks. They claim that people's perception, and in relation to it altruism, is critical for damage control and recovery, by examining a case study on Thai flood in 2011. Minami and Tanjo discuss one particular strategy in damage control, namely, isolation, and proposes an efficient algorithm to partition an electrical grid when a disaster occurs. Chapter "Disease Outbreaks: Critical Biological Factors and Control Strategies" by Matsumoto, Kawashima, and Akashi deals with a potentially very high-stake hazard, pandemics, with reviews on its history, theories, and countermeasures including detecting, isolating, and forensics and future R&D investments.

5 Summary

We have to build resilience into the design of our economical, engineering, organizational, and societal systems in order for us to be sustainable. As a first step towards the science of resilience, we categorized various resilience concepts according to three dimensions. Then, we presented 25 general resilience strategies and related them to the taxonomy. We hope that this chapter gives you a useful roadmap for the readers to navigate in the book.

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Part II
Planning Urban Resilience

Urban Economics Model for Land-Use Planning

Yoshiki Yamagata, Hajime Seya and Daisuke Murakami

Abstract This chapter introduces our newly developed Spatially explicit Urban Land-use Model (SULM) as a tool for resilient urban planning. The SULM can create land-use and social economic scenarios at micro districts level based on an urban economic theory. In order to co-design transformative urban plans with local stake holders, it is important to visualize possible future land-use scenarios. This model makes it possible to endogenously project the residential choice of households, floor space and land area with considering location-specific disaster risk as well as economic and environmental factors. With this model, we can create scenarios for not only urban growth, but also urban shrinking, thus the method could be useful for both developing and developed countries' situations. In this study, the model was developed and calibrated for the Tokyo Metropolitan Area (Greater Tokyo) at the micro-district level (around 1 km grid) and used to simulate possible land-use scenarios with different urban forms. We have specifically looked at the implications for climate change mitigation and adaptation capacities. This chapter explains mainly the tested three land-use scenarios; (1) Business as usual scenario, (2) Extreme urban compact city scenario, and (3) Combined mitigation and adaptation scenario. The scenarios were assessed with multiple criteria including disaster/energy resilience and environmental sustainability (CO_2 emissions, urban climate) and economic benefits. The obtained results have shown that fairly large future economic costs could be saved by additionally considering adaptation (flood risk) in combination with mitigation (CO_2 emissions) in the scenario that we call "Wise Shrinking". Our research suggests that integration of resilience thinking into urban planning is important and promising.

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Keywords Spatially explicit model · Land use · Urban form · Mitigation and adaptation · Synergy and trade-off

1 Introduction

One of the most important agendas that urban planners are facing in the coming decades is to establish new designs that actually improve the sustainability and resilience of cities responding to known and unknown risks. To support such planning, researchers can create possible future urban land-use scenarios. Then, in the process of co-designing with the local stakeholders, the scenarios can be evaluated in terms of environmental sustainability and human welfare. Such land-use scenarios may also help local policy makers to come up with effective urban policies (land use, transport, energy etc.) which would improve the urban sustainability and resilience.

Various attempts have been made in this direction (Al-Kodmany 1999; Nicholson-Cole 2005) considering natural hazard risks (Buchecker et al. 2013) and local climate change impacts (Schroth et al. 2015; Murakami et al. 2016). Especially, recent literature highlights the importance of considering trade-offs and co-benefits of climate change mitigation and adaptation measures (Larsen et al. 2012; Landauer et al. 2015). However, there are very few studies that have creates and tested landuse scenarios at the local level.

We have succeeded in creating a new model by employing the micro-economic urban modeling approach. The newly developed model is called Spatially explicit Urban Land-use Model (SULM) and it has been applied to several case studies in Tokyo Metropolitan area. This Greater Tokyo area is the largest mega-city in the world and the population in the area is 37 million and still growing though the whole national population has been decreasing since 2009.

In our series of case studies, we have been paying attention mainly to the implications of different spatial urban forms such as Compact and dispersed city scenarios. Using the model, we have simulated different urban forms incorporating expected changes from the current land use by different urban policies that influence residential locations. Actually, we have assumed several land-use and transport incentive policies that would induce substantial agglomeration or suburbanization. The created land-use scenarios with different urban forms were then tested against different sustainability and resilience criteria (Yamagata et al. 2013, 2015a; Yamagata and Seya 2013; Nakamichi et al. 2013; Adachi et al. 2014).

Yamagata et al. (2013) described the basic model structure and analyzed the implications of new land uses such as re-vegetation at the created open spaces in the Compact city scenario by comparing them with those of heavy suburbanization in the Dispersion scenario. Also, Yamagata and Seya (2013) simulated the distribution of spatial energy demand for Greater Tokyo in the future under Business As Usual (BAU) and Compact city scenario. In fact, Japanese urban planning has been actually shifted towards Compact city scenario due to “the Act on Special Measures Concerning Urban Renaissance”.

Nakamichi et al. (2013) focused on the implications of combining urban forms and technological changes by considering the wide deployment of Electric Vehicles (EV) and Photovoltaic Panels (PV), and simulated the impacts on CO_2 emissions from the residential sector. Adachi et al. (2014) simulated urban form impacts on urban climate using high resolution climate simulations with our land-use scenarios as their boundary condition. The results have shown that the re-vegetation in the Compact city scenario has a significant impact to mitigate the heat island effect and has a lot of adaptation values.

Especially, since the Great Tohoku Earthquake in 2011, we have been exploring effective ways to integrate different sustainability criteria from the resilience point of view in assessing a variety of urban forms. At this stage, our new integrated approach was not yet completely established, however in this chapter, we will elaborate our original urban design concept called “Wise shrinking”. This is a kind of extension of the Compact city scenario. The additional power of the “Wise shrinking” scenario manifested itself in constraining compaction which occurs only at places avoiding risk susceptible areas. Our analysis also has shown that the “Wise shrinking” concept could be successfully implemented as recently advocated “climate resilient” development where both climate mitigation and adaptation strategies are simultaneously achieved (Yamagata et al. 2013).

Our urban form scenarios and their assessment tool is supposed to be able to help urban planners. When they design compact urban plans in connection with climate policy, they can effectively combine Compact city (mitigation) policy and flooding risk management (adaptation) policy. Namely, by carefully considering the possible co-benefits and trade-offs between mitigation and adaptation strategies, climate resilient urban design would be achieved by “Wise shrinking”. In this chapter, we demonstrate such a possibility by modeling spatial complexity at the district level through actual case studies in Tokyo.

Firstly, we explain three land-use scenarios that have created and tested; (1) BAU scenario, (2) Compact city scenario (mitigation), and (3) “Wise shrinking” scenario which combines Compact city scenario and Resilience (adaptation) scenario that avoids flood risk areas for urban compaction. The results showed that the “Wise shrinking” scenario can additionally achieve a large economic benefit in achieving Compact city by inducing people to move to areas with less flooding risk. Then, the expected future damages due to floods can be decreased. In addition, we can also expect economic agglomeration effects from the newly created high density office and residential area in the Compact city scenario. In that case, the integration of climate change adaptation policy into Compact city policy could be implemented by financing the cost by the future revenue (mitigation of cost). If successfully managed, even during the process of shrinking, economic growth could be induced and the policy cost such as incentives could be compensated financially.

So, the “Wise shrinking” policy has a good economic rationale as a policy tool in aging societies with declining population like Japan. However, even though the “Wise shrinking” policy is beneficial to society in the long-run, there remains the difficulty that policy makers as well as local people, who would not like to change or move, usually find it difficult to support such policy, because it requires relatively large political and economic costs at the beginning. This is another reason why we call it "Wise shrinking" in the sense that we need to be wise enough to find a way to overcome the barrier. On the other hand, once actually implemented, the "Wise shrinking" scenario could improve urban resilience not only against flooding but also against all kinds of extreme events such as heatwaves. Furthermore, to illustrate a wide range of effectiveness, we also assess the scenarios in terms of various additional resilience criteria including energy, ecosystem and human well-being.

In fact, the Compact city scenario reduces the number of detached houses in the suburbs, so if the re-created open lands are vegetated, it would contribute to absorbing CO_2 and mitigating urban heat-island effect as well. The open space could also be used for mega-solar deployments which have a large potential to make the electricity production low-carbon and improve energy resilience in case of disasters. These varieties of urban form implications clearly demonstrate the importance of assessing both sustainability and resilience using indicators in the urban planning. The methods described in this chapter have been also applied and further discussed in the following Chaps. Modeling Urban Heatwave Risk in Adelaide, South Australia, Flood Risk Management in Cities and Land-Use Planning for Depopulating and Aging Society in Japan.

2 Model Structure

Following Yamagata et al. (2013), we explain about our model structure. The structure of our model is similar to the work by Ueda et al. (1995). It was originally inspired from the model by Anas (1982, 1984) and additionally implemented for the Japanese real estate market situation in which land and buildings are traded separately. The structure of our model is represented in Fig. 1. The model describes the behaviors of the three model agents; households, developers, and landlords, using variables such as spatial distribution of households, land rent, building rent, land demand and supply, building floor demand and supply. In this model, we excluded firm or business agents because it is difficult to model the choice behavior of firm location with high accuracy at the micro zone level. The model development is an ongoing project, at the moment, we also excluded transportation from the model because of data unavailability.

The major assumptions of our model are summarized as follows: (1) There exists a spatial economy whose coverage is divided into zones. (2) The society is composed of three types of agents: households, developers, and absentee landlords. The behavior of each agent is formulated on the basis of microeconomic principles, that is, utility maximization by the households and profit maximization by the developers and the absentee landlords. (3) The households are divided into seven categories shown in Table 1. (4) The total number of households (or population) in the metropolitan area is given (closed city). (5) The households choose their locations in accordance with indirect (maximized) utility and zone-specific attributes. (6) There is one residential land market and residential floor (building) market in each zone. These markets reach equilibrium simultaneously.

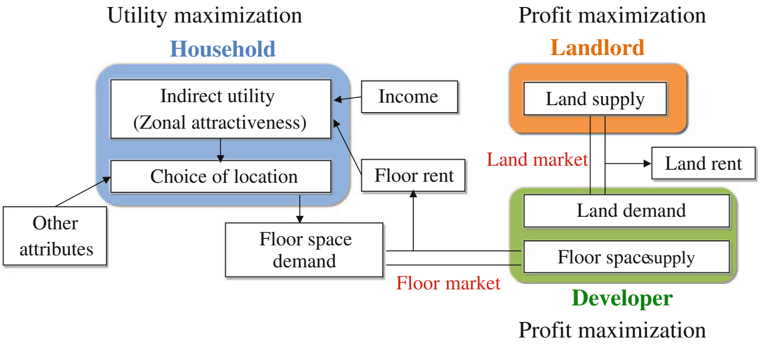

Fig. 1 The structure of SULM

Table 1 Household family type

Household family type
a. One-person households (65 years of age or over)
b. One-person households (under 65 years of age)
c. Married couple only (either of them 65 years of age or over)
d. Married couple only (both under 65 years of age)
e. Married couple with child(ren)
f. Single parent with child(ren)
g. Other type

The model can output a set of variables which describe a real urban economy such as distribution of locators (households), distribution of land rent and building floor rent, land and building floor area, etc. Also, the model can naturally deal with not only urban growth, but also urban shrinkage, which is becoming an important issue for developed countries confronting population decrease. Land-use equilibrium models are typically constructed using relatively large zones (e.g., municipality level) especially when one's study area is large. Our challenge was calibrating the model at the micro-district level (finely divided regions based on the seven-digit postcode, called cho-cho-moku in Japan) for the whole Tokyo Metropolitan Area. By doing so, we can look at the implications of district-scale Compact city policy such as the relaxation of the regulation on floor area ratio around train stations. The number of zones in our study area (the Tokyo Metropolitan Area) is 22,603. Regarding the notational explanations, please see Yamagata et al. (2013).

3 Creation of Urban Land-Use Scenario for the Year 2050

Using the model explained above, we have created three urban form scenarios for 2050: BAU (Dispersion city) scenario and two Compact city scenarios with and without Adaptation. In projecting the 2050 scenario, we have assumed that the

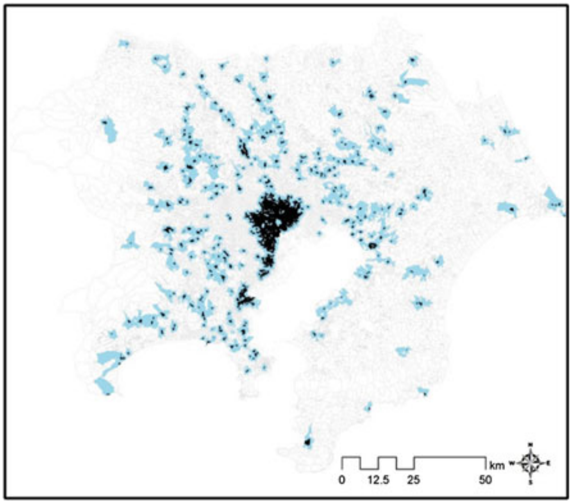

Fig. 2 Agglomerated office areas (*black*) and urban centers (*sky-blue*) (Color figure online)

number of each household type would change to (a): 2.07, (b): 1.07, (c): 1.39, (d): 0.66, (e): 0.69, (f): 1.32, (g): 0.85 (ratio to the number in 2005), which was estimated by log-linear extrapolation of estimates for the year 2030 produced by the National Institute of Population and Society Research, Japan. In the “Dispersion scenario”, the total number of each household group is allocated based on the current share.

For the “Compact city scenario”, the proximity of workplace to home is important for reducing trip length. Hence we quantified the degree of spatial agglomeration of office space using a spatial clustering technique (shown in black in Fig. 2), and defined the zones whose zonal distances were less than 500 m as *urban centers* (Yamagata et al. 2013). We subsidized these urban center zones by 1200 $/year (1$ = 100 yen), referring to the policy of Toyama city of Japan, which we call “Compact city scenario” in this study. For keeping the size of economy, we assumed that the total amount of income in the study area did not change among the scenarios. That is, the amount of subsidy is just cancelled out by the fixed property tax imposed on the other zones.

Compact urban form does not necessarily lead to the reduction of natural disaster risk. Hence we considered a scenario where only the zones whose average inundation depth was less than 5 m were subject to the subsidy, which we call “Combined scenario”. In order to calculate inundation depth, we used the “possible inundation areas,” designated and published by MLIT in around 2001 (Fig. 3) (available at: National Land Numerical Information download service, http://nlftp.mlit.go.jp/ksj-e/). The figure represents the areas which may be inundated by river flood.

Subsequent sections compare these scenarios in terms of disaster and energy resilience, CO_2 emissions, revegetation, and urban climate, respectively.

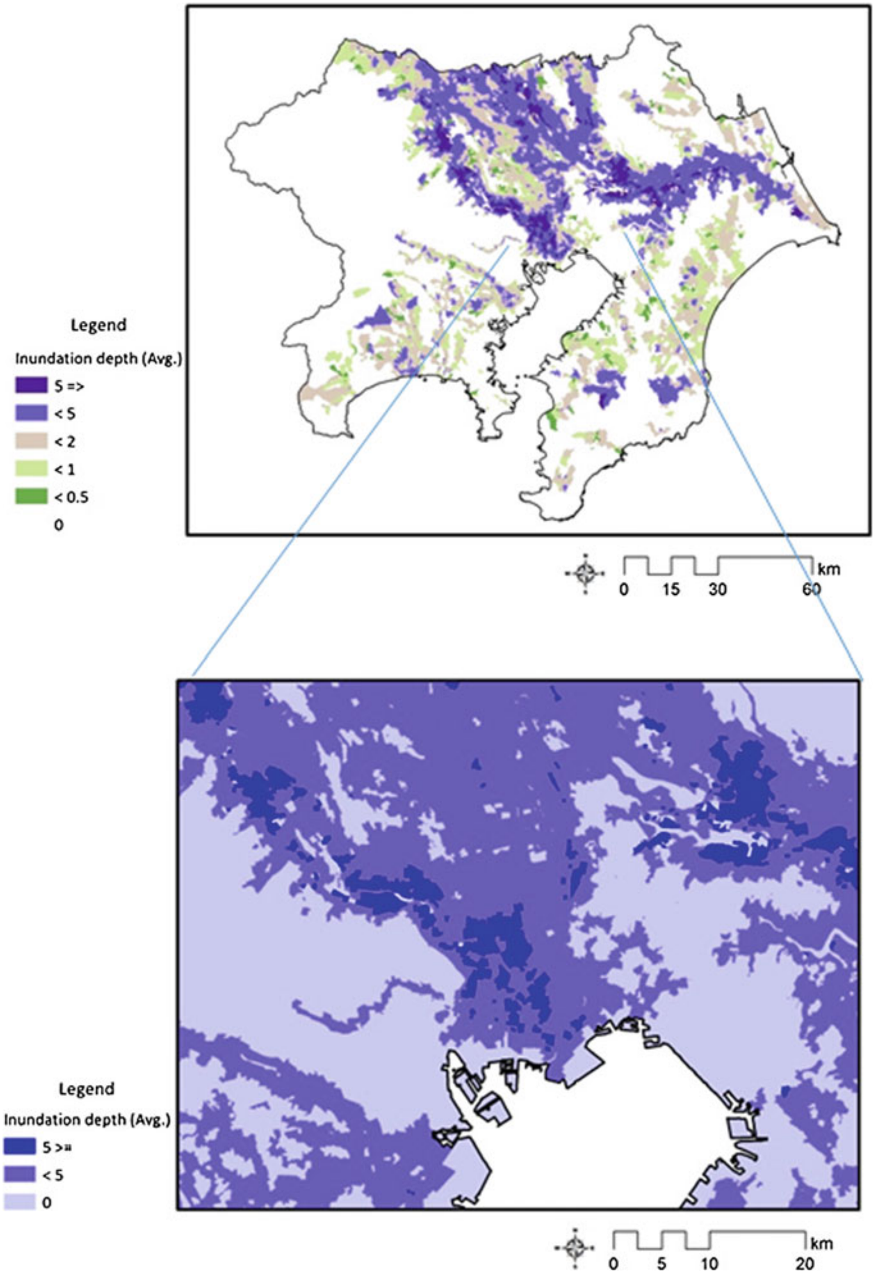

Fig. 3 Possible inundation areas (hazard map) of the Tokyo Metropolitan area

4 Disaster Risk Resilience: Economic Damages

For the economic evaluation of expected loss due to flood damages, the Japanese Ministry of Land, Infrastructure, Transport and Tourism (MLIT) has prepared a flood control economy investigation manual (MLIT 2005). The losses of households (HH) compose damages to the house and furniture, are calculated as in Tezuka et al. (2013):

$$\begin{aligned} \mathit{house\ damage} = {} & \mathit{house\ assetes} \times \mathit{inundation\ area} \\ & \times \mathit{damage\ rate\ by\ inundation\ depth}, \end{aligned} \tag{1}$$

$$\begin{aligned} \mathit{furniture\ damage} = {} & \mathit{furniture\ assetes} \times \mathit{inundation\ household} \\ & \times \mathit{damage\ rate\ by\ inundation\ depth}. \end{aligned} \tag{2}$$

The house assets (yen/m^2) and furniture assets (yen/HH), and the damage rate by inundation depth is defined in MLIT (2005). The inundation area and depth are defined using the data shown in Fig. 3. Once house and furniture damage is calculated, it is multiplied by the return period, and transformed to the present value with a social discount rate of 4 %. The expected loss is calculated by summing it up to the next 50 years from the calibration year of 2005. In fact, to reflect the impacts from the climate change that should happen by the year 2015, it is necessary to evaluate the impact using downscaled climate change scenarios such as those that IPCC has created. In order to simplify the study focusing on urban forms, we did not consider climate risk change such as flooding risk in our study explained in this chapter. However, it is an important research topic for our future study.

Figure 4 represents the differences in projected population (left: Compact—BAU; right: Combined—BAU). In both scenarios, the population increased in urban centers. However, in the combined scenario, the population of high risk zones decreased as expected. The projected changes of expected flood damage under the Compact and Combined scenarios (compared to BAU scenario) are −7.2B$ and −30.4B$, respectively. This result suggests that a careful selection of subsidized area may lead to fairly big differences in expected loss.

Currently, many Japanese urban master plans mention the importance of Compact city as a “future vision” of the cities. However, as far as we know, few of them have the co-benefit viewpoint as our Combined scenario, but our results suggest the importance of the co-benefit viewpoint. In our study area, the Kinugawa River actually broke through a breakwater on September 10th, 2015 and Joso city, which is about 50 km north of Tokyo, was heavily damaged by huge flooding. The hazard map of Joso city clearly suggested the danger of this area, but flood risk was not capitalized into land prices and many households actually live in that area. Our empirical analysis in the future should be focused on such areas to help local governments in their decision making about urgent risk management.

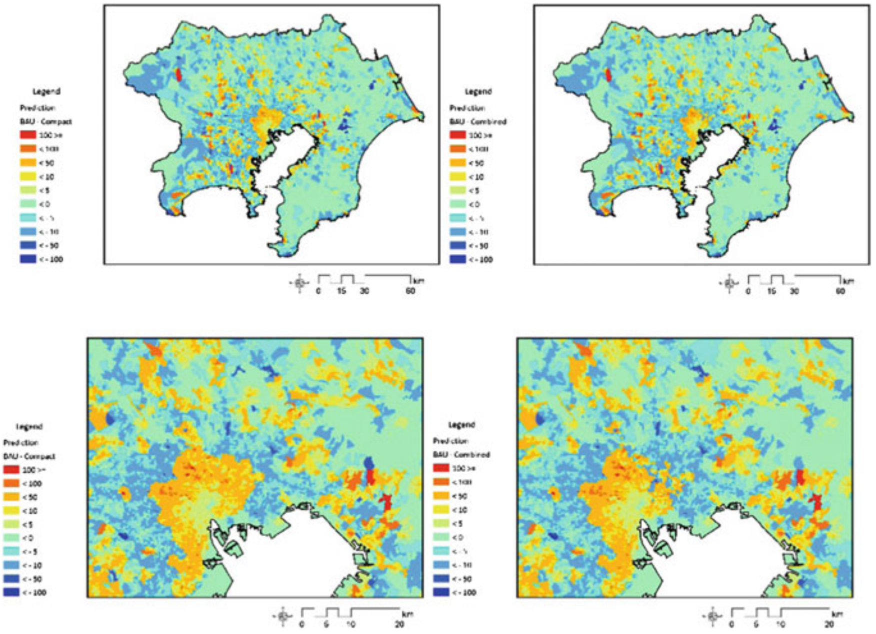

Fig. 4 Distribution of population in 2050 (*Left* compact—BAU; *Right* combined—BAU)

5 Disaster Risk Resilience: Affected People

Economic damage must be appropriately and accurately evaluated to design disaster prevention plans that would be necessary for risk management. Especially, the number of people affected must be estimated for the land-use regulations in hazardous areas, evacuation plan, placement of shelters, etc.

We have first estimated the number of people affected by inundation above floor level, by 2050. Specifically, the number of affected people in the *i*-th zone in *s*-th scenario, $p_{i,s}^{Fl}$, was estimated by the following equation.

$$p_{i,s}^{Fl} = p_{i,s} \times d_i^{Fl} \times \frac{(2050 - 2015)}{y_i^{Fl}}, \tag{3}$$

where $p_{i,s}$ is the total population in the *i*-th zone in *s*-th scenario, d_i^{Fl} is the probability of suffering from a flood with a depth of more than 0.5 m pear year,[1] and y_i^{Fl} is the return period of the flood (source: National Land Numerical Information download service).

We have also quantified the population affected by major earthquakes, $p_{i,s}^{Eq}$, using

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[1] 0.5 m has often been assumed as the floorboard height.

$$p_{i,s}^{Eq} = p_{i,s} \times d_i^{Eq} \times \frac{(2050 - 2015)}{30}, \tag{4}$$

where d_i^{Eq} is the occurrence probability of more than one earthquake whose seismic intensity exceeds 6.5 [Fig. 5; source: Japan Seismic Hazard Information Station (National Research Institute for Earth Science and Disaster Prevention)].

Figures 6 and 7 display the difference between the affected population in BAU scenario and those in the Compact/Wise shrinking scenario. These figures show that in the Compact city scenario the number of affected people increased in the central area, in which many people are concentrated. Actually, in the Compact city scenario the number of people affected by floods increased by 1617, whereas the number of people suffering from earthquakes increased by 147. This result suggests that city compaction, which ignores disaster resilience, can inflate disaster risks.

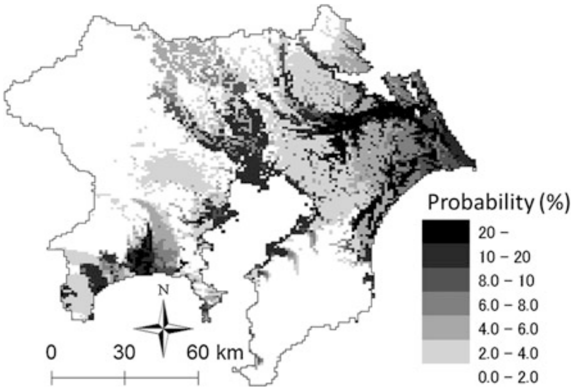
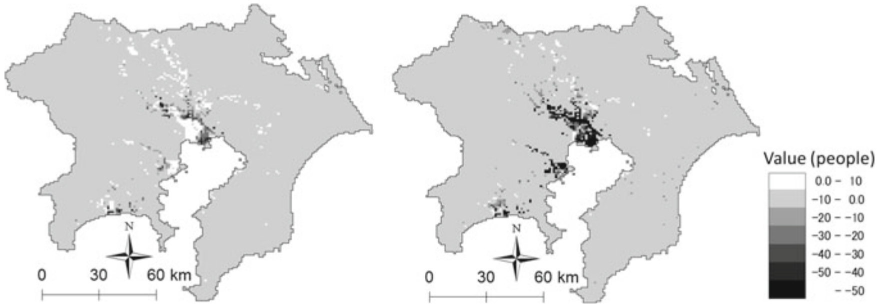
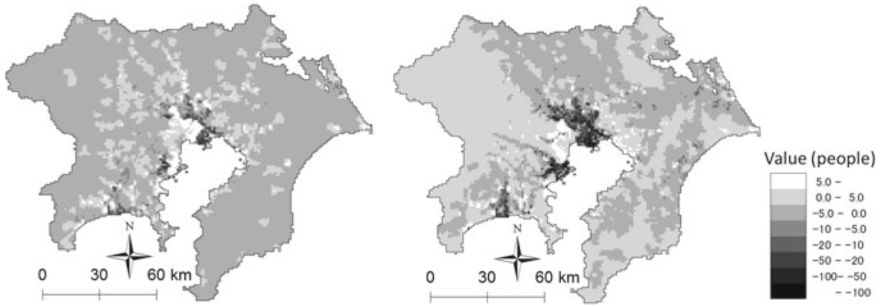


Fig. 5 Occurrence probability of earthquakes whose seismic intensity exceeds 6.5, within 30 years



Compact – BAU Combined – BAU

Fig. 6 Differences in population in areas with an inundation depth of more than 0.5 m. The population increases in the white zones whereas it decreases in the *black* zones



Compact – BAU

Combined – BAU

Fig. 7 Differences in the expected number of people who suffer from earthquakes whose seismic intensity is more than 6.5 by 2050

By contrast, the combined scenario decreased both of these risks in the central area. In total, the number of people suffering from floods decreased by 23,996, and those affected by earthquakes decreased by 11,978. The combined scenario makes cities compact while mitigates influences of disasters on people.

6 Energy Resilience

Urban form is a key driver determining energy demand and supply. This section introduces SULM by Yamagata and Seya (2013) for a comparison of the aforementioned scenarios in terms of energy resilience.

We first estimated PV (Photovoltaics) electricity demands and supplies. Then, we estimated the hourly electricity supply in each month using an equation proposed by Yokoi et al. (2010):

$$PV_i = I \times \tau \times L_i^{PV} \times \eta pc \times Kpt \times T. \tag{5}$$

where I is the monthly total irradiance (source: METPV-2 database (New Energy and Industrial Technology Development Organization)), τ is the array conversion efficiency (=0.1), L_i^{PV} is the area for PV panel installation, ηpc is the running efficiency of power conditioner (=0.95), Kpt is the temperature correction coefficient which is 0.92221 from May to October, and 1.00 for the other months. L_i^{PV} is estimated using the following equation:

$$L_i^{PV} = L_i \times \xi \times \iota \times 1/\cos\psi, \tag{6}$$

where L_i is the building land estimated in each scenario by SLUM, ζ is the building-to-land ratio, ι is the possible area of installation on the roof (=0.3), and ψ is the optimal angle of inclination (=30°).

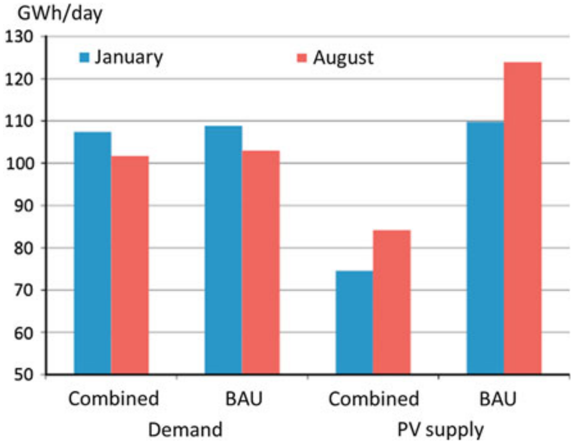


Fig. 8 Daily electricity demand and PV supply. *Source* Yamagata and Seya (2013)

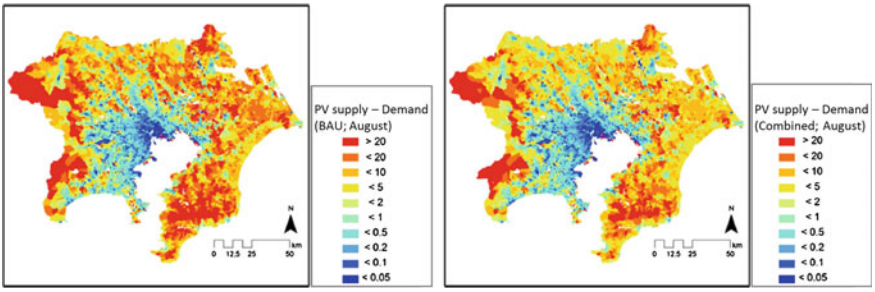


Fig. 9 Electricity demand and PV supply as the ratio of demand in August (*Left* BAU; *right* combined). *Source* Yamagata and Seya (2013)

Concerning the electricity demand, we calculated monthly demand in the *i*-th zone by multiplying the flood area, which was estimated using SULM under each scenario, and monthly basic unit consumption per floor area, which was published by The Japan Institute of Energy (2008).

Figure 8 shows the estimated total energy demand and supply in August in the BAU and combined scenarios. While electricity demands are similar between these scenarios, PV supply in the combined scenario is significantly smaller than that in the BAU scenario. This is because the combined scenario reduces residential building land, L_i, in suburban and/or high-risk areas. To achieve an urban computation while keeping energy resilience, it would be important to discuss how to ensure lands for PV panels.

Figure 9 maps the difference between electricity demand and supply in each zone in August. This figure demonstrates that PV electricity supply cannot cover the electricity demand in the central area in either the BAU or the combined scenario. To increase energy resilience, efficient energy use would be important in the central area.

Fortunately, city compaction allows us to implement efficient smart grids and community heating and cooling systems with low cost (OECD 2012). Integration of the Compact city scenario with the community level energy sharing system would be a very effective strategy in terms of energy resilience (see, Yamagata et al. 2015b).

7 CO_2 Emissions

Reduction of CO_2 emissions is a central issue toward climate change mitigation. Nakamichi et al. (2013) applied scenarios established by SULM to project the lifecycle of CO_2 from household sectors using the following equation:

$$CE_i = \sum_j H_{i,j}\left[\sum_k E_{i,j,k}(ic_{i,k} + dc_{i,k})\right], \tag{7}$$

where CE_i is the annual CO_2 emission in zone i, $H_{i,j}$ is the number of households with type of j in that zone (see, Table 1), $E_{i,j,k}$ is the annual expenditure on the k-th item by j-th household in the i-th zone, $ic_{i,k}$ and $dc_{i,k}$ are indirect and direct CO_2 emission intensities for the k-th item. The items include Food, Housing, Fuel, and so on. The annual expenditure of each item, $E_{i,j,k}$, was calculated based on the Household Expenditure Survey in Japan, and the emission intensities were based on Embodied Energy and Emission Intensity Data for Japan (National Institute for Environmental Studies).

The number of households $H_{i,j}$ was estimated using SULM under the BAU, Compact, and combined scenarios. Besides, to assess trade-offs/synergies between city compaction and use of renewable energy, the authors combined these scenarios with a scenario of PV (photovoltaic panels) and EVs (electric vehicles) dissemination. Specifically, they assumed the dissemination scenarios summarized in Table 2. In each scenario, CO_2 emission reductions by PVs and EVs were estimated by replacing emissions from fuel consumption of gasoline cars with indirect emissions from EVs. PVs were assumed to be installed on the roof tops of detached houses based on Eqs. (5) and (6), where L_i^{PV} is scaled based on the assumption in each scenario. EVs are installed by replacing gasoline cars in each zone following the dissemination rates.

Table 2 Dissemination scenarios of EVs and PVs. *Source* Nakamichi et al. (2013)

Scenarios of EVs and PVs	Dissemination rate of EVs (%)	Dissemination rate of PVs (%)
0	0	0
100	100	100
50	100	50
30	100	30
20	100	20

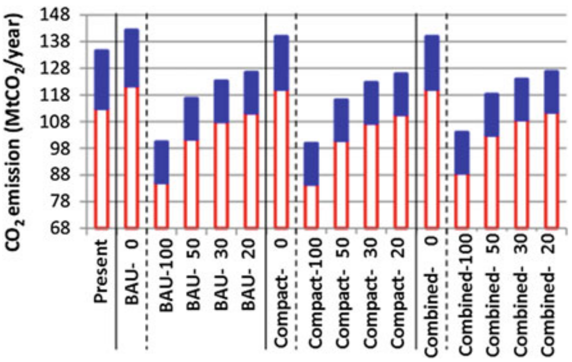


Fig. 10 CO$_2$ emissions of all households under different scenarios. *Source* Nakamichi et al. (2013)

Figure 10 summarizes the estimated total direct and indirect CO$_2$ emissions from households. BAU-*x* denotes BAU scenarios whose scenarios of EVs/PVs are *x* (see, Table 2). This figure suggests that PVs and EVs effectively reduce CO$_2$ emissions; in each of BAU, Compact, and combined scenarios, CO$_2$ emissions when PVs/EVs are fully installed (100 %) are about half of CO$_2$ emissions when they are not installed (0 %). Unfortunately, at each dissemination rate, the CO$_2$ emissions in the compact and combined scenarios are on average slightly larger than those in the BAU scenarios. This is because Compact or Combined scenarios imply a smaller number of detached houses. Thus, it would be important to explore how to achieve city compaction and CO$_2$ emission reduction at the same time.

8 Revegetation

This section estimates how much the Compact and the Combined scenarios contribute to revegetation, based on building land areas L_i given in each scenario. To examine it, we first modeled the composition of land uses using land attributes by employing a compositional data model (see, Pawlowsky-Glahn and Buccianti 2011). This model describes $l_{i,d}$, which is the composition of d-th land-use ($d \in \{1, 2,\ldots, D\}$) in zone i using Eqs. (8) and (9):

$$l^{*}_{i,d\neq D} = \log\left(\frac{l_{i,d\neq D}}{l_{i,D}}\right) \tag{8}$$

$$l^{*}_{i,d\neq D} = \sum_{p} x_{i,p}\beta_p + u_i \tag{9}$$

where $x_{i,p}$ is the p-th explanatory variable, β_p is the coefficient, u_i is a disturbance. In this model, Eq. (8) transforms $l_{i,d}$ to $l^{*}_{i,d}$ to eliminate the constant sum constraint (i.e., the sum of compositions must be constant). Equation (9) quantifies the impacts of the explanatory variables (see, Table 3) on $l^{*}_{i,d}$.

Table 3 Explanatory variables for the compositional model

Variables	Source	Variables	Source
Log of population density	MIC[a]	Dummy of alluvial fun	NIED[c]
Mean elevation	MLIT[b]	Dummy of natural levee	
Distance to the nearest railway station		Dummy of back marsh	
Distance to the nearest primary river		Dummy of delta	
Road density		Dummy of sandbar	
Dummy of urbanization control area			
Dummy of lake			

[a] MIC: Ministry of international affairs and communications, Japan
[b] MLIT: Ministry of land, infrastructure, transport and tourism, Japan
[c] NIED: National research institute for earth science and disaster prevention

The model is estimated by fitting it with the land-use composition data in 1997 [source: National Land Numerical Information (MLIT)] whose categories include paddy field, other agricultural land, forest, wildland, building land, other land (e.g., roads), and river/lake. Specifically, Eqs. (8) and (9) are fitted for each land-use type except for building land that we assume as the base land use, D (i.e., 6 models are estimated separately).

Table 4 summarizes the estimated coefficients. The coefficients in the d-th model are positive if a unit increase of $x_{i,p}$ attracts $l_{i,d}$ rather than the base land use, $l_{i,D}$ (building land), and negative vice versa. For example, the negative coefficients of lnPop for each land-use type suggest that lnPop attracts building lands rather than any other land uses; and, the negative coefficient of Avg_Elv for paddy fields suggests that paddy fields tend to be located in lower elevation areas than building lands, whereas the positive coefficients for other agricultural land, forest, wildland, and water show that they tend to be in higher elevation areas. Overall, the signs of the estimated coefficients are intuitively reasonable.

Based on the obtained model, we have estimated how much building areas are converted to green areas (paddy field, other agricultural land, and forest) in the scenarios. Figure 11 shows the estimated revegetation. Because of the depopulation, a certain level of revegetation occurred even in BAU. The Compact city scenario indicates a very similar revegetation pattern with BAU. In other words, this scenario does not necessarily effectively increase green areas. On the other hand, green areas significantly increase in the combined scenario, especially in the north and eastern areas. As a result of the revegetation in the city, future climate change risks such as heat wave and flush flooding are also expected to be reduced significantly as well as the river flooding risk. These are several multiple important benefits of the combined scenario.

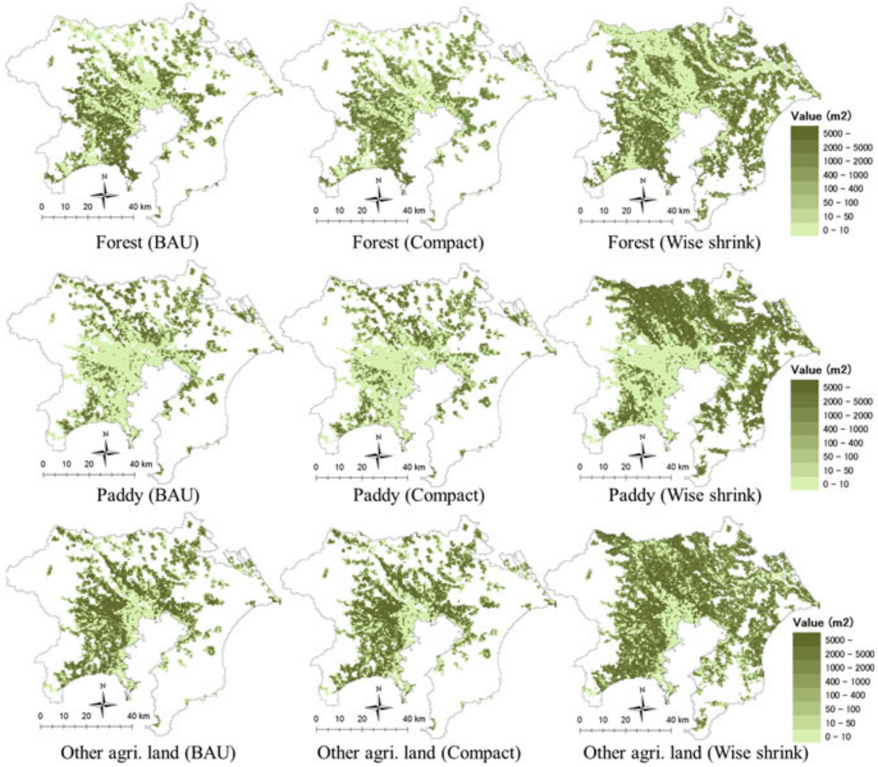


Fig. 11 Estimated revegetation in 2050

9 Urban Climate: Influence on the Urban Heat Island

Urban form determines the intensity of urban heat island. Adachi et al. (2014) quantified the influences of the BAU and the combined scenarios for urban heat island. Specifically, distribution of population, total floor area, and building area in these scenarios were used as inputs of the Weather Research and Forecasting model (WRF; Skamarock and Klemp 2008), and the influences of these scenarios on future heat island were estimated.

Figure 12 shows the change in nighttime temperature brought by the modification of the urban form. In the BAU scenario, temperatures in suburbs are increased because of the urban expansion. This tendency is significant in the eastern area, which is currently less urbanized, and projected to be urbanized in BAU. In contrast, in the combined scenario, because of the urban compaction, the suburban temperatures are decreased. On average, the temperatures in the combined scenario are roughly 0.2° lower than those in the BAU scenario.

Table 4 Estimation results (spatial compositional data model)

	Paddy	Agricultural	Forest	Wild	Other land	Water
Const	3.28^{***a}	2.54^{***}	6.45^{***}	-0.46^{*}	-2.05^{***}	-1.24^{***}
lnPOP	-0.76^{***}	-0.09^{***}	-0.96^{***}	-1.03^{***}	-0.34^{***}	-0.94^{***}
Avg_Elv	-0.01^{***}	0.00^{***}	0.01^{***}	0.00^{***}	0.00^{***}	0.00^{***}
Dist_Sta	0.26^{***}	0.10^{***}	-0.07^{***}	-0.09^{***}	-0.23^{***}	-0.14^{***}
Dist_River	0.06^{***}	-0.02^{***}	0.07^{***}	0.03^{***}	-0.02^{***}	0.02^{***}
Den_Road	-0.47^{***}	-0.46^{***}	-0.30^{***}	-0.13^{***}	0.16^{***}	-0.11^{***}
D_UCA	0.12	0.06	0.18^{*}	0.19	0.02	-0.51^{***}
D_Lake	-2.14^{**}	-3.67^{***}	-1.96^{**}	−0.66	0.20	10.01^{***}
D_AF	3.71^{***}	−0.14	-6.74^{***}	-2.53^{***}	0.08	3.92^{***}
D_NL	3.51^{***}	-1.92^{***}	-7.95^{***}	-1.99^{***}	-0.93^{***}	6.08^{***}
D_BM	4.49^{***}	-2.90^{***}	-7.70^{***}	-1.92^{***}	-0.62^{***}	2.84^{***}
D_Delta	2.45^{***}	-3.47^{***}	-6.27^{***}	-1.70^{***}	-1.45^{***}	3.39^{***}
D_SB	0.67^{**}	-1.07^{***}	-4.38^{***}	-2.13^{***}	−0.17	0.69^{*}
Adj_R2	0.47	0.30	0.71	0.39	0.07	0.29

^{a*}, **, and *** denote statistical significance whose levels are 10, 5, 1, and 0.1 %, respectively

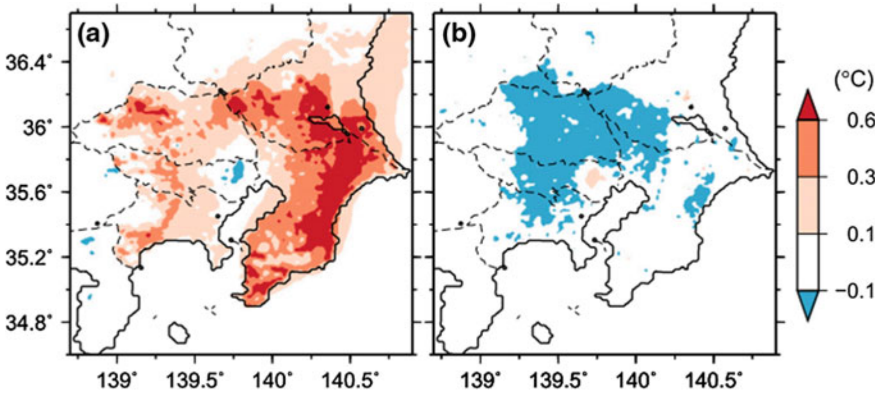


Fig. 12 The difference in monthly nighttime surface air temperature between 1:00 and 5:00 JST in August 2010 between the real situation and **a** the BAU scenario and **b** the combined scenario. *Source* Adachi et al. (2014)

10 Conclusion and Outlook

This study assessed the co-benefits of a mitigation measure (Compact city policy) and an adaptation measure (retreat from high flood hazard areas) from the view point of disaster and energy resilience, and other factors characterizing sustainability. We showed an example of effective Compact city policy which attains co-benefits with the adaptation measure. That is, our results suggest that if we carefully choose the subsidized area, we can mitigate fairly big expected loss due to the flood damage.

We also demonstrated that, while the combined scenario significantly increases green areas and mitigates the urban heat-island, it lowers the energy resilience. These results suggest the importance of considering trade-offs and synergies among factors determining resilience and sustainability in urban planning.

We found some similar attempts for Paris (Viguié and Hallegatte 2012; Viguié et al. 2014; Masson et al. 2014), which are based on urban economic model. Comparing our approach and theirs theoretically and/or empirically is an interesting next topic.

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Modeling Urban Heatwave Risk in Adelaide, South Australia

Simon Benger, Daisuke Murakami and Yoshiki Yamagata

Abstract Summer heatwaves are increasingly a feature of a warming global climate and their deleterious effects are most pronounced in urban centres, where populations are concentrated. Large areas of urban green space can have a significant ameliorating effect on high temperatures along with other amenity benefits and are one strategy for improving urban resilience to heatwave hazards. We used a range of spatially explicit climatic and socio-economic data to model hazard, vulnerability and exposure associated with an individual severe heatwave event in Adelaide, South Australia in 2014. Three greening scenarios for the city were then used to model the effects of heatwave risk mitigation on economic valuation and residential location choice under a residential sorting model. We found a greater willingness to pay (WTP), as measured by residential housing prices, by residents in areas with close proximity to green space. Younger age groups, in particular, were more likely to pay for lower temperatures in the urban environment.

1 Background

Heatwaves or episodes of extreme hot weather are a common feature of Australian summers. The highly urbanised population concentrated in the main cities experience heightened impacts of heatwaves (Guest et al. 1999) due to extensive areas of impervious surfaces and associated Urban Heat Island (UHI) effects. Australian cities also contain high numbers of vulnerable elderly and are susceptible to infrastructure failure including prolonged disruptions to electricity supplies and

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transportation in extreme heat events. Climate change is predicted to increase the frequency and intensity of extreme heat events across Australia (CSIRO 2007).

Adelaide, population 1.3 million, is a medium-sized low density city located in south eastern Australia. It is the only major city in the state of South Australia, which is the driest state in Australia. Heatwave events occur several times each summer on average, and the city experiences longer and more intense heatwaves than other Australian cities (BoM 2014). Heatwaves cause spikes in ambulance callouts (Nitschke et al. 2007) and heat related illness, including cardiac arrests and significant excess deaths (Williams et al. 2011). These effects are most apparent in the elderly, whose vulnerability is due to factors such as lower socio-economic circumstances, social isolation, reduced mobility, cognitive decline and high levels of dependence on others for care (Basu and Samet 2002). Increased air pollution during hot weather has also been found to contribute to mortality and morbidity in Adelaide (Williams et al. 2012). Heatwaves are also highly associated with catastrophic bushfires, which often threaten peri-urban and sometimes urban areas (Teague et al. 2009) resulting in loss of life and property. The past decade has seen increasing frequency of heat waves, droughts and record breaking high temperatures (BoM 2014), and has led to some concerns over the effects of global warming and man-made climate change on the city. Nine of the 10 warmest years ever recorded in Adelaide have occurred since 2002, with 2013 being the hottest year ever. To deal with the heat, Adelaide households have a high level of installed air conditioning, with some 75 % of households able to cool homes to some extent during heatwave events (ABS 2014).

Geographically, Adelaide is spread linearly along a narrow coastal plain, constrained to the east by the cooler, forested Adelaide hills and to the west by the beaches. Both of these features cool the metropolitan fringes along with the large green spaces associated with the Adelaide parklands, which surround the city centre. A strong UHI effect has been observed in the CBD (Zhu et al. 2013) with a temperature difference of up to 8 °C observed over a distance of a few kilometres from the city centre to the surrounding parklands on hot summer nights.

Three factors determine natural disaster risk: hazard, vulnerability, and exposure (Schneiderbauer and Ehrlich 2004). Heatwave risk, for example, arises when the elderly, who are vulnerable to heat, are exposed to heatwave hazards. To mitigate heatwave risk, it is important to understand these factors and model the relationships between them.

Increasingly, Australian cities will need to develop strategies to deal with more frequent and more intense heatwave events (McInnes and Ibrahim 2013). Among heatwave mitigation measures, greening is a promising one. Bowler et al. (2010) demonstrated that, on average, a park decreases localised temperature by 0.94 °C in a day while Adachi et al. (2014) estimated that urban compaction, which increases suburban green areas, decreases night time air temperature by about 0.2 °C in the Tokyo metropolitan area. Greening is also preferable in terms of its positive impact on amenity, natural environment, landscape, and so on (see, e.g. Jim and Chen 2009; Waltert and Schläpfer 2010). Hence, green areas must be located so as to maximize the well-being of urban residents, considering not only cooling effects, but also other impacts relating to amenity.

The objective of this chapter is to examine the effectiveness of urban greening scenarios in terms of their likely impacts on reducing heatwave risk and increasing resident's well-being in Adelaide. Section 2 estimates the spatial distribution of heatwave risk across the city, and Sect. 3 quantifies impacts of greening on heatwave risk mitigation. Based on these results, Sect. 4 quantifies willingness to pay (WTP) for these greening scenarios. Section 5 further discusses heatwave risk mitigation in Adelaide, and Sect. 6 concludes our discussion.

2 Heatwave Risk Estimation

2.1 Materials and Methods

Heatwave risk in Adelaide was evaluated through modelling hazard, vulnerability and exposure associated with an individual severe heatwave event in 2014, which was well represented in available surface temperature data. Three greening scenarios for the city were then used to model the effects of heatwave risk mitigation on economic valuation and residential location choice under a residential sorting model.

2.1.1 Hazard Estimation

The average temperature over Greater Adelaide for the period January 9–16, 2014 was derived from MODIS (MODerate resolution Imaging Spectroradiometer) daytime surface temperature observations. The period covers one of the most intense heatwave events ever recorded in Adelaide (BoM 2014). Severe heat was experienced across Adelaide with average daily temperatures exceeding 40° in most areas.

To quantify the seriousness of the heat, we evaluated a heatwave hazard measure called the Wet-Bulb Globe Temperature (WBGT), which is formulated as follows:

$$WBGT = 0.7T_w + 0.2T_g + 0.1T_d \tag{1}$$

where T_w, T_g, and T_d denote natural wet-bulb temperature, globe thermometer temperature, and dry-bulb temperature. Equation (1) is difficult to evaluate because T_w, T_g, and T_d are not observed in most official climate monitoring. Fortunately, a number of approximated WBGTs have been proposed. For instance, Gagge and Nishi (1976) proposed the following approximation that is widely applied (e.g. by the Australian Bureau of Meteorology):

$$WBGT = 0.567T + 0.216\rho + 3.38 \tag{2}$$

$$\rho = \frac{RH}{100} \times 6.105 \exp\left(\frac{17.27T}{237.7 + T}\right) \tag{3}$$

where T and RH are temperature and relative humidity, respectively. Here, we used the average relative humidity map for January (BoM 2015) for RH.

2.1.2 Vulnerability and Exposure

Heatwaves pose the greatest health risk for the most vulnerable members of society. Usually, the elderly are more vulnerable to heatwaves than younger people due to a range of factors (Fouillet et al. 2006; McInnes and Ibrahim 2013). Numbers of persons aged 65 and over were derived from 2011 census data (ABS 2013) and mapped at Statistical Area level 1 (SA1) resolution, which approximates 100 households.

The distinction between vulnerability and exposure in the context of extreme heatwave events is problematic, as both are closely related. In this study we used median household income as an indicator of exposure. While Adelaide has a highest level of installed residential air conditioning of any Australian city, many low income elderly live in older homes without air conditioning, or may be reluctant to use installed air conditioning due to high electricity costs, which for South Australia are among the highest in the world. Additionally, the elderly usually experience limited mobility and increased isolation, which can decrease the chance access to medical assistance when needed, and may also contribute to greater exposure to heatwave risk. Numbers of low income households were derived from 2011 census data (ABS 2015) and mapped by Statistical Area level 1 (SA1).

2.1.3 Risk Estimation (Hazard × Vulnerability × Exposure)

As discussed, disaster risk arises when hazard, vulnerability, and exposure appear simultaneously. In our case, the heatwave risk appears when a heatwave (hazard) affects areas where many low income elderly reside, which tend to be both vulnerable to and exposed to the heatwave.

Based on the above, we estimated the heatwave risk by Eq. (4):

$$\text{Heat wave risk} = \begin{cases} (WBGT - 30) \times \text{Density of elderly in low income households} & \textit{if } WBGT > 30 \\ 0 & \textit{otherwise} \end{cases} \tag{4}$$

where *WBGT* is estimated by Eq. (2), and the density of elderly in low income households is estimated by [the density of elderly (Fig. 3)] × [the ratio of households whose income per person is in the lower 25 % range]. Equation (4) assumes that the heatwave risk arises if only WBGT > 30, which is categorized into "extreme heat" based on Hot Weather Guidelines, (Sports Medicine Australia 2007) (see Sect. 2.1.1).

2.2 Results

2.2.1 Hazard Distribution

Figure 1 shows the average daytime surface temperature over Greater Adelaide for the period January 9–16, 2014. Figure 2 shows the WBGTs estimated by Eqs. (2) and (3). The Hot Weather Guidelines for Australia (Sports Medicine Australia 2007) specify that a heatwave poses an extreme risk of thermal injury when WBGT > 30. Figure 2 shows that most areas in Greater Adelaide are affected by an extreme heatwave hazard over the observed period in January 2014, while the remainder (green areas) poses a high to very high risk.

The coastal zone to the west of the city provides a clear cooling and heatwave mitigation effect. Interestingly, the central city area which has the highest density of housing and also contains the central business district (CBD) is also cooler than the surrounding suburban areas. This can be explained by the cooling effect of the extensive Adelaide parklands which fringe the CBD and also by the high albedo of many office and high density residential buildings comprising the CBD (Zhu et al. 2013). A much larger cooling effect is provided by the Adelaide Hills running roughly northeast-southwest through the metropolitan area, which are largely devoid of development due to planning regulations, are mainly forested and exhibit temperature decreases with elevation.

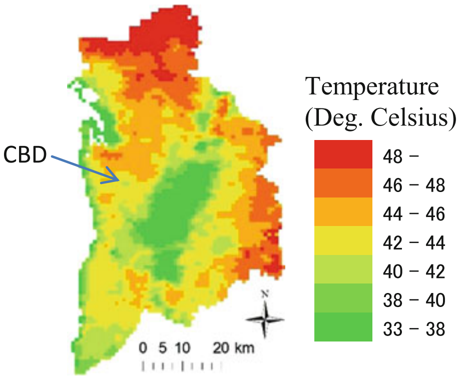
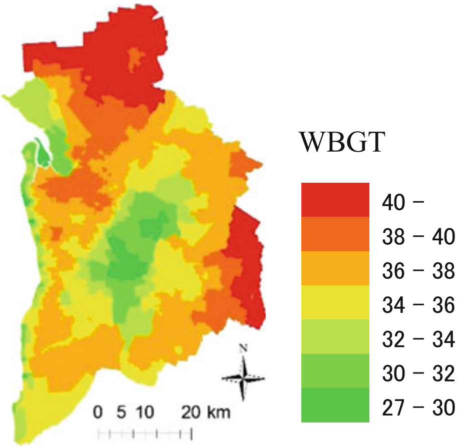


Fig. 1 Average daytime surface temperature (January 9–16, 2014)

Fig. 2 WBGT estimates (January 9–16, 2014)



2.2.2 Vulnerability and Exposure

Figure 3, which plots the density of elderly persons 65 years and older, suggests high concentrations of elderly in the western suburbs and the older suburbs around the city center.

Figure 4 plots median household income per person. Figure 4 indicates that low income households are distributed mainly in the northwestern and southwestern areas and the western coastal area. These findings for Adelaide suggest that poorer households are located in the hotter parts of the city, which is consistent with the findings across 52 countries by Park et al. (2015). Additionally, low income

Fig. 3 Density of elderly

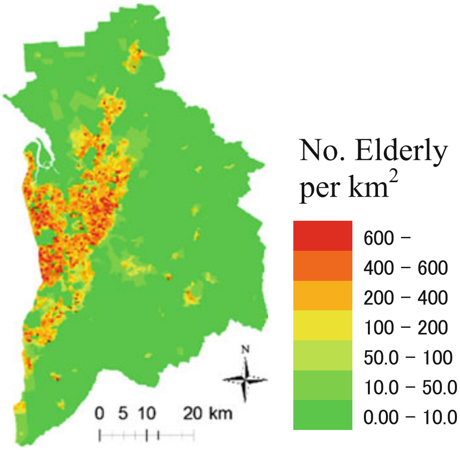
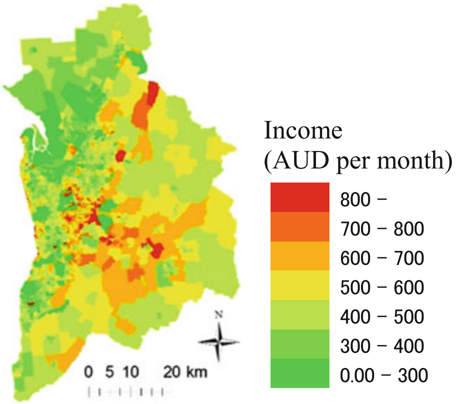


Fig. 4 Median household income

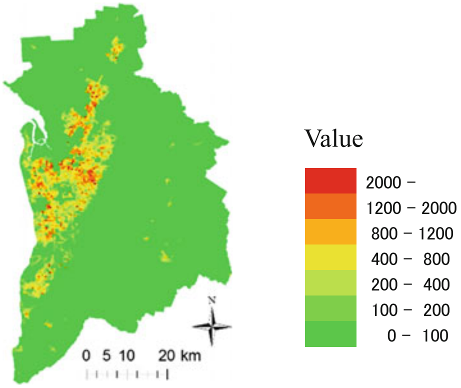


households are also most likely to work in occupations which have high levels of exposure to heat stress and also include a large proportion of elderly households.

2.2.3 Heatwave Risk Estimation

Figure 5 plots the estimated heatwave risk distribution based on the hazard x vulnerability x exposure calculation. This figure shows that the risk is high in the northern suburbs and the older suburbs close but not adjacent to the CBD. Not surprisingly, the built up suburban areas exhibit the elevated risk relative to the metropolitan and rural fringe. The coastal zone and the city centre show lower risk due to the cooling effects of the ocean and the CBD parklands, as discussed previously.

Fig. 5 Heatwave risk estimates



3 Greening and Heatwave Risk

3.1 Materials and Methods

Among possible countermeasures to heatwave risk, urban greening offers possibilities to mitigate the risk, while also increasing human amenity, landscape, ecosystem services, and so on. The green space and water bodies in and around cities generate amenities, and therefore economic value, while also providing local climate regulation and air quality improvement (Ruth and Franklin 2014). Thus, in this study we focus on greening in the urban landscape and its effect on temperature.

Figure 6 shows the ratio of the respective area per km^2 for each of the four temperature mitigating landuse types related to green space and water bodies. The largest forest and reserve areas are associated with the Adelaide Hills, while recreation areas are concentrated over the densest residential areas. Water bodies tend to be more common in the less densely settled rural/urban fringe localities.

Prior to discussing greening scenarios, we need to know how much greening decreases temperatures. Green areas in Adelaide were derived from forest, recreation and reserve landuse classes extracted from the 2012 South Australian Landuse dataset (SA Government 2015). To understand this, the relationship between temperatures and green areas are quantified using a geostatistical regression model, which is formulated as follows:

$$T_i = \sum_p x_{i,p}\beta_p + \varepsilon_i \quad \varepsilon_i \sim N(0, c(v_{i,j})) \tag{5}$$

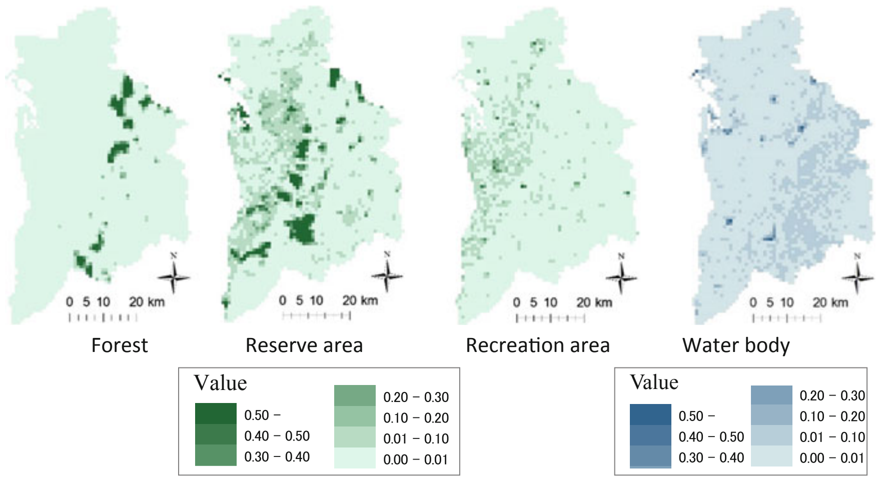


Fig. 6 Ratio of natural landuse

where T_i is the temperature (Fig. 1) at ith MODIS grid, $x_{i,p}$ is p-explanatory variable, and β_p is the coefficient. ε_i describes a spatial process whose covariance is parameterized by $c(v_{i,j})$, which is defined as follows:

$$c(v_{i,j}) = \begin{cases} \sigma^2 + \tau^2 \\ \tau^2 \exp(-v_{i,j}/r) \end{cases} \tag{6}$$

where $v_{i,j}$ is the distance separating grids i and j, σ^2 and τ^2 are variance parameters and r is a range parameter. Consideration of the underlying spatial process is important to avoid an overestimation of the impact from explanatory variables (Type I error).

The explanatory variables are as follows: Forest (ratio of forest area in each MODIS grid (km^2)); Recreation (ratio of recreation area (km^2)); Reserves (ratio of reserve area (km^2)); Water (ratio of water body (km^2)); Ocean_dist (distance to the ocean (km)); Center_dist (distance to Victoria Square (km)); Trans_dist (distance to the nearest public transport station (km)); Popden (population density (people/km^2)).

3.2 *Results: Effects of Greening on Ambient Temperatures*

Table 1 summarizes the estimated parameters from the geostatistical regression model. It can be observed that all of the green areas (Forest, Recreation, and Reserve) decrease ambient temperatures in a statistically significant manner. The temperature decrease by Forest cover is the largest and that of Recreation is the smallest. It is also verified that water areas decrease temperatures. Similarly, temperature increases as distance from the ocean increases. Urban-related variables (Center_dist, Trans_dist, and Pop_den) were statistically insignificant.

Table 1 Estimated coefficients (β_p in Eq. (5))

Variables	Estimates	t-value	Variables	Estimates	t-value
Intercept	3.85×10	6.98^{***}	Center_dist	-7.77×10^{-5}	-8.67×10^{-1}
Forest	-1.72×10^{-1}	-6.85^{***}	Trans_dist	3.05×10^{-5}	2.42×10^{-1}
Recreation	-3.81×10^{-2}	-2.06^{**}	Pop_den	-1.83×10^{-5}	-8.42×10^{-1}
Reserve	-8.55×10^{-2}	-5.99^{***}	σ^2	0.00	
Water	-6.53×10^{-2}	-2.79^{***}	τ^2	46.95	
Ocean_dist	3.60×10^{-1}	5.21^{***}	r	121	
			AIC	7666	

*,**,***Suggest statistical significances (1, 5, and 10 %, respectively)

4 Greening Scenario Analysis

4.1 Materials and Methods

The analysis described in Sect. 1.5 confirms that greening decreases temperatures. This section quantifies the economic value of possible greening scenarios utilizing the estimates shown later in Table 2.

4.1.1 Scenarios

This section considers increasing recreation areas. This is because recreation areas have a higher affinity for urban areas, whose heatwave risks are high, rather than forest and reserve areas. We assumed the following greening scenarios (hereafter, we refer to recreation areas as green areas):

BAU (Business as usual)	No greening.
Greening1	A scenario of increasing green areas in proportion to the current amount of green area.
Greening2	A scenario of increasing green areas in higher risk areas.

In scenario Greening2, districts whose heatwave risks are in the upper 10 % are regarded as high risk districts, and a lower limit regulation for the green space ratio is imposed for these districts. We tested three lower limits: 10 % (Greening2_10 %), 20 % (Greening2_20 %), and 30 % (Greening2_30 %). On the other hand, we also assume three Greening1 scenarios (Greening1_10 %; Greening1_20 %; Greening1_30 %;) whose total increase in the green area is the same as Green2_10 %, Green2_20 %, and Green2_30 %, respectively.

Table 2 Explanatory variables: residential sorting model

Category	Name	Description	Source
Price (p_d)	Med_rent	Median mortgage repayment (AUD per month)	Census 2011
District ($X_{d,D}$)	Center_dist	Distance to Victoria Square	Government of South Australia
	Station_dist	Distance to the nearest station public transportations (km)	
	Ocean_dist	Distance to the ocean (km)	
	Green (Rec.)	Ratio of recreation areas	
	Green (other)	Ratio of forest + reservation areas	
	Temperature	Temperature January 9–16, 2014 (Fig. 1)	MODIS
Household ($Z_{h,H}$)	Income	Income of householder (15 levels)	Census 2011
	Age	Age of householder (8 levels)	

4.1.2 Model for Estimating Economic Value of the Greening Scenarios

Here, we quantified the economic value of each scenario. We need to consider at least two factors: (i) the impact of greening on heatwave risk (temperature) mitigation, whose statistical significance was proved in through the analysis described in Sect. 1.5, and; (ii) other possible impacts of greening on human amenity. Hence, in this section, we quantified the economic value focusing not only on greening but also its impact on temperature decrease.

In this economic value evaluation, we used the residential sorting model (Van Duijn and Rouwendal 2013), which is an economic equilibrium-based residential location choice model. The residential sorting model is a form of hedonic model, which are widely used for evaluating the economic value of environmental amenities (Kuminoff et al. 2010). These amenities are not explicitly traded in formal markets, but are implicitly valued by consumers through choice of a location for a home.

This model describes the probability that *h*th household selects *s*th district as their residential location, $u_{h,s}$, using Eqs. (7) and (8):

$$u_{d,h} = \delta_d + \sum_D \left(\sum_H \beta_{H,D} (Z_{h,H} - \bar{Z}_H) \right) X_{d,D} + \varepsilon_{d,h}, \tag{7}$$

$$\delta_d = bp_d + \rho \sum_{d \neq d'} w_{d,d'} \delta_{d'} + \sum_D \beta_D X_{d,D} + \xi_d, \tag{8}$$

where $Z_{h,H}$ is *H*th household-level explanatory variables, $X_{d,D}$ is *D*th district-level explanatory variables. They explain the residence location selection probability, $u_{d,h}$. p_d denotes the standard housing price in the district *d*. $w_{d,d'}$ measures the spatial connectivity between districts *d* and *d'*. *b*, ρ, $\beta_{H,D}$ and β_D are coefficients, and $\varepsilon_{d,h}$ and ξ_d are household-level and district-level disturbances, respectively. Equation (7) describes the location choice behavior of each household, and Eq. (8) describes the district level heterogeneity. Note that the second term in Eq. (8) is a spatial autocorrelation term; it is known that an inclusion of this autocorrelation effectively mitigates the omitted variables bias (i.e., the bias in parameter estimates that is caused by factors that could not be introduced in the residential sorting model, e.g., due to the difficulty of data acquisition).

We estimated the economic value of greening and its impact on temperature decrease using the residential sorting model. Explanatory variables are as shown in Table 2. Although Eq. (8) includes the cross-product of, not only Age and each $X_{d,D}$, but also Income and each $X_{d,D}$, to avoid multicollinearity, the latter cross-product terms are omitted. In other words, the explanatory variables of Eq. (8) consist of Income and the cross-products of Age and each $X_{d,D}$, whereas explanatory variables of Eq. (8) are all of $X_{d,D}$.

4.2 Results

4.2.1 Estimation of WTP

Table 3 shows the estimated coefficients, which are used for the Willingness to Pay (WTP) evaluation. The signs of the coefficients in the district-level model are intuitively consistent; namely, green areas have positive impacts while temperature increase has a negative influence. Among them, only Ocean_dist and the spatial interaction term (ρ) are statistically significant.

Age$_{cent}$ in Table 3 denotes the centered Age, which corresponds to $Z_{h,H} - \bar{Z}_H$ in Eq. (7). The estimation result of the household-level model suggests that preferences for Cent_dist, Ocean_dist, Green(Rec.), Green(Other), and Temperature vary significantly across ages..

WTPs of Green(Rec.) per 1 % increase in area, and Temperature per 1° increase, which we consider in our scenario analysis, were evaluated based on the coefficient estimates, by age class.

Finally, economic values of each greening scenario are evaluated. The WTP for sth greening scenario in dth district (in terms of the greening itself), $WTP_{green,d}(s)$, is evaluated by the following equation:

$$WTP_{green,d}(s) = \Delta g_d(s) \sum_a w_{green,a} h_{d,a}, \tag{10}$$

where $\Delta g_d(\alpha)$ is the increase of green area (Green(Rec)) in dth district under sth scenario, $w_{green,a}$ is the WTP of ath age for an unit increase of green area (which was estimated by the residential sorting model), and $h_{d,a}$ is the number of households categorized into ath age in dth district. Equation (10) simply sums up WTPs of households in dth district. Likewise, the WTP of sth greening scenario in terms of its impact on temperature decrease, $WTP_{temp,d}(s)$, is evaluated by Eq. (11):

$$WTP_{temp,d}(s) = \Delta t_d(s) \sum_a w_{temp,a} h_{d,a}, \tag{11}$$

where $\Delta t_d(\alpha)$ is the decrease of green area (Green(Rec)) in dth district under sth scenario, which is evaluated by [-3.81×10^{-2} (see, Table 1) × the increase of green area], $w_{temp,a}$ is the WTP of ath age for an unit increase (decrease) of temperature (which was estimated by the residential sorting model; see Table 3).

We summed up these WTPs across households in the Adelaide metropolitan area, and total WTPs for each scenario are evaluated.

4.2.2 Valuation of Greening Scenarios and WTP

Table 4 summarizes estimated WTPs (WTP of each greening scenario minus WTP of BAU scenario). This table suggests that Greening2 scenarios, which encourage

Table 3 Estimates of the residential sorting model ()

Household-level model (Eq. 7)			District-level model (Eq. 8)		
Variables	Estimates	*t*-value	Variables	Estimates	*t*-value
Intercept	-1.74	-6542^{***}	Intercept	6.63×10^{-3}	0.72
$\text{Age}_{cent} \times$ Cent_dist	-1.70×10^{-4}	-1.77^{*}	Cent_dist	-1.42×10^{-4}	-0.24
$\text{Age}_{cent} \times$ Station_dist	-1.73×10^{-5}	-0.17	Station_dist	-1.18×10^{-4}	-0.27
$\text{Age}_{cent} \times$ Ocean_dist	-6.08×10^{-4}	-9.02^{***}	Ocean_dist	7.86×10^{-4}	1.85^{*}
$\text{Age}_{cent} \times$ Green(Rec)	-8.64×10^{-3}	-8.35^{***}	Green(Rec)	9.14×10^{-4}	0.19
$\text{Age}_{cent} \times$ Green (Other)	-7.00×10^{-3}	-8.90^{***}	Green(Other)	4.01×10^{-3}	1.16
$\text{Age}_{cent} \times$ Temperature	5.13×10^{-5}	4.01^{***}	Temperature	-8.92×10^{-5}	-0.49
Income	3.05×10^{-4}	163^{***}	ρ (interaction)	5.43×10^{-1}	2.26^{**}

*,**,***Suggest statistical significances (1, 5, and 10 %, respectively)

Table 4 WTPs of greening scenarios (million AUD per year)

WTP	Scenario					
	Green1 10 %	Green1 20 %	Green1 30 %	Green2 10 %	Green2 20 %	Green2 30 %
For greening	136	307	480	282	632	984
For temperature decrease	14.5	25.2	32.7	27.2	37.0	42.7
Total	151	332	512	309	669	1027

greening in high risk areas, have greater WTPs than Greening1 scenarios, not only for temperature decrease but also for greening. As a result, total benefits of the Greening2 scenarios are about twice those of the Greening1 scenarios. These results verify that the Greening2 scenarios are likely to have the highest amenity for Adelaide residents. The WTP evaluation result indicates that urban planning implemented to achieve greening of the urban landscape will also have a measurable benefit for heatwave mitigation.

WTPs of Green(Rec) and Temperature, which we consider in our scenario analysis, are evaluated based on the coefficient estimates, and summarized by age class in Table 5. As expected, Green(Rec) has positive WTPs across all ages. In addition, the elderly have greater WTP for Green(Rec) than younger people. According to this analysis, the elderly demonstrate a higher preference (as measured by WTP) for living in areas with high proportions of green space. This finding is consistent with other hedonic studies (e.g. Geoghegan 2002; Anderson and West 2006), which found that older, higher income households have a greater WTP for open/green space. In contrast, while Temperature has a negative WTP, again as expected, our results show that younger people have a greater WTP for temperature decrease. That is, younger people show a preference for living in cooler areas of the city. The WTP figures for temperature increase in Table 5 are likely

Table 5 Estimated willingness to pay (AUD per year)

Age class	Green_Rec (per 1 % increase)	Temperature (per 1 °C increase)
20–24	20	−1281
25–34	34	−1179
35–44	52	−1044
45–54	71	−909
55–64	89	−773
65–74	107	−638
75–84	126	−503
85–	144	−368

exaggerated as a result of individual neighborhood characteristics, but are nevertheless similar to the extensive hedonic pricing literature suggesting substantial WTP for milder climates (Maddison 2003). While many of these effects are often observed at more regional and global scales, which point to a strong relationship between heat in particular and production and macroeconomic output (Heal and Park 2013), they are clearly present at the city scale.

5 Discussion

Cities such as Adelaide are subject to external climate impacts which may be beyond their control, but they can change their local climate through choices in landuse planning and consumption that may influence heat flux, air quality, wind speed and precipitation (Ruth and Baklanov 2012). Moderate climates can be a consumption amenity affecting individual utility directly, along with the marginal utility of types of consumption affected by climatic conditions such as using neighbourhood parks and reserves (Park et al. 2015). Greening the urban environment facilitates the consumption of the ecosystem services and amenity that green spaces provide while minimizing the risks associated with external shocks such as heatwaves (Ruth and Franklin 2014).

A common response to increased temperatures is to increase installed air conditioning capacity, which has also been stimulated in recent times by decreasing unit costs and rising incomes in Australia. All of the hotter states have very high levels of residential air conditioning (ABS 2014). Air conditioner use forms a type of adaptive capacity in the resilience equation, through reducing exposure to extreme heat. Conversely, it also contributes to increased energy consumption and greenhouse gas production (Ruth and Franklin 2014). The elderly are often marginalized in terms of access to this amenity due to their low incomes and older homes.

Increasing urbanization has been a feature of Australian life over the past century, a trend which is occurring throughout the world. This increases geographical concentration, creates hotspots of energy use and heat retention and generates a matrix of urban diversity that results in pockets of social inequity and differing access to the resources that a city provides. Human impacts on the environment are greatest in cities but also the impacts of the environment are greatest due to the high density of inhabitants and high value of assets (Ruth and Franklin 2014). The numbers of elderly individuals continues to rise in many countries, and Adelaide, in particular, has the highest proportion of elderly persons of any capital city in Australia (ABS 2013). Concentrations of the vulnerable make it easier to respond to their needs during emergencies but also require specialized approaches due to their marginality.

Improved disaster management and emergency preparedness (Blanco and Alberti 2010) is key to dealing with the threats posed by extreme heat events to vulnerable members of society. The challenge for governments is to simultaneously develop heatwave plans, as emergency planning and response policies, in the short term and to develop longer term policies and plans to address exposure through transport, urban planning and building design, changes to behavior and health education (Bi et al. 2011). The provision of greater areas of green space in cities forms an important component of urban planning approaches to facilitate cooler and more climate resilient cities.

Most cities around the world will need to work toward development of the policies and knowledge on how to manage the risks of climate change, which include increased frequency and intensity of heatwave events, and build resilience in their systems. Cities are social, economic and environmental systems and the degree to which they can cope with climate induced risks defines their vulnerability (Parry 2007). The components and people that comprise the urban system are not affected equally and will have different vulnerabilities (Lundgren and Jonsson 2012). Addressing the needs of the vulnerable elderly is an important social consideration in most developed nations, but there is a need to also reduce their exposure to environmental hazards such as heatwaves through better environmental design in cities.

The concept of urban “liveability” has been a guiding principle for planners and policymakers (Pacione 2003). Provision of green space and the amenities that it provides is one part of the city environment which is a key element of liveability. While this is due to a range of factors such as visual amenity, recreation opportunities, access to open space and others, green space also contributes to the resilience of cities through the moderating effects of cooler temperatures. A cooler climate in turn reduces the risks to the urban population posed by extreme heat events. Adelaide was fortunate to have a highly planned beginning which left the city a legacy of green space, particularly in and around the city centre, which our results show contributes to reduced heatwave risk. Expanding and consolidating green space will form an important future requirement for planners while also delivering urban inhabitants the features of the urban residential environment that they desire and are willing to pay for.

6 Conclusions

Planning for urban resilience under a future of climate change and increasing temperatures will most likely prove a costly challenge for urban planners and policy makers. Repurposing of urban land from industrial or residential to green space must compete against the requirements for new land for high value urban residential and commercial developments. Many cities around the world have developed "organically" as economic and population growth have driven the need for expansion of infrastructure, housing and industry. Green space in cities, where present, has often been the legacy of foresight by planners and politicians in the early stages of city evolution. Many cities, particularly in developing and emerging economies, have only been able to integrate green space as part of the urban fringe. It has long been recognized that social and environmental dynamics in cities shape the character, and wellbeing, of the urban population, although different cities place varying emphasis on their importance. Heatwave–prone cities such as Adelaide and many others in Australia need to focus on utilizing the cooling effects of green space and water bodies to improve urban resilience. Resilience, amenity and livability concepts are relatively new and implementing them in cities requires a range of interventions and investment at multiple scales, while their economic value remains contentious against the more measurable economic impacts of traditional urban growth. It will require a transformative approach to anticipate future impacts of global climate change and take difficult decisions and actions that will radically alter the spatial arrangement of our cities.

Our research demonstrates, through hedonic spatial analysis, the greater WTP by urban residents for residential proximity to green spaces, due in part to their temperature ameliorating effects as well as a range of other amenity benefits. This also likely translates into higher land values and tax benefits to government for these areas, along a with reduced health care cost burden. Vulnerable members of society have less ability to pay for a desirable living environment and it therefore becomes incumbent on city planners to deliver equitable outcomes for all members of urban society. Greater provision of green space is one mechanism by which this may be achieved, particularly in the face of more frequent and intense extreme heatwave events. Issues of adaptation and resilience to extreme heat in cities will need to be an important focus of both future research efforts and urban governance.

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Flood Risk Management in Cities

Daisuke Murakami and Yoshiki Yamagata

Abstract While bayside areas, which enjoy coastal natural environment, amenity, scenic landscapes, and so on, are typically attractive residential areas, they are very often vulnerable to flooding too. Unfortunately, flood risk is gradually increasing in Asian cities. In particular, the Tokyo metropolitan area is known as a high-risk metropolis. Building flood risk resilience while keeping the attractiveness of the bayside area is a critical issue in Tokyo. The objective of this study is to analyze the trade-off between benefits from the ocean and flood risk as a first step to increase urban resilience. To quantify the trade-off, this study uses the hedonic approach. We first review related hedonic studies and discuss which hedonic model is suitable to apply in our analysis. Subsequently, we perform a hedonic analysis of condominium prices and quantify the benefits from ocean-related variables, including ocean view and proximity to the ocean, and the negative effects from the flood risk. Here, a spatial additive multilevel model is used. The analysis results reveal that the flood risk is highly underestimated while the benefits from the ocean are appropriately evaluated in the target area.

Keywords Flood risk · Trade-off · Hedonic analysis · Normalcy bias · Yokohama

1 Introduction

A gradual increase of natural disaster risks is projected on the global scale (Pachauri et al. 2014). Dettinger (2011) and Kundzewicz et al. (2014) projected that storms are more and more frequent and severe in East Asia, North, Central, and Caribbean America, while Hirabayashi et al. (2013) and Kundzewicz et al. (2014) projected an increase of flood risks in Asia and some other areas. These regions include

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megacities like Tokyo and New York and many growing cities, which are typically in developing countries, and are vulnerable to disaster risks (OECD 2012). Building resilience is increasingly important especially in these cities (Hammond et al. 2015).

Unfortunately, cities are not always resilient against disaster risks. Cities are typically located in bayside/riverside areas where storm and flood risks are high, because these areas are convenient for trading, agriculture, and so on. Furthermore, inside these cities, people usually prefer living nearby the ocean (or rivers) that enjoys coastal natural environment, amenity, and landscapes. Numerous studies have empirically verified the significant attractiveness of bayside areas (e.g., Pompe and Rinehart 1994; Jim and Chen 2009; Hamilton and Morgan 2010; Landry and Hindsley 2011; Yamagata et al. 2015a, 2016).

It is important to increase the resilience of bayside cities while keeping their attractiveness. However, policy making for that purpose is not necessarily straightforward because of the trade-off between risks and other factors (e.g., Rascoff and Revesz 2002). For example, a land-use regulation to a high-risk area might stop some economic activities, while an embankment construction, which decreases flood risks, might destruct natural environment and obscure scenic ocean views. Even compact city policy (see, Chapter "Urban Economics Model for Land-Use Planning"), which is a popular policy toward sustainable development, does not specifically consider disaster risks (OECD 2012). A city compaction can lower the flood risk resilience if the policy concentrates people in a bayside area.

Unfortunately, urban structures are not necessarily adaptive to disaster risks. For example, Fig. 1 shows the spatial distributions of population density (source: Census 2010) and anticipated inundation depth (source: National Land Numerical Information download service; URL: http://nlftp.mlit.go.jp/ksj-e/index.html) in the central area of Tokyo. This figure suggests that the eastern area with large population density is also a high-risk area (note that this area also is known as a high-risk area of liquefaction and earthquakes). Although the Tokyo Metropolitan

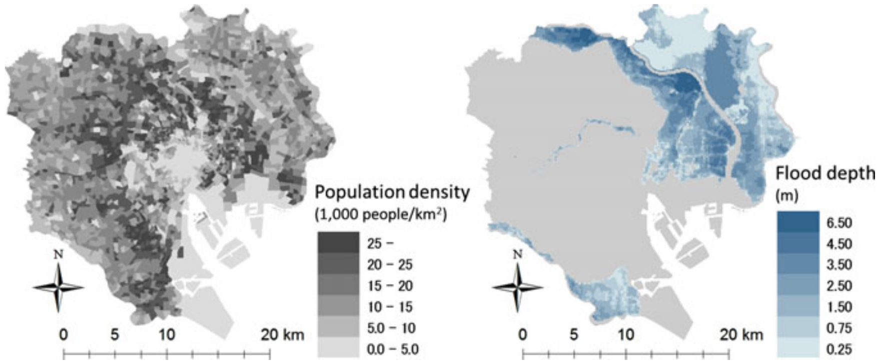

Fig. 1 Population density (*left*) and anticipated flood depth (*right*) in the 23 wards of Tokyo

Government has published hazard maps to disseminate disaster risks, the population in this vulnerable area is still growing.

Such an underestimation of the disaster risk is attributable to the normalcy bias (e.g., Omer and Alon 1994), which refers to a mental state that people tend to be too optimistic about unusual and inconvenient events such as disasters. This bias allows people to reside in high-risk areas without specifically considering disaster risks.

To cope with the normalcy bias and to increase the resilience against flooding, it is necessary to quantify the trade-off between flood risks and other factors. The objective of this chapter is to discuss how to quantify such a trade-off, and to empirically analyze whether or not the disaster risk is underestimated. The subsequent sections are organized as follows. The next section introduces the hedonic approach which we will use, and discuss which hedonic model is suited for our analysis. Then, the risk trade-off is analyzed using that model. Finally, we conclude our discussion.

2 Hedonic Approach

2.1 Hedonic Analysis of Flood Risk

The hedonic approach (Rosen 1974) is a representative approach to quantify economic values of non-market goods, such as accessibility, environment, and disaster risks. This approach evaluates their economic values by regressing them on property values. Existing hedonic studies have revealed the positive premium of natural resources, including greens, parks, and the ocean (see, Waltert and Schläpfer 2010; Brander and Koetse 2011). Thus, the results of hedonic analyses regarding natural environment are intuitively consistent in many cases.

By contrast, the results of hedonic analyses regarding flood risk are controversial. Daniel et al. (2009) showed in their meta-analysis of 19 relevant studies that the premium of flood risk varies between −52 and +58 %. For example, Bin and Kruse (2006) and Atreya and Czajkowski (2014) suggested a statistically significant positive economic value of flood risk that is counterintuitive, Cavailhès et al. (2009) showed an insignificant value, and Bin et al. (2008) and Samarasinghe and Sharp (2010) showed a statistically significant negative premium.

A consensus is that flood risk has a significant negative impact after a catastrophic flood (see, Zhai et al. 2003; Bin and Polasky 2004; McKenzie and Levendis 2010; Atreya et al. 2013). However, Bin and Landry (2013) showed that the negative influence disappeared in about five or six years after the flood. Atreya et al. (2013) also suggested the disappearance of negative impacts in four to nine years. These results imply that people forget flood events quickly, and the underestimation of the risk appears just like before the threat (see, McKenzie and Levendis 2010).

Based on the literature review, it is likely that the inundation risk is underestimated in the Tokyo bayside area where catastrophic flooding may occur within decades. Voss (2006) estimated that the Tokyo metropolitan area is the most vulnerable metropolis in the world because of the high risk of storms, floods, and other disasters. Furthermore, a great earthquake called the Nankai-Trough earthquake is projected to hit the Tokyo area within 30 years. The increase of disaster risk resilience is among the most crucial issues in Tokyo.

As a first step of building resilience in Tokyo, the rest of this chapter analyzes whether flood risks are underestimated in Yokohama city, which is a bayside city nearby Tokyo.

2.2 Hedonic Models

As discussed, the hedonic analysis regresses risk variables and other variables on property prices. In case of using condominium price, Eq. (1) is one of the most basic models:

$$\ln(y_{i-j}) = \sum_{p=1}^{P} x_{i-j,p}\beta_p + \varepsilon_{i-j}, \quad \varepsilon_{i-j} \sim N\left(0, \sigma_\varepsilon^2\right), \tag{1}$$

where i and j are indexes of condominium units and buildings, respectively; y_{i-j} is the price of ith unit in jth building; $x_{i-j,p}$ is pth explanatory variable whose influence on $\ln(y_{i-j})$ is assumed to be linear; β_p is the regression coefficient; and ε_{i-j} is the unit-level disturbance with variance of σ_ε^2.

Although Eq. (1) has been widely used in hedonic analyses, it has some serious limitations. Firstly, it does not consider the multilevel structure of condominiums (units-buildings), whose ignorance can introduce a serious bias in parameter standard errors (Hox 1998). Secondly, it does not consider the possible non-linear influences from explanatory variables (e.g., flood risk might have a non-linear impact such that the influence becomes significant only when the risk exceeds a threshold). Thirdly, Eq. (1) tends to suffer from the omitted variables bias. When we construct a statistical model, it is common that some factors, whose data are not available, are omitted from the model. Therefore it is crucially important to eliminate the effects of such omitted factors. Although the conventional way against this problem is to use instrument variables (Gibbons and Overman 2012), the selection of good instrument variables is not an easy task. Then, if omitted factors have spatial dependent patterns, we can mitigate their influences by applying a model considering spatial dependence (see, e.g., Schabenberger and Gotway 2004; LeSage and Pace 2009).

Based on the above, this study applies the spatial multilevel additive regression (SMAR) model, which is formulated as follows.

$$\ln(y_{i-j}) = \sum_{p=1}^{P} x_{i-j,p}\beta_p + \sum_{q=1}^{Q} f_q(z_{i-j,q}) + s(lon_j, lat_j) + u_j + \varepsilon_{i-j}, \qquad (2)$$
$$u_j \sim N\left(0, \sigma_u^2\right) \quad \varepsilon_{i-j} \sim N\left(0, \sigma_\varepsilon^2\right)$$

where $z_{i-j,q}$ is explanatory variables whose impacts are allowed to be non-linear (SMAR is a model considering both linear and non-linear influence). The non-linear influence from $z_{i-j,q}$ is modeled by the smoothing spline function, $f_q(\cdot)$. For the smoothing function, we used the conventional thin plate spline (Wood 2003). $s(\cdot)$ is the bivariate spatial smoothing spline function, and lon_j and lat_j are the longitude and latitude of the jth building. Here, we use the Tensor product smoothing operator for $s(\cdot)$ (Wood et al. 2013). Thus, non-linearity is modeled by $f_q(\cdot)$ while the omitted variables bias is mitigated by introducing $s(\cdot)$.[1] Equation (2) considers the multilevel structure using u_j, which is the building-level disturbance (variance: σ_u^2), and the building-level disturbance ε_{i-j} (variance: σ_ε^2). In this way, all three shortcomings of Eq. (1) have been avoided.

3 Empirical Analysis

3.1 Yokohama City

Our study area is the seven central wards of Yokohama city (Naka, Nishi, Minami, Isogo, Hodogawa, Konan, and Tostuka wards; see, Fig. 2). Yokohama is situated

Fig. 2 The 7 wards in Yokohama city

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[1] Although the spline function does not explicitly consider spatial dependence, the introduction of variables describing the map pattern of y_{i-j}, like the spline function, effectively captures the underlying spatial dependence and mitigates the omitted variables bias (spatial filtering; see, e.g., Getis and Griffith 2002; Murakami and Griffith 2015).

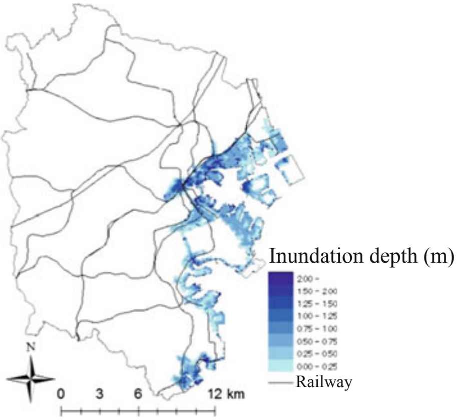


Fig. 3 Inundation area anticipated after the Nankai Trough earthquake

about 20 km south from the Tokyo central business district (CBD), and its population was 3.71 million in 2015. The seven wards include the city center around Yokohama station, a redevelopment area called Minato Mirai 21, and the biggest China town in Japan. They are all near the ocean. Also, many parks and historical buildings are found in the bayside area. Owning to them, the bayside area is a popular residential area.

On the other hand, as shown in Fig. 3, which displays the expected inundation area after the anticipated Nankai Trough earthquake, the bayside area is predicted to suffer from a flood due to the tsunami after the earthquake.

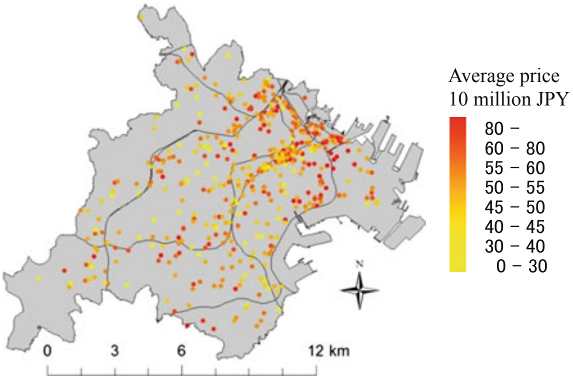
3.2 Condominium Data

We used the data on condominium prices from 1993 to 2008. The data were provided by Marketing Research Center (MRC) Co. Ltd. These price data were based on registration (seller pricing) and not on transaction (actual traded price). However, with regard to residential condominium prices in Japan, discount negotiation is considerably rare, except in cases of high-grade residences. Therefore, the registered price level is representative of the market situation. The average condominium prices in each building are plotted in Fig. 4. In our sample, the numbers of buildings and rooms are 694 and 27,446, respectively.

3.3 Explanatory Variables

Our hedonic analysis regresses flood risk variables, variables explaining positive influences from the ocean, and other variables.

Fig. 4 Condominium prices in the target area



We estimated the flood risk around the *j*th condominium building based on the flowing flood risk function proposed by Koshimura et al. (2009):

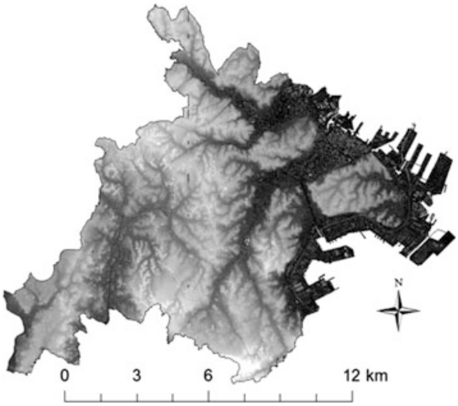
$$Flood_j = \Phi\left[\frac{F_j - \mu}{\omega}\right] = \int_{-\infty}^{F} \frac{1}{\sqrt{2\pi\omega^2}} \exp\left(-\frac{(F_j - \mu)^2}{2\omega^2}\right) df \qquad (3)$$

where F_j is the anticipated flood depth given by the flood map (Fig. 3), $\mu = 3.92$, and $\omega = 1.15$. Equation (3) describes the risk of being a victim. It is near zero if the flood depth is below 2 m, which means almost all people survive, whereas it is near one if it exceeds 6 m, which implies that almost all people are sacrificed. Note that Eq. (3) was used to estimate flood damage in Yokohama city. In addition to the building-wise indicator, we also introduced a dummy variable indicating 1 if the unit is a 1st floor unit in a flood-prone area, and 0 otherwise. This variable is needed to capture the greater risk in 1st floor units.

On the other hand, this study considers "Ocean dist.," which refers to the Euclidean distance to the ocean (log-scale), and "Ocean view," which is the visible ocean area (log-scale), as variables explaining the positive aspects of the ocean. Ocean view was calculated using a digital surface model (DSM: Fig. 5), which had been acquired from a LiDAR (Light Detection and Ranging) observation. Our DSM is a collection of 0.5 m by 0.5 m cells recording heights of the ground and objects on it such as buildings and trees. In a word, DSM describes 3D urban structure. Ocean view was calculated by counting visible ocean cells from each condominium unit within 500 m, which is assumed as the maximum visible range following Yasumoto et al. (2012). Note that we also calculated "Open view," by counting visible cells within 500 m, and "Green view," by counting visible tree cells. For further details about 3D visibility calculation, see, Yamagata et al. (2015a, 2016).

This study analyzes the trade-offs not only within ocean-related variables, but also other variables. To be specific, we evaluated the trade-offs between flood risk and landscape, natural environment, and accessibility. Table 1 summarizes the explanatory variables to evaluate flood risk. Based on a preliminary analysis,

Fig. 5 Digital surface model (DSM)



non-linear impacts were allowed for unit attributes (Area, Floor), Flood, landscape variables (Open view, Green view, Ocean view), and a time variable (Time).

3.4 Results

Table 2 and Fig. 6 summarize the linear and non-linear influences respectively, from explanatory variables ($x_{i-j,p}$ and $z_{i-j,q}$), estimated by the SMAR model. As discussed, this model considers (i) the multilevel structure, (ii) spatial dependence (to mitigate the omitted variables bias), and (iii) non-linearity. The Akaike Information Criteria (AIC) of the SMAR model was −79,053, whereas that of Eq. (1) ignoring (i), (ii) and (iii) was −36,557, the AIC of the multilevel model considering (i) was only −76,336, and the AIC of the spatial multilevel model considering (i) and (ii) was −76,407.[2] Thus, (i), (ii), and (iii) must be considered to quantify and infer the impact of each explanatory variable appropriately.

Table 2 displays statistically significant negative influences of "Semi Ind," and significant positive influences of "Green" and "Major dev." In other words, (semi-) industrial districts have negative economic values probably due to factors such as gas emissions and noise from firms, and poor landscapes; whereas green areas have positive economic values; and, condominiums developed by major developers are preferable. These results are intuitively reasonable.

Figure 6, which summarizes the non-linear estimates, suggests significant influences from "Area." "Floor," "Open view," "Green view," and "Ocean view." Estimates of "Area" and "Flood" simply demonstrate that larger and upper floor units are preferable.

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[2] If AIC is small, the model is accurate. Roughly speaking, two models have a significant difference in their accuracy when the gap of their AICs is more than 2.

Table 1 Explanatory variables, including risk, landscape, natural environment and accessibility variable (color table online)

Category	Variables	Description	Assumed influence
Unit attributes	Area	Logarithm of unit area [m^2]	Non-linear
	Floor	Logarithm of floor of the unit	
Building attributes	SRC	Steel reinforced concrete structure [dummy]	Linear
	WRC	Steel wall concrete structure [dummy]	
	Num.dev	Number of related developers	
	Major dev	Ratio of major developers called MAJOR 8[a]	
Risk	Flood	Death ratio estimates projected after the Nankai Trough earthquake	Non-linear
	Flood_1F	Dummy of 1st floor units in the flooded area	Linear
Land-scape	Open view	Logarithm of the visible area [km^2]	Non-linear
	Green view	Logarithm of the visible tree area [km^2]	
	Ocean view	Logarithm of the visible ocean area [km^2]	
Natural Environ.	Green	Logarithm of the number of tree cells within 500 m (irrelevant of whether or not visible)	Linear
	Park	Logarithm of the distance to the nearest urban park [km]	
	Ocean	Logarithm of the distance to the ocean [km]	
Access	Station	Logarithm of the travel time to the nearest train/bus station on foot [minute]	Linear
Location	C1 res.	Dummy of category 1 (C1) residential districts (RD)	Linear
	C1 low	Dummy of C1 low-rise exclusive RD	
	C1 high	Dummy of C1 medium-to-high exclusive RD	
	C1 exclusive	Dummy of C1 exclusive RD	
	C2 res.	Dummy of C2 low-rise exclusive RD	
	C2 high	Dummy of C2 medium-to-high exclusive RD	
	C2 exclusive	Dummy of C2 exclusive RD	
	Industry	Dummy of industrial districts	
	Semi Ind.	Dummy of semi-industrial districts	
	Commerce	Dummy of commercial districts	
	Neigh. Com.	Dummy of neighborhood commercial districts	
Time	Time	Elapsed months from January 1993 [Year]	Non-linear

[a]MAJOR 8 comprises Sumitomo Realty & Development Co., Ltd, Tokyu Land Corporation, Mitsubishi Estate Co., Ltd., Towa Real Estate Development Co., Ltd., Daikyo Inc., Nomura Real Estate Development Co., Ltd., Mitsui Fudosan Residential Co., Ltd. and Tokyo Tatemono Co., Ltd

Significant non-linear influences are found from landscape variables. The positive impact from “Open view” increases rapidly once the value exceeds a certain threshold (around 10, see Fig. 6). It suggests that while very nice view (in terms of the amount of visibility) may be capitalized into condominium prices, poor to moderate views might not. The estimates of “Ocean view” also suggest that ocean view has a positive impact only if the quality is prominent. The effect of “Green view” has also been found to be non-linear. That is, Green view has a statistically significant negative influence when it has a value of less than 6 or more than 10. It

Table 2 Estimated linear influences from $x_{i-j,p}$

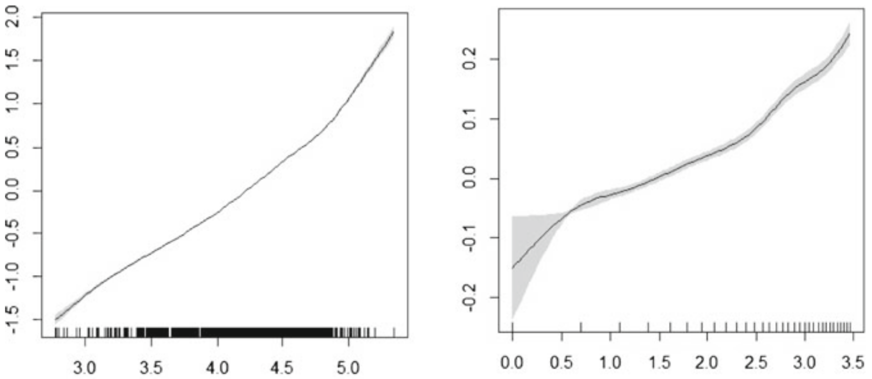
Category	Explanatory variables	SMAR	
		Coef.	*t*-value
Intercept	Intercept	7.784	38.46^{***}
Building attributes	SRC	−0.018	−1.20
	WRC	0.007	0.17
	Num.dev	0.007	0.62
	Major dev.	0.054	4.47^{***}
Risk	Flood_1F	0.094	2.01^{**}
Environment	Green	0.038	4.47^{***}
	Park dist.	−0.007	−1.54
	Ocean dist.	−0.003	−0.25
Access	Station dist.	−0.001	−0.19
Location	C1 res.	−0.027	−1.41
	C1 low	−0.020	−0.95
	C1 high	−0.002	−0.11
	C1 exclusive	0.003	0.11
	C2 res.	−0.003	−0.09
	C2 high	−0.007	−0.22
	C2 exclusive	0.005	0.18
	Industry	0.028	0.68
	Semi Ind.	−0.073	-3.38^{***}
	Commerce	−0.009	−0.41
	Neigh. Com.	0.005	0.26
See Fig. 5 for estimated non-linear influences from $z_{i-j,q}$			
AIC		−79,053	
Room level variance		0.0028	
Building level variance		0.0138	

Significant levels: ***0.1 %; **1 %; and *5 %

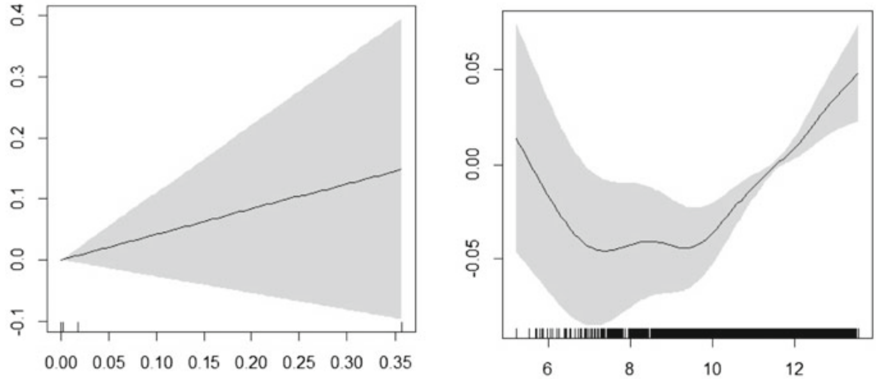
implies that a moderate amount of “Green view “is preferable, but scarce and too much “Green view” is not.

The signs of the economic values of natural environmental variables (Green: +; Park dist: −; Ocean dist: −) are also intuitively reasonable although only “Park” and “Ocean dist.” are statistically significant. The negative sign of “Station dist” is also reasonable. In summary, values of landscape, natural environment, and accessibility are reflected appropriately in this area.

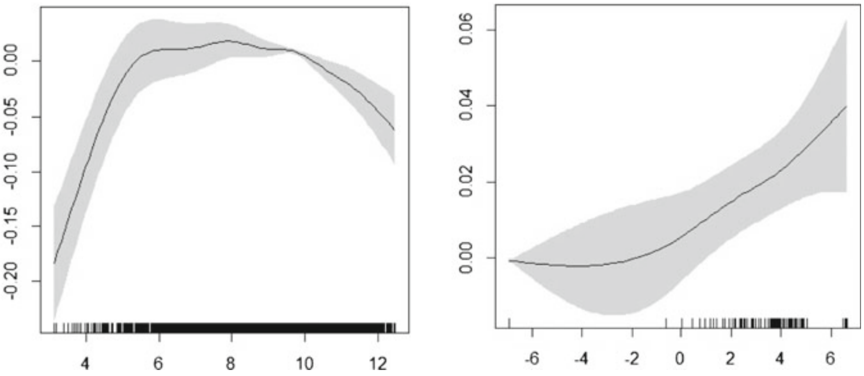
On the other hand, if Flood risk is appropriately recognized, Floor and Flood_1F must have negative signs. However, Floor is statistically insignificant with positive sign, and Flood_1F is positively significant statistically at the 5 % level. Thus, the flood risk might not be reflected appropriately as a negative factor. The result is consistent with a suggestion from the literature review in Sect. 2.1 that a clear negative premium of flood risk appears only if the area suffered from a major flood within the past several years (see, also Daniel et al. 2009).



Area Floor



Flood Open view



Green view Ocean view

Fig. 6 Estimation results (non-linear effects). The x-axis denotes the values of regressors, $z_{q,i-j}$, the y-axis denotes the estimated non-linear influences (i.e., estimates of $f(z_{q,i-j})$), and *grey shadowed regions* represent 95 % confidence intervals

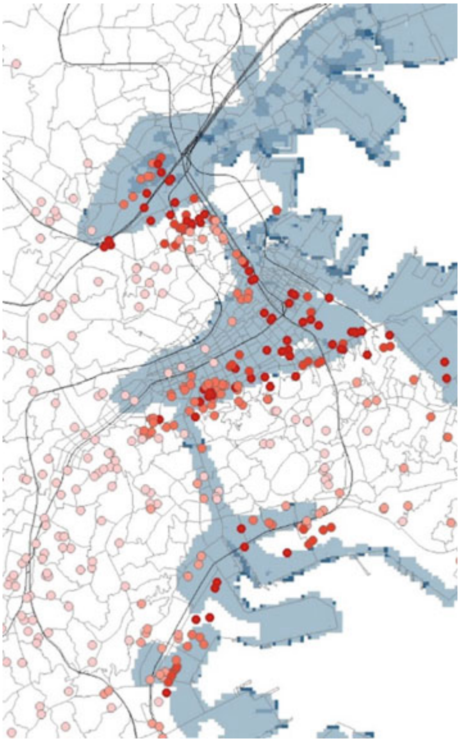


Fig. 7 Estimated marginal benefit from the ocean. *Red dots* represent condominiums. Condominiums with greater marginal benefit are colored by deep red. *Blue areas* denote anticipated flood areas (color figure online)

This ignorance or underestimation of flood risk can make urban form less adaptive to the flood risk. To examine it, estimated influences from the ocean are summed ("Ocean dist." + "Ocean view" + "Flood") and plotted in Fig. 7. This figure shows that, as a result of only "Ocean dist." and "Ocean view" being appropriately evaluated, the economic value of the anticipated flood zones is inflated. Note that Yokohama city provides flood risk information in multiple ways, including a web-GIS system and hazard maps. Our analysis result suggests that the web-GIS system or hazard map publication might not always reduce disaster risks efficiently. Considering the gradual increase of disaster risk, an urban policy that lowers disaster risks even if people underestimate risks, would be needed.

4 Concluding Remarks

This section quantifies the trade-off between flood risk and other factors, including landscape, natural environment, and accessibility. The analysis result revealed that the flood risk was highly underestimated in the study area whereas the other factors were appropriately evaluated. The underestimation of the risk would be partly due to the normalcy bias.

To increase the resilience to flood risk, an enforceable policy such as land-use regulation might be effective. Still, it is not clear how we can design such an urban policy in an efficient manner. Fortunately, since our hedonic analysis quantifies economic values of multiple factors, the results might be useful for establishing a policy preferable from multiple perspectives. Integration of the hedonic model, which can quantify economic values of micro-scale attributes (e.g., like location of trees and placement of dikes), and the spatially-explicit urban land-use model (e.g., Yamagata and Seya 2013; Yamagata et al. 2013, 2015b; see, Chapter "Urban Economics Model for Land-Use Planning"), which describes relatively global economic activities, might yield a powerful model for a sensible policy making. Furthermore, consideration of participatory censoring information might allow us real-time disaster risk management (see, Murakami et al. 2016). Extending the hedonic model and implementing it to actual policies would be an interesting research endeavor.

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Land Use Planning for Depopulating and Aging Society in Japan

Akito Murayama

Abstract This chapter, based on author's experience as a professor planner who works closely with local governments and consultants in Japan to draft master plans or planning guidelines, introduces several cases of land use planning for depopulating and aging society with various sudden and progressive risks. The cases include urban master plans for Yokosuka City, Shizuoka City and Suzuka City as well as Mie prefecture's planning guidelines for disaster mitigation. The author emphasizes that there is no universal approach to land use planning for depopulating and aging society. "Networked-Compact City" might be a broad concept to follow, but actual urban master planning practices show diversity of issues and approaches.

1 The Changing Planning Context

Cities in Japan are facing both progressive and sudden risks that should be considered in long-range land use and infrastructure planning. "Networked Compact City" or any other sustainable urban forms have been considered in many cities to respond to the progressive risks such as decline of working population, hyper-aging, economic stagnation, widening disparity, governments' financial difficulties and intensification of environmental problems including climate change, energy, biodiversity, food and water. Recently, more proactive planning measures are called for to respond to the sudden risks including major earthquake, tsunami, typhoon, isolated rain and volcanic eruption as planners and citizens saw the tragedy of the Great East Japan Earthquake in March 2011, the new estimations of potential damages by the next predicted major earthquake (Nankai-Trough Major Earthquake) and the flood damages by the increasing and intensifying occurrence of typhoons and isolated rains possibly due to the global climate change. It is inevi-

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table to direct the de-intensification or even the withdrawal of existing urban areas at high risks in long-range planning for Japanese cities.

There have been intensive discussions after the Great East Japan Earthquake in 2011 in urban planning and disaster prevention/mitigation fields how cities can prepare for the next major earthquake. The Draft Mie Prefecture Urban Planning Guideline for the Mitigation of Earthquake and Tsunami Disaster (2015), for example, organizes mitigation measures into three categories. The short-term measures that aim to protect people's lives within 10 years include the preparation and presentation of hazard maps including potential area of tsunami disaster, the development of evacuation ways and facilities as well as seismic strengthening of buildings and infrastructure. The mid-term measures that aim to protect urban functions and reduce damages in 20 years include the modification of land use regulations and the relocation of important facilities. And the long-range measures that aim to create safe and comfortable city in 50 years include the development of grand visions and transformation of urban structures. The mid-term and the long-term measures are related to long-range land use and infrastructure planning that should not only respond to the sudden risks of major earthquake and tsunami but also other sudden and progressive risks introduced earlier.

Consensus building and decision making processes for the transformation of urban structure including land use and infrastructure will be a great challenge as the transformation requires the partial changes in property ownership and lifestyles. The careful process should be led in the process of developing master plans for cities and regions as it is not about individual facilities but about the whole city or region. Participatory planning approach or co-working approach that emphasizes the link between different places and spatial scales and the learning process for planning professionals and various actors of society including citizens, businesses, governments and non-profit organizations seems to be the key for this transformation taking into account the reality of urban governance in Japan.

2 Urban Land Use Planning Concept and System in Japan

The current urban planning system in Japan has its foundation in the City Planning Act of 1968 that focuses on developing new urban areas and installing new infrastructure under the pressure of population growth. The City Planning Act provides for:

- Designation of City Planning Area and Quasi-City Planning Area
- Establishment of Master Plans for City Planning Areas (by the prefectural governments) and Municipal Master Plans (by the local governments)

- Land use regulations that include the division of the City Planning Area to Urbanization Promotion Area and Urbanization Control Area, the designation of zones and districts (12 category basic zones and overlay zones and districts) and the development of district plans that provide for detailed regulations and projects
- Development of Urban Facilities including transport facilities (roads, railways, terminals, etc.), public spaces (parks and green space, etc.) and supply/treatment facilities (water works, sewerage, waste management facilities, etc.) and others
- Implementation of Urban Development Projects including Land Readjustment Projects and Urban Redevelopment Projects

Implementation measures of land use regulation, urban facilities and urban development projects are presented in a City Planning Map of each local government or Urban Planning Area as shown in Fig. 1. A Master Plan provides basic policies of urban planning that will be the foundations of these implementation measures.

The current planners and researchers realize the need for a major transformation of the system to build more competitive, resilient and sustainable city under the totally new socio-economic and environmental conditions. However, it is difficult to change the established system, the designated measures and the existing urban environment. Therefore the only way to adapt to the changing conditions and to transform urban land use planning is to carefully re-develop prefectural and local master plans, i.e. basic policies of urban planning, that direct the implementation measures.

Recently, Siting Optimization (“Ricchi Tekiseika” in Japanese) Planning System under the Act on Special Measures Concerning Urban Reconstruction was introduced to promote “Networked-Compact Cities” by attracting urban functions and residents to areas well served by public transit. Local governments can designate areas to attract urban functions and residents within the Urbanization Promotion Area as illustrated in Fig. 2. The idea of this planning system is to maintain urban functions such as welfare, medical, commercial, etc. as well as population density in a city center and areas around transit stations while controlling developments and managing de-intensified or vacant lands outside the designated areas. This planning system can help local governments move forward to plan to mitigate progressive and sudden risks as it strengthens land use and infrastructure planning to “shape up” the existing built environment. Many local governments are now preparing Siting Optimization Plans or updating their Master Plans to define policies for their future Siting Optimization Plans. The greatest challenge is to draw the lines of Urban Function Attraction Area and Dwelling Attraction Area within Urbanization Promotion Area that result in defining area outside dwelling attraction area where people are likely to experience a decline of population and an increase of vacant properties.

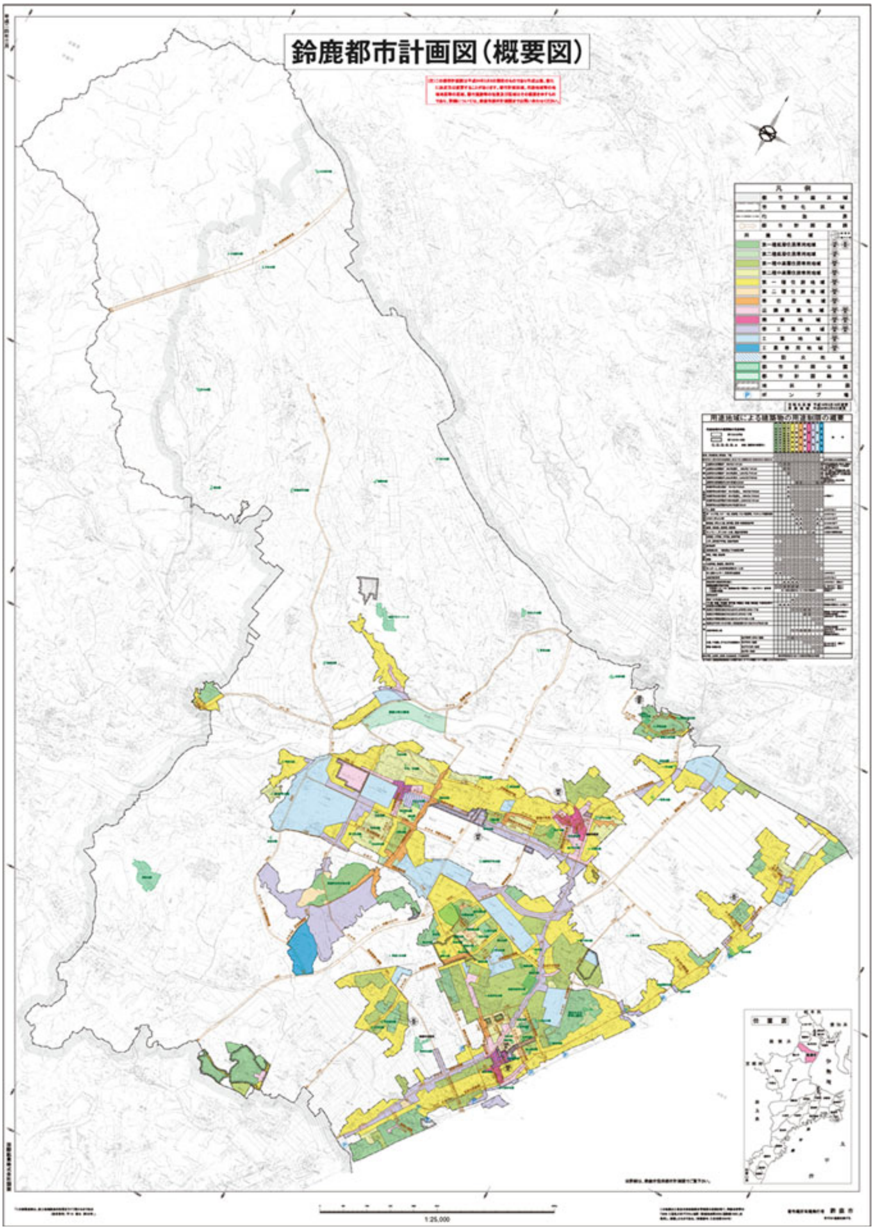

Fig. 1 Suzuka City planning map (*gray* boundary indicates Suzuka urban planning area, *white area* is urbanization control area and the *colored area* is urbanization promotion area with twelve category zoning. Urban facilities and urban development projects are also indicated in the map.)

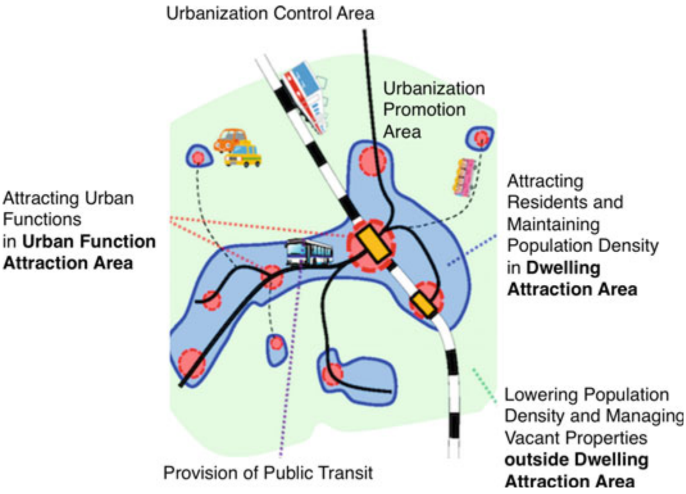

Fig. 2 The concept of siting optimization to promote "Networked-Compact City"

3 Implications from Experiences Abroad—A Brief Literature Review

Regarding land use planning for population shrinking cities, there have been several literatures that include implications to Japanese depopulating and aging cities.

Wiechmann and Pallagst (2012) compared various degrees, spatial patterns and reasons of shrinking urban regions in the United States and European Union. The authors explains that shrinking cities had not been on the agendas of politicians and planners, but now we need a new transatlantic discussion on policies and planning strategies to re-establish shrinking cities. Haase et al. (2013) explains that urban shrinkage is uneven in space and time, that reasons for shrinkage varies and that research on urban shrinkage should be changed from outcome-oriented approach to process-oriented approach. Lang (2012) states that, besides survey on the current conditions of urban shrinkage, political debate and normative consideration should be conducted. Lang also explains that spatial transformation is a result of social transformation, and the problems are social peripherization and spatial/social disparities. Mallach (2011) discusses about demolition and conservation in shrinking cities in the United States and shows there are demolished neighborhoods and conserved neighborhoods. Mallach states that it is more important to discuss about demolition and conservation of neighborhoods rather than individual buildings. Zaninetti and Colten (2012) analyzed Hurricane-hit New Orleans. Though the City of New Orleans had been experiencing depopulation for the past 50 years, the region as a whole had been sustaining population due to growth in suburban municipalities. However, after the disaster by Hurricane Catrina, the region has shifted to the shrinking mode and the city of New Orleans experienced a big change in the ethnic landscape.

4 The Recent Urban Land Use Planning Practices in Local Governments

This section, based on author's experience as a professor planner who works closely with local governments and consultants in Japan to draft Master Plans, introduces several cases of land use planning for depopulating and aging society with various sudden and progressive risks mentioned in the beginning of this chapter. The cases include the draft Master Plans for Shizuoka City, Yokosuka City and Suzuka City.

4.1 Shizuoka City—Sustaining a Mid-Sized Vibrant Regional City

Shizuoka is a regional city with the population of around 700,000 located between Tokyo Metropolitan Region and Nagoya Metropolitan Region. The population of the city is forecasted to decrease to less than 600,000 by 2040.

Figure 3 is the networked-compact city structure for Shizuoka City presented in the Draft Shizuoka City Master Plan (2015). First, urban centers, regional centers, industrial centers, potential industrial centers and sight-seeing/recreational centers are designated. Second, corridors of public transport (trains and arterial buses), arterial roads, Shinkansen (Super Express Train), industries, sightseeing/interaction and natural environment are shown. And third and the most important, "Convenient Urban Zone" and "Spacious Urban Zone" are designated within Urbanization Promotion Area while "Natural Harmony Zone" is designated in Urbanization Control Area. The division of Urbanization Promotion Area into "Convenient Urban Zone" and "Spacious Urban Zone" corresponds to the potential designation of "Dwelling Attraction Area" in the future Siting Optimization Plan.

As shown in Fig. 4, six types of dwelling lifestyles are envisioned in relation to the zone designation and the density concept. "Convenient Urban Zone", high-density, mixed-use urban areas in urban centers and around public transit or high-density single-family housing areas will increase its density, while "Spacious Urban Zone", mid-density single-family housing areas, and "Natural Harmony Zone", settlements in Urbanization Control Area, will decrease their densities. Thus Shizuoka City is taking challenges to shape "Networked-Compact City" urban structure even in the situation where the city is forecasting population decline as a whole. The most controversial zone is "Spacious Urban Zone" where it is likely to experience a decline of population even though the zone is located within Urbanization Promotion Area. The zone could be spacious and maintain property values if planned properly otherwise will see many unmanaged vacant homes and land.

The division of Urbanization Promotion Area into "Convenient Urban Zone" and "Spacious Urban Zone" was the most difficult task for the planners of the Draft

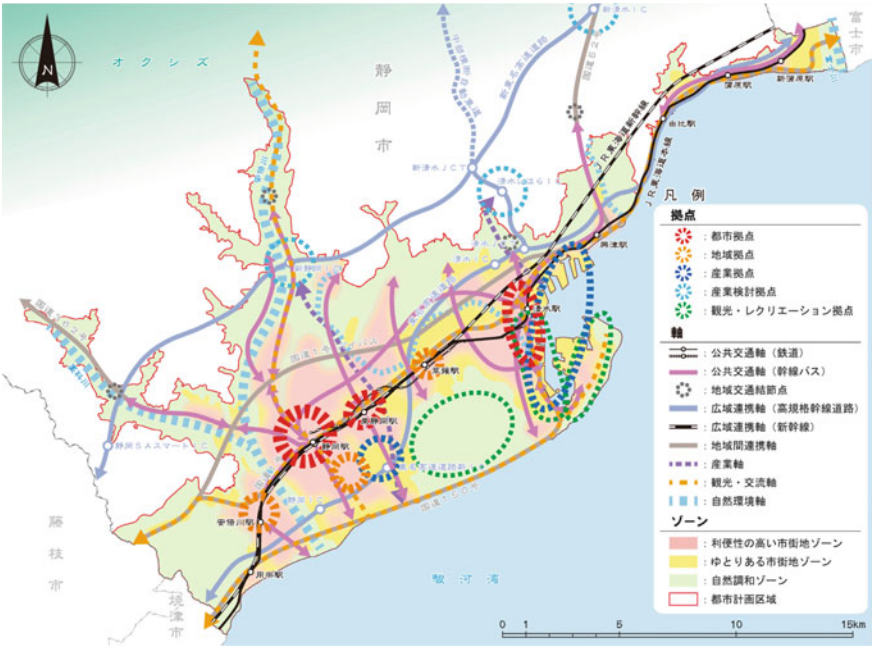

Fig. 3 Networked-compact city structure for Shizuoka City

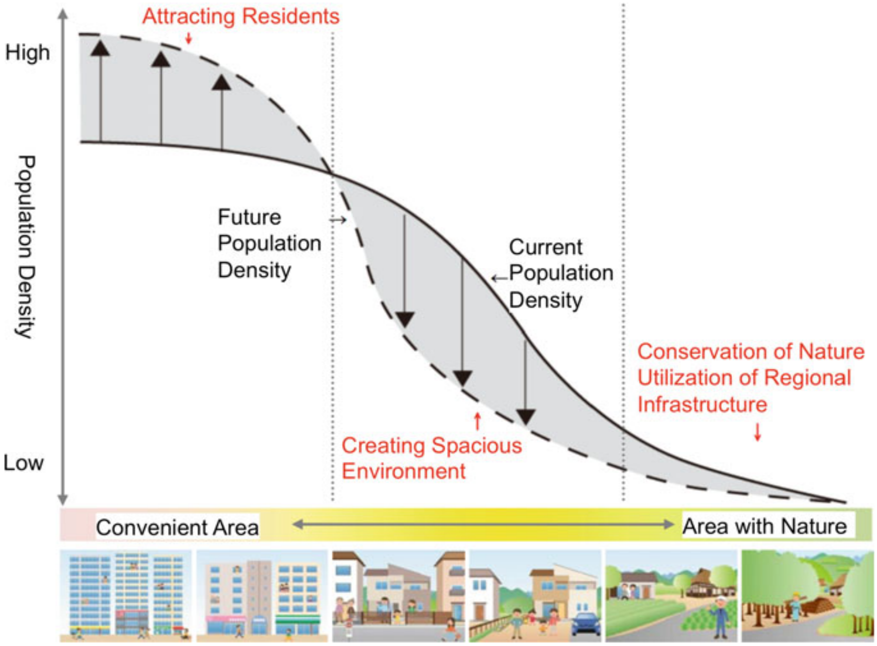

Fig. 4 Density concept and envisioned lifestyles of Shizuoka City

Shizuoka Master Plan. Planners, based on the analysis of various data related to population and household, land use and buildings, facilities, public transport, disasters, etc. defined where in the city is suitable to maintain or increase population to achieve economic, social and environmental sustainability under the conditions of population decline, hyper-aging, spread and dispersal of urban areas and less public money. They also defined vulnerable urban areas in the city where they are likely to experience flood damages by typhoon and isolated rains or tsunami damages by major earthquake therefore the decrease of population is favored in order to save the cost of damage and reconstruction. In addition, they considered the current trend of population growth or decline and some political elements.

After the planners presented a draft map of the networked-compact city structure of Shizuoka City to the planning discussion group consisting of experts of the related field and stakeholders in the city, the group conducted a workshop to confirm the merits and demerits of the proposed urban structure. The group recognized many merits as follows:

- It can cut development and maintenance costs of infrastructure such as roads and sewage systems
- People will be able to live in safe places outside flood or tsunami effected areas
- Urban center will revitalize
- Vacant buildings and lands can be utilized
- Livable residential environment can be created with the concentration of facilities
- Distance between home and workplace will be shortened
- Private services can be efficient with more people living in concentration
- Educational standard can be improved
- Forests, farmlands and natural environment can be protected from further urbanization

On the other hand, demerits were also recognized as follows:

- Traffic congestion will worsen with more density in urban centers
- The increase of mid or high rise apartment buildings will change the city's landscape
- Increase of buildings will decrease open spaces including children's playgrounds
- The increase of population will affect local communities
- Land value might decrease in the suburban area
- Conveniences in the suburban area will decrease

Through further discussion after the workshop in the planning discussion group, the group concluded that overall benefits of networked-compact city structure should be pursued, but at the same time, positive vision and effective implementation measures for urban areas with decreasing population should be urgently considered.

4.2 Yokosuka City—Issues of Rapidly Depopulating City in the Edge of Tokyo Metropolitan Region

Yokosuka City is a rapidly depopulating city in the edge of Tokyo metropolitan region after several manufacturing, research and development companies had left or downsized. The population of 2010 was around 420,000 and it is forecasted to decrease to less than 340,000 by 2035.

The result of categorization of residential areas (Category I exclusively low-rise residential zone, Category II exclusively low-rise residential zone, Category I mid/high-rise residential zone and Category II mid/high-rise residential zone under the City Planning Act) in Yokosuka City shown in Fig. 5 implies:

- Some neighborhoods are still experiencing population/household growth
- Many neighborhoods are experiencing population decline (due to separation of households) followed by the decrease in number households.
- The older neighborhoods in valleys or mountainous areas with low quality infrastructure are already under pressure of decline.
- City is not shrinking physically like a balloon, but rather transforming itself in a complex manner

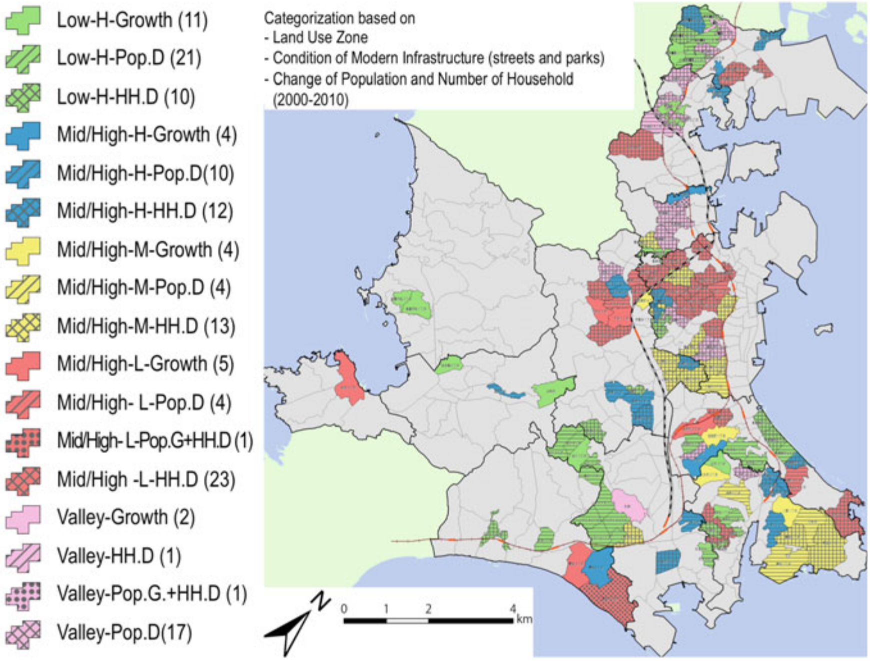

Fig. 5 Categorization of residential areas in Yokosuka (*Low* low-rise residential zone; *Mid/High* mid/high-rise residential zone; *Valley* residential and forest; *H* high quality infrastructure; *M* mixed infrastructure; *L* low quality infrastructure; *Growth* population and household growth; *Pop.D* population decline; *Pop.G* population growth; *HH.D* household and population decline (*Data Source* Yokosuka city planning map, national census 2000, 2010)

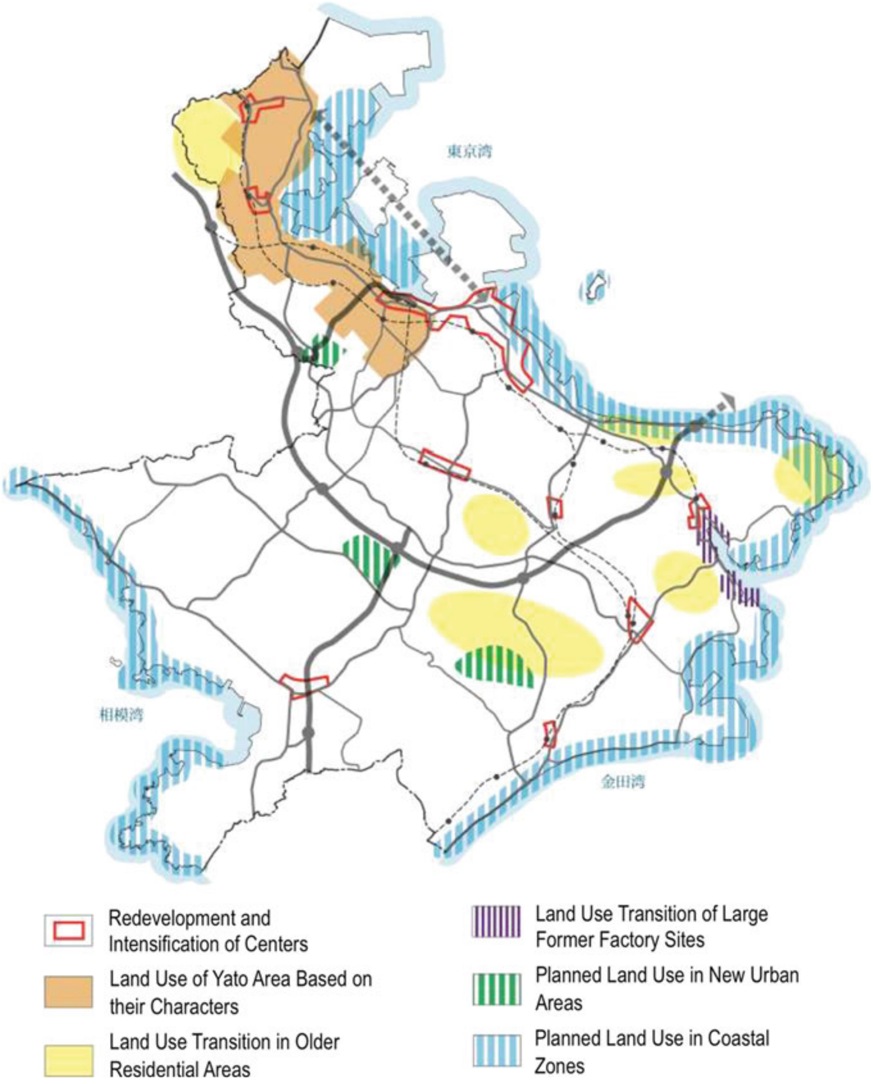

Fig. 6 Land use transition policy for Yokosuka City

The Draft Yokosuka City Master Plan (2015) aims to mitigate the rapid population decline by creating urban attractiveness and to adapt to inevitable population decline by clearly setting a policy to consider de-intensification or even the withdrawal of existing urban areas. The current potential areas to withdraw are some of the Yato Areas (the valley-shaped landform created as a result of the erosion of hills) with stairs, slopes, narrow and curved roads and small parcels. In the near future, the planned residential areas with high-quality infrastructure developed in the 1970s are expected to experience depopulation resulting in considerable amounts of vacant houses and lots as baby-boomer residents pass away. Figure 6 shows a land use transition policy in the draft urban master plan.

Although the draft master plan sets the above policy, no concrete areas are designated subjected to de-intensification or withdrawal, and no effective implementation measures is presented. This is the limitation of a top-down master planning where the planners have no opportunity to discuss closely with stakeholders in potential de-intensification or withdrawal areas. Participatory planning approach or co-working approach at a neighborhood level is essential to designate these areas in the master plan. How to plan and design the transformation process for de-intensification and withdrawal is a big question to answer through the discussion among planners and stakeholders. The city will work on this in the future Siting Optimization Planning process.

4.3 Suzuka City—Reorganizing a Small Dispersed Automobile City in Nagoya Metropolitan Region

Suzuka City is an industrial city with automobile and textile related plants with the population of around 200,000. Although the city has been experiencing population growth in the past, the city is likely to see the slow decline of population in the future. The city has dispersed urban structure and it is far from the illustration of Siting Optimization Planning to promote networked-compact city (Fig. 2). The Draft Suzuka City Plan (2015) proposes policies with accompanied maps for the five themes of vibrant urban development, disaster prevention and mitigation, compact settlements, high mobility and water, greenery and landscape. The followings are the highlights of the proposal:

- Vibrant Urban Development
    - Intensification of urban centers for retail revitalization
    - Land use to promote new industries and regional interaction
    - Smooth network of arterial roads and adequate roadside land use
    - New developments near Suzuka Interchange and Suzuka Parking Area Smart Interchange
    - Maintenance and revitalization of existing industries to support residents' life and employment
- Disaster Prevention and Mitigation
    - Promotion of measures for earthquake/tsunami, floods and landslides including the consideration of re-zoning in low-rise residential area along the coast with 10 m height limit
    - Promotion of disaster prevention and mitigation in high density urban areas
    - Development of evacuation places and routes

- Compact Settlements
    - Intensification of land use and attraction of urban functions in major centers
    - Conservation and development of high-quality residential areas in Urbanization Promotion Area
    - Conservation and planned development of designated existing settlements in Urbanization Control Area
- High Mobility
    - Building a network of safe and smooth roads
    - Universal design of neighborhood streets, school routes and bicycle lanes
    - Better public transport services and improvement of conveniences in transport nodes

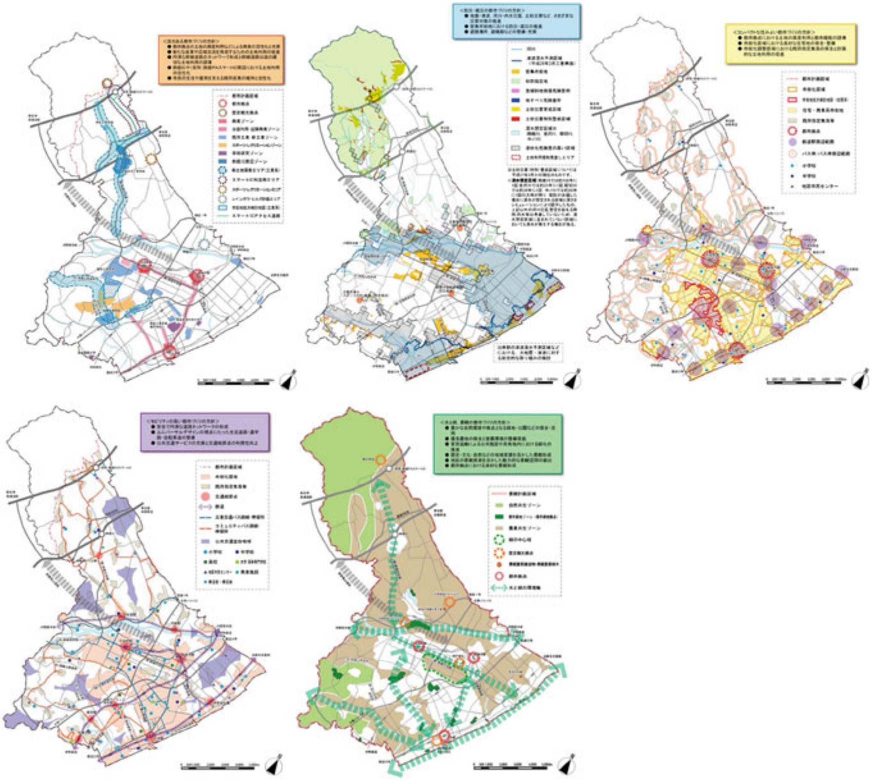

Fig. 7 The thematic policy maps for Suzuka City (from *top-left* to *bottom-right*: vibrant urban development, disaster prevention and mitigation, compact settlements, high mobility, water, greenery and landscape)

- Water, Greenery and Landscape
  - Conservation and utilization of abundant natural environment and hubs of green spaces and parks
  - Conservation of high-quality agricultural land and promotion of sustainable agriculture
  - Promotion of greening in public facilities and private properties
  - Landscape based on history, culture and natural resources
  - Creation of attractive landscape (Fig. 7)

Based on the thematic policy maps, existing land use zoning and existing land use, the land use policy map shown in Fig. 8 was created. This is an example of reorganizing the dispersed urban structure to respond to the current issues of the city and the urban structure is far from the illustration of Siting Optimization Planning to promote networked-compact city (Fig. 2).

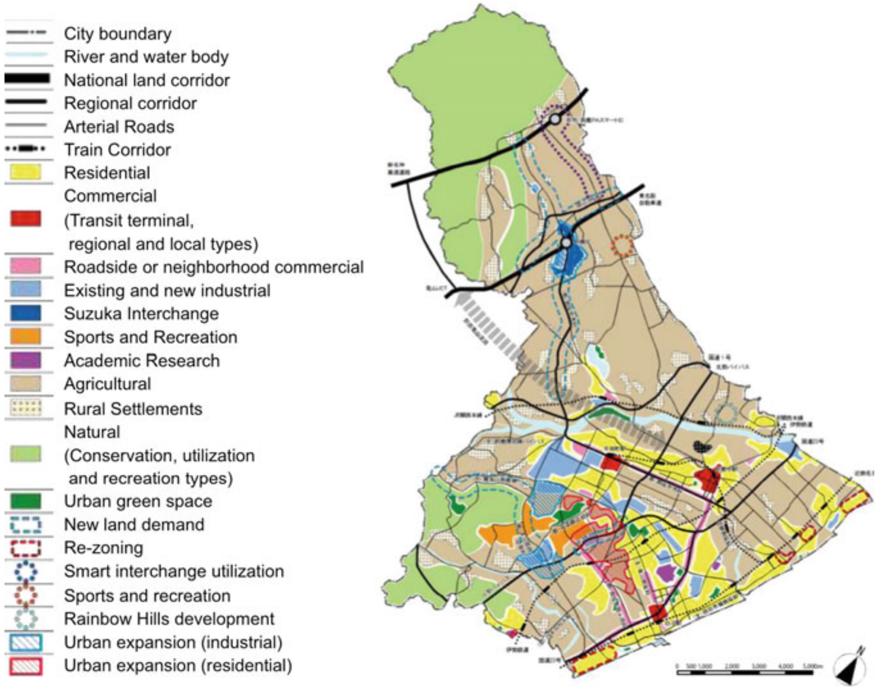

Fig. 8 Land use policy map of Suzuka City

5 Conclusion

There is no universal approach to land use planning for depopulating and aging society. “Networked-Compact City” might be a broad concept to follow, but actual urban master planning practices show diversity of issues and approaches. Shizuoka City was able to come close to the aim of the Siting Optimization Planning System by dividing Urbanization Promotion Area into “Convenient Urban Zone” and “Spacious Urban Zone”. Yet the boundary of the above two zones is still vague and detailed consideration will be needed in the upcoming Siting Optimization Planning process. Yokosuka City, although it clearly sets a policy to de-intensify or even withdraw parts of the existing urban area, it avoids to show the potential areas on maps. Suzuka City carefully organized its policies along the five themes and the resulting land use policy map does not resemble the concept of siting optimization to promote “networked-compact city”. However, both Shizuoka City and Suzuka City recognize disaster-vulnerable areas to be de-intensified or to be cared in other ways of land use planning.

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Part III
Responding to Shocks

Perception-Based Resilience: Accounting for Human Perception in Resilience Thinking with Its Theoretic and Model Bases

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Abstract We have previously introduced the concept of perception-based resilience that accounts for the impact of human perception in resilience thinking. In this paper, we further this concept as we argue for our novel perception-based resilience model by elucidating its theoretic and model bases and how they fit coherently in the model. To provide traces of evidence to support our model, we analyzed thousands of social media contents that were posted during an actual disaster, and we framed our analyses based on the various aspects of our model. In doing so, we moved our analyses beyond the anecdotal and conventional contribution of social media-based analysis and contribute a novel high-level analysis of social resilience.

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1 Introduction

We have argued for the notion that human perception can explain why the resilience of individuals and communities may differ in the course of unfolding, or in the wake of, shocking and stressful events despite being presented with the same forms of stimuli (e.g., facts, conditions, support, assurance, and resources)—hence, *perception-based resilience* (Legaspi et al. 2014). Resilience has become a viable conceptual tool in elucidating how people respond to many changing hazards of different nature (Jones and Tanner 2016). For instance, we have seen how the existence of communities are significantly altered due to massive devastations in terms of human lives, livelihoods and infrastructures brought about by natural hazards, such as Katrina of 2005, the Haiti earthquake of 2010, the triple disaster of 2011 in Tohoku, and Haiyan of 2013, all of which brought significant human and economic losses. Communities were not only evacuated, but even worse, they were uprooted permanently as the natural and physical environments that once supported their existence were completely destroyed. We have also seen the heart-wrenching scenes of millions of escapees and refugees from war-torn countries who had no choice but to uproot themselves from their habitation. They crossed international borders through sea and land, battled the elements against all odds, and found new dwellings in lands whose people, language, and culture are totally foreign to them. They adapted, and even transformed the objective and nature of their existence, if only to survive. With looming world crises, resilience has rapidly found itself at the top of global development agenda (Jones and Tanner 2016).

It is the case, however, that since resilience as a concept is fraught with complexity (Jones and Tanner 2016), we previously developed a taxonomy for general resilience (Maruyama et al. 2014). Our taxonomy contextualizes resilience into four dimensions, i.e., in terms of the nature of the system and the shocks and stresses that perturb it, and the phases and kind of resilience that the perturbed system may undergo. What is significantly missing in our taxonomy, however, is the important notion that our responses to perturbations from a range of hazards, be it environmental, physical, social, or technological (e.g., accidents, disasters, terrorist attacks, cyber attacks, economic depression, pandemics, and social upheavals, among others) are conditioned by our perception of each of the resilience dimension (Legaspi et al. 2014), as well as our subjective assessment of our own resilience and that of others (Jones and Tanner 2016). Consequently, our perception influences our behavior that leads either to our resilience or vulnerability in the face of extreme constraints, sub-optimal conditions, or unexpected changes (Legaspi et al. 2014).

Our aim has been to account for the impact of human perception on resilience thinking and how collective behavior emerges from the dynamics of individual perceptions (Legaspi et al. 2014). In this paper, however, we argue for a novel perception-based resilience model by elucidating its theoretical and model bases. Furthermore, in contrast to the analysis we provided in Legaspi et al. (2014) that was derived from agent-based simulations, we analyzed here an actual disaster brought about by a natural hazard that happened in Thailand in 2011. Our analysis provides evidence to support our perception-based resilience model.

2 Perception, Behavior, and Social Resilience

Perception is the process in which we actively and intentionally (Lang 1994) acquire, organize, recognize, and interpret the sensory information we receive in order to make sense of what we perceive (Ittelson et al. 1974; Schacter et al. 2011). We achieve recognition and awareness of what we perceive through our memory, knowledge, learning, attention, expectation, motivation, and experience (Bernstein 2008; Gregory 1987; Johns and Saks 2001). Therefore, perception allows us to take in all or part of the sensory information presented to us, and transform them into something meaningful (Gärling and Golledge 1989). Perception then includes how we respond to the information we receive (Gärling and Golledge 1989). An input to our perception triggers in us a psychological (i.e., both cognitive and affective) response, and on the basis of this response, we perform an action (Golledge 1987). Experimental psychologists have documented how human behavior can be unconsciously influenced by the knowledge we possess that is activated, in most cases unintentionally, in memory during perception (Ferguson and Bargh 2004). Hence, perception can automatically influence behavior. Psychologists have also long investigated the significance of the perception-behavior link, i.e., perception is crucial in our understanding of a wide-range of social phenomena (noteworthy survey in Dijksterhuis and van Knippenberg 1998) (Legaspi et al. 2014).

It has been premised that we have a good understanding of *our own* capabilities, as well as limitations, to prepare for, meet head on, and withstand hazards. Jones and Tanner (2016) call this *subjective resilience*, which relates to our cognitive and affective valuation of our own capacity to adapt to adverse changes. It also relates to the notion that our resilience is comprised of the availability of both objective (e.g., various livelihood assets) and subjective (e.g., social, cultural and psychological elements, such as beliefs, norms, social cohesion, and cultural identity) elements. Carpenter et al. (2009) cited actual events that challenged the notion that experts are in the best position to assess situations, evaluate people's lives, and provide solutions, and highlighted the fact that individuals have a good understanding of their own capabilities to deal with hazards. They admonished that our society should engage evaluative perceptions on all levels and not just heavily rely on dominant models, i.e., the by-product of the monoculture of few experts, since they can emphasize narrow, segregated, domain-dependent, and incomplete views. They noted, for example, that crucial information provided by village hunters and loggers prompted new approaches that saved species from endangerment or sudden demise. Another example is the research of Howe et al. (2013) on global perceptions of local temperature changes, which showed that those who actually live and experience rising average temperatures can perceive local warming more accurately than others (e.g., those who spend most of their day in air-conditioned places).

Ultimately, in resilience thinking, our individual perceptions are part of the larger whole since we interact with and within larger systems and networks that are social, ecological, physical and technological. These systems are intricately connected and contain continuous flow of resources, information, energy, and capital with the resilience of any component (which includes us humans) critically depending on its place in the system and how it, and the entire complex system, can withstand many changing shocks and stresses (Legaspi and Maruyama 2015). Moreover, our perception will affect our resilience thinking (Legaspi et al. 2014), as our perception is shaped by the various forces exerted upon our systems that may dynamically change in the course of unfolding, or in the wake of, perturbations or adverse changes (Bernstein 2008; Gregory 1987; Johns and Saks 2001; Downs and Stea 2011; Tuan 1974). In human development, Masten and Obravodic noted that research on individual resilience involves investigating how the individual, as a complex living system, interacts adaptively or maladaptively over time with the systems in which it is embedded (Masten 2001; Masten and Obradovic 2008). Another example is that some people would situate their perceptions within broader social and physical contexts that link the individual, the social organization, and the culture in which they operate (Jones and Tanner 2016).

In the wider context of social resilience, our perceptions will allow us to answer the questions, "*Resilience to what?*" and "*Resilience for whom?*" As Keck and Sakdapolrak (2013) pointed out, all concepts of social resilience concern social units, from individuals and households to organizations or communities, and their ability to be resilient to environmental and social hazards. They also reiterated what Obrist et al. (2010) have pointed out, i.e., the initial inquiry in empirical social resilience investigation is to examine the threat or risk. The relevant aspect of the second question is whether the individual is focused on self or others, as each would likely produce different consequences. Consequently, we choose our behavior depending on how we perceive the risk and who is at risk.

3 Our Perception-Based Resilience Model and Its Theoretical and Model Bases

To answer the two questions above, i.e., being resilient against what and for whom, we looked at certain theories and models of how people choose to behave when faced with hazards depending on the target of their resilience. We started with those that link threat perception to self-protective behaviors. The notion is that our motivation to protect ourselves results from a perceived threat and our desire to avoid the threat's potential negative outcomes (Floyd et al. 2000). The notion of self-protection stems from them being designed for the health domain wherein the concern is inherently the individual patient protecting himself from harm. One model, however, also showed that this concept of self-protection can be found in another domain with a global hazard, specifically, climate change. We then looked at theories on empathy, i.e., perceiving the thought, affect, intention, and/or situation of another, expressing an understanding of this perception, attempting to project oneself into the state of the other, and possibly extending support and help provisions (Stotland et al. 1978; Ickes 1993; Preston 2007). We briefly explain here each of the theories and models, pointing to their significance in the literature and their relevance to our objective. We then elucidate the various components of our perception-based resilience model as derived from these theories and models.

3.1 Theories and Models

We begin with the *protection motivation theory* (PMT) (Rogers 1975; Rogers 1983; Rogers and Prentice-Dunn 1997), which is one of the four key theories on psychological health behavior change models (Floyd et al. 2000; Grothmann and Patt 2003) [together with the health belief model (Rosenstock 1974), theory of reasoned action (Fishbein and Ajzen 1975; Ajzen and Fishbein 1980), and the subjective expected utility (Savage 1954)]. The PMT, however, is the only one that has self-efficacy as a distinct component (Floyd et al. 2000). Self-efficacy refers to one's confident view of his or her capability to reach the level of performance necessary to influence life events (Bandura 1994). Self-efficacy beliefs determine how people think, feel and behave (Bandura 1992, 1994). In relation to resilience, self-efficacy helps one deal with certain shocks and stressors in life (Schwarzer and Warner 2012).

The PMT was based on the work of Lazarus (1996) that explained how people behave and cope during stressful situations. It was originally created to help better understand fear appeals on health attitudes and behaviors (Rogers 1975), and was later on extended to emphasize the cognitive processes mediating behavioral change (Rogers 1983; Rogers and Prentice-Dunn 1997). It is assumed that through fear appeal the perception of threat elicits fear, which, as an unpleasant affective state, motivates an individual cognitively, affectively, and behaviorally to protect himself by either alleviating the threat or reducing the fear (Ruiter et al. 2001).

Next is the *extended parallel process model* (EPPM) that borrowed heavily from the PMT and two other theories, namely, the fear-as-acquired drive model and parallel process model (Popova 2012). In the fear-as-acquired drive model (Hovland et al. 1953), it is only after fear is experienced that an individual is motivated to reduce the fear, and any action that successfully reduced it then becomes the habitual response to the same threat when it is experienced in the future. Hence, EPPM adopts the notion that threat is appraised first and it is only when the susceptibility to and the severity of the threat are high that the perceiving individual experiences fear arousal. If the level of threat reaches a certain threshold, then fear is aroused and the individual is motivated to make an efficacy appraisal. The contribution of EPPM is that it specified the conditions under which greater fear may actually lead to maladaptation (Popova 2012) (e.g., defensive mechanism

(Popova 2012), wishful thinking (Grothmann and Patt 2005), fatalism (Grothmann and Patt 2005), etc.).

Last in our list of self-protection models is the *model of private proactive adaptation to climate change* (MPPACC) (Grothmann and Patt 2003, 2005) that extended the broad appeal of the PMT beyond the health domain and applied it to a global natural hazard. The MPPACC extended the PMT to include socio-cognitive factors with perceived adaptive capacity as a main determinant of adaptation. MPPACC differentiated perceived (i.e., as affected by cognitive biases, judgment heuristics, experience appraisal, etc.) and objective (i.e., resources such as money, entitlements, staying power, institutional support, etc.) adaptive capacities. MPPACC also distinguished intention and motivation from actual behavioral adaptation. A person may intend an action, but not carry it out due to lack of objective adaptive capacity. Hence, the MPPACC made more explicit the role of perceptual processes. In terms of its social dimension, MPPACC added reliance on public adaptation and social discourse as perceived inputs.

MPPACC incorporated socio-cognitive variables since they have been shown to influence people's intentions and actions (Grothmann and Patt 2005). Similarly, empathy (Preston 2007; Preston and de Waal 2002; Davis 1996; Hoffman 2000), which is a social phenomenon with both cognitive and affective components, influences our behavior. However, unlike the previous concepts that are self-protective, empathy places the person in the "shoes of another"—as its German term einfühlung refers to projecting oneself into the object being perceived (Preston 2007).

The *perception-action model* (PAM) (Preston 2007; Preston and de Waal 2002) for empathy posits that empathy is shared between the perceiver and the object when the perceiver feels the same emotions as the object's. According to PAM, there are processes that must take place in order for the perceiver to have the ability to empathize, namely, the perceiver must be able to attend to the object, feel the same emotional state as the object's, and respond appropriately to the object while maintaining focus on the object and yet not being affected by the distress of the object. Furthermore, with PAM, whether the perceiver empathizes to the object depends crucially on their interrelationship and interdependence—the stronger their ties are, the more similar representations will be activated and the more the perceiver will respond appropriately to the object's situation or predicament.

3.2 Perception-Based Resilience Model

Figure 1 shows the cognitive, affective, and behavioral processes of our perception-based resilience model, which we now detail. Unless the specific theory or model (as per Sect. 3.1) from which a component is derived is indicated in parentheses, the component is assumed to be present in all the theories and models. We start with the various components of the hazard and response appraisals.

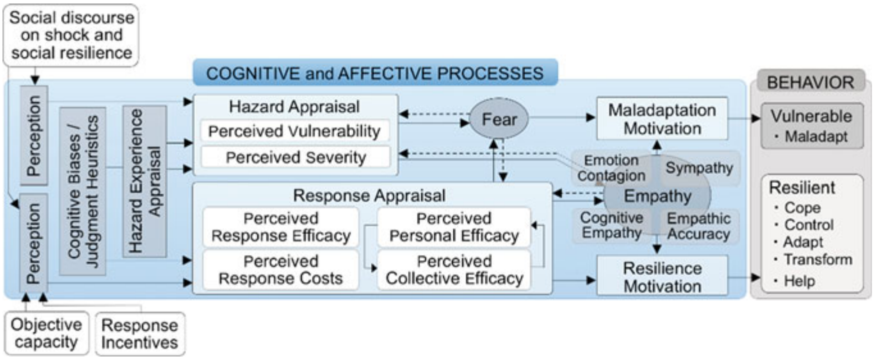

Fig. 1 Our perception-based resilience model with its components derived from different theories and models, namely, protection motivation theory, extended parallel process model, model of private proactive adaptation to climate change and perception-action model

We use the term *hazard*, instead of threat (in PMT and EPPM) and risk (in MPPACC), to mean hazards that are impending (threatening), ongoing, or ensuing and cause shocks or stresses. We explained in our taxonomy (Maruyama et al. 2014) that a hazard may be geophysical (e.g., earthquake, powerful typhoon, tsunami) or biological (diseases or infestations), or can be man-made (e.g., cyber-attacks, terrorism, war). It may also be endogenous or exogenous to the system. While some hazards happen frequently, which make them more predictable and preventable, others are unexpected, which makes it difficult even for state-of-the-art technologies to accurately predict their occurrence. If the hazards are due to slow drivers (e.g., climate change) then we can plan to revert the on-going effect, which, on the other hand, will be difficult if they are instantaneous or unexpected. Perceived *vulnerability* (MPPACC calls it *probability*) refers to the perceiver's expectancy or her perceived likelihood of being exposed to the hazard. Perceived severity is the perceiver's appraisal of the extent of harm posed by the adverse outcomes of the hazard to what she values (e.g., loved ones, properties, belongings, etc.). *Hazard experience appraisal* (from MPPACC) is an assessment of the severity of a similar hazard based on past experiences.

Second, we use the term *response* to encompass the actions that relate to coping (in PMT) or persisting (Legaspi and Maruyama 2015), controlling (in EPPM), adapting (in MPPACC), or transforming (Legaspi and Maruyama 2015) in the midst of an impending, ongoing, or ensuing hazard with its shocks or stresses. These responses motivate resilient behavior (Legaspi and Maruyama 2015). Perceived *response efficacy* (*adaptation* is the response in MPPACC) is the belief that the response will produce the intended outcome. Perceived response costs are the assumed costs associated to particular responses. Perceived *personal* (or self-) *efficacy* is the perceiver's confidence in his ability to actually perform the response.

What we added in the response appraisal, as it is not present in the other theories and models we mentioned, is perceived *collective efficacy*. As we explained earlier, social resilience requires collective response to produce the desired results. We are most of the time a household, town, organization, country, or even a global community when we respond to wide-scale or extreme hazards. Bandura (1998) clearly explained this concept as follows: Collective efficacy refers to the people's shared belief in the power of their collective responses to produce their desired or intended outcome. Bandura also explained that self and collective efficacies are related since self-efficacy contributes to group-directedness, i.e., to accomplish together, each member has to contribute with a high sense of self-efficacy. However, collective efficacy also impacts personal efficacy either positively as it provides motivation and encouragement when self-efficacy is low, or negatively as we take less precaution and do little when we rely too much on public response (Grothmann and Patt 2005).

Our appraisal is affected by, at the same time impacts, our fear and empathic arousals. EPPM posits that it is only when fear is aroused that responses are appraised. However, it is possible that even in the absence of fear, an individual may be motivated to respond due to empathy. Hence, we added the empathic dimension, which is not present in PMT, EPPM, and MPPACC. Preston and de Waal (2002) and Preston (2007) explained well in PAM the ultimate and proximate bases of empathy as follows: *Emotion contagion* means that the same emotions are aroused in the perceiver as a result of perceiving the object of empathy, but the perceiver does not attend nor respond to the object's situation. *Sympathy* means that the perceiver feels sorry for the object but may or may not help depending on his perceived response costs. *Cognitive empathy* means that the perceiver has accurate representation of, but not necessarily matching mentally or emotionally, the object's situation or predicament. Helping behavior is more likely demonstrated towards familiar or similar objects. *Empathic accuracy* refers to having a matching emotional state, and helping behavior increases or decreases with familiarity or similarity with the object's situation or predicament. An empathic perception would normally motivate a person to be altruistic and to help, which is a pro-social resilient behavior. However, it is also possible that the perceiver may have empathically identified with the object but dismissed any intention to help and instead resorts to maladaptation.

An individual perceives various input information that impacts her appraisal. Social media has become the fertile ground for social discourse on a topic to root and grow. It has become a novel mechanism and source of new information that enables societies worldwide to organize themselves and communicate (Poblete et al. 2011). Perception of *social discourse* (in MPPACC) is important as our cognition is shaped by the message contained in the discourse (Popova 2012; Grothmann and Patt 2005). Unlike perception that is subjective, hence hard to measure, *objective capacity* (in MPPACC) can be measured through socio-economic indicators (Jones and Tanner 2016) and quantified by tangible resources (Grothmann and Patt 2005). Lastly, *response incentives* (in MPPACC), e.g., tax reductions, motivate positive response.

4 Case Study: The Thai Flood of 2011

The flood in late 2011 was one of the largest that Thailand ever experienced. In that year alone, large areas in all regions suffered several floods. The largest one, however, was between July and November that impacted the northern and central regions. This was a result of heavy rainfalls caused by multiple tropical storms. The capital, which is Bangkok, and its suburb also experienced critical situations in many of its densely populated areas. In fact, this capital metropolis had never been inundated since 1942. Furthermore, the flood affected the country both socially and economically. Several assessments conducted by independent organizations provided details on the severe consequences in agricultural and industrial sectors, education, tourism, public heath, and communications (Policy and Planning Bureau and Ministry of Interior 2015; World Bank 2016).

While the government, with local and international support, led the role in protecting, rescuing, and helping the country recover, the community in and by itself should be resilient. We found evidence of this resilience in Twitter where several online communities, both existing and newly formed, communicated to ask and provide help, share information, and warn others. Some of the online communities tended to focus on specific issues, e.g., volunteer requests and traffic reports, while others forwarded various kinds of information to a wider audience. We believe that all of these online communities together contributed to achieving social resilience.

We obtained tweets that were collected by the website *thaiflood.com*, analyzed them, and presented here the summarized information about the flood. Our main objective, however, is to understand how people perceived the situations and how online communities contributed to a collective perception.

4.1 The Hazard

From July until November of 2011, the flood that resulted from five storms caused more than 800 deaths in the northern, northeastern and central Thai regions. It affected roughly four million households and left more than 13 million people in need of help. As a result, 65 provinces declared a state of emergency. The World Bank estimated the cost of all damages and losses to be USD 46.5 billion, with losses accounting for 56 % of the total (World Bank 2016).

Multiple sectors were simultaneously severely affected. More than 2000 schools were inundated costing approximately USD 38.4 million. The agricultural sector experienced even greater devastation. According to the National Disaster Warning Center, 130,041 farmers were affected by the flood. The industrial sector was not spared as well as many industrial estates suffered severe damages. Inundated factories caused a shortage of exported commodities. Furthermore, the tourism industry took a blow as tourists who were supposed to come to the country changed their plans after several countries issued a warning. As for the locals, they had no choice but to exercise extreme caution in the midst of possible pandemic, poisonous animals, hazardous garbage, shortage of medicines, injuries, life-threatening accidents, and mental issues. It became even more difficult to cope with the problems or to provide help as communication infrastructures, particularly roads, were disconnected that isolated many communities.

4.2 Twitter Analysis

To account for people's perception of the disaster that ensued due to the flood, we realized that the thousands of tweets that were posted during that time were a good source of information. We collected tweets that contained the hashtag *#thaiflood* from the website thaiflood.com. This website collected 651,183 tweets from October 2010 to March 2013 and made them publicly available. We analyzed 423,401 tweets between October 15 and December 31 of 2011, which was the time the flood approached Bangkok and its suburb. Interestingly, the number of tweets increased by 52 % from September to October, and continued to increase until November (Kongthon et al. 2012). Figure 2 shows the various trends in terms of the numbers of tweets and retweets, as well as the number of tweets/retweets that contained URLs during this period. Since about 77.65 % of the tweets were actually a retweet, we later decided to use retweet networks to detect communities.

At the beginning, we ranked the popular tweets each week based on the number of their retweets. We designed our analysis on a weekly basis since this timescale allowed us to measure people's perception changes by comparing results between weeks. Popular users across all weeks were ranked based on how many times their tweets were retweeted. Among all 61,162 users, less than 10 % had more than nine retweets. The 99.9th percentile is 435.96 retweets.

Many of the users in the top list were in fact not individuals. For example, @*thaiflood* belongs to a private company running thaiflood.com, @*SiamArsa* is an account dedicated to providing and exchanging information about volunteering, and @*traffy* is operated by a government organization that reports traffic conditions. We also learned that many of these top users were community hubs.

To detect communities from retweet networks, we used the community extraction method proposed by Blondel et al. (2008). This algorithm is based on modularity optimization and is efficient in community extraction from a large network. The modularity is a value between -1 and 1 that measures the density of links within communities as compared to links between communities. Some of the communities evolved from a small group of users in the early weeks to a large community of up to about a thousand users who were generating thousands of tweets each week. We considered the influential users in each community each week based on their number of retweets.

After we observed the networks, we moved on to categorize the contents shared by the communities. Table 1 shows our categorizations of the various Tweets.

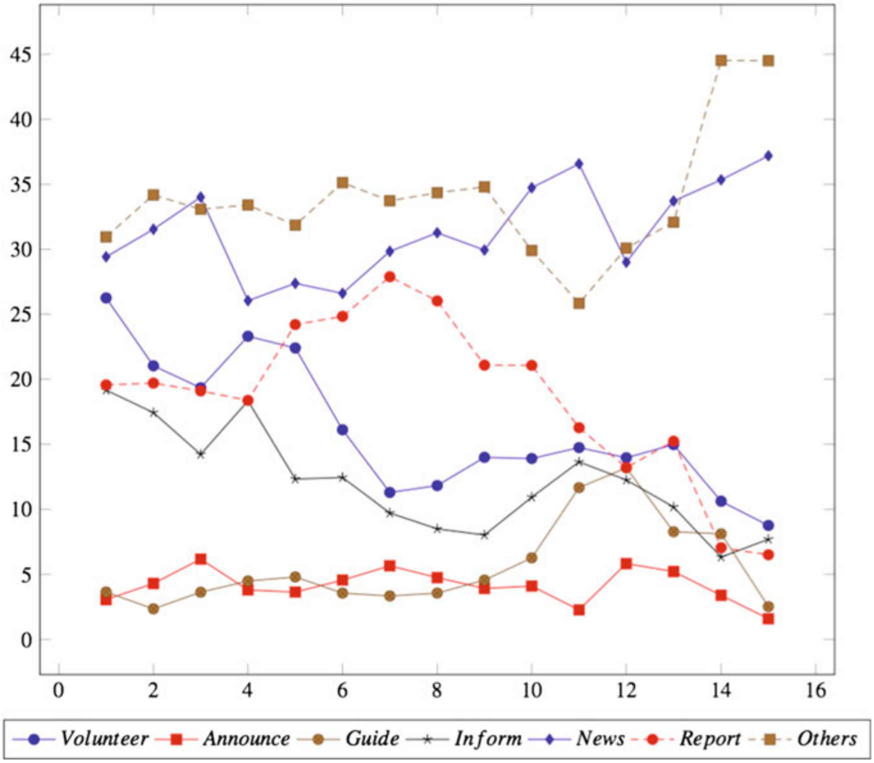

Fig. 2 Weekly percentage of tweets by category from mid-September until the end of December

Tweets that were categorized as news are the ones that shared news article, while tweets categorized as reports are those generated by corresponding users to report the flood situation. Categorization of tweets have been used in many other studies (Naaman et al. 2010; Sinnappan et al. 2010). In the same case study as ours, for example, Kongthon and her colleagues also used categorization to analyze the tweets they collected (Kongthon et al. 2012).

We then identified the important keywords each week by calculating the TF-IDF scores. However, due to a limited number of characters allowed in a tweet, the TF-IDF scores could not be appropriately calculated when we considered each tweet as a separate document. It is simply because of the low possibility that a word would appear more than once in a tweet. As our analysis is based on a weekly timescale, instead of having each tweet as a document, we grouped all tweets each week as a document. This gave us 15 documents from our entire tweet collection.

Automatic classification methods and language processing are still a huge challenge because of several complications in processing the Thai language. This problem led to difficulty in extracting meaningful words from the TF-IDF scores. This is not the case, however, when it came to the names of places. They were fairly

Table 1 Percentage of tweets per category, starting from 16th of September

Week	User	Tweet	V/D	W/A	Guide	Info	News	Report	Other
1	1398	3988	26.25	3.06	3.64	19.16	29.41	19.56	30.94
2	3727	9183	21.03	4.30	2.35	17.43	31.53	19.70	34.17
3	6386	18,124	19.34	6.17	3.63	14.22	34.00	19.10	33.07
4	7453	31,337	23.30	3.80	4.49	18.33	26.04	18.37	33.40
5	7813	39,446	22.40	3.64	4.80	12.32	27.37	24.20	31.85
6	7717	39,073	16.11	4.56	3.56	12.44	26.60	24.83	35.11
7	7127	42,382	11.29	5.66	3.34	9.72	29.83	27.88	33.72
8	6245	39,526	11.82	4.75	3.56	8.50	31.26	26.02	34.34
9	6832	32,389	13.99	3.92	4.56	8.03	29.93	21.08	34.79
10	4800	31,026	13.90	4.10	6.27	10.93	34.72	21.06	29.89
11	3410	21,818	14.74	2.27	11.66	13.64	36.56	16.27	25.83
12	1644	8814	13.96	5.83	13.18	12.25	28.99	13.21	30.08
13	894	4116	14.97	5.22	8.28	10.18	33.70	15.23	32.07
14	374	1121	10.62	3.39	8.12	6.33	35.33	7.05	44.51
15	144	753	8.76	1.59	2.52	7.70	37.18	6.51	44.49

V/D Volunteering and donation, *W/A* Warning and announcement

accurate when it came to word segmentation. Table 2 shows the TF-IDF scores for the different places affected by the flood. These names, when selected from TF-IDF scores and mapped with inundated areas, indicated where people were focusing on. While automatic processing with the Thai language remains a challenge, we used our rule-based categorization and TF-IDF scores to understand the contents. While categorization and TF-IDF, together with other manual and automatic approaches have been used in many previous studies (Syliongka et al. 2015; Smith 2010; Beduya and Espinosa 2014), our approach is novel in terms of its temporal dimension analysis. Because of the time dimension, we were able to observe changes in people's perception.

We then compared all of the results to the news articles that we collected. By doing the comparison, we are able to analyze the situations each week, which reflected the changes in people's perception over time.

4.3 Finding Traces of Perception-Based Resilience

In this section, we further analyzed the Thai Food case as per our perception-based resilience model. What we are able to gather are traces of the various components of the model. Admittedly, however, more analyses have to be provided so as to validate the entirety of the model and the dynamics of its components. The traces, however, significantly show the potential of the model to explain social resilience.

Table 2 TF-IDF scores of terms referring to places

Sept 16–22		**Sept 23–29**		**Sept 30–Oct 6**	
Chainat^{P}	15.98	Chiangmai^{P}	27.73	Lampang^{P}	36.06
Singburi^{P}	13.16	Ubonrachathani^{P}	19.74	Chiangmai^{P}	24.26
Ubonrachathani^{P}	4.23	Srisaked^{P}	15.12	Ayuthaya^{P}	17.09
Angthong^{P}	4.03	Yasothorn^{P}	12.48	Lopburi^{P}	12.08
Chanthaburi^{P}	3.35	Chainat^{P}	7.05	Kampangpetch^{P}	9.70
Nakornsawan^{P}	2.59	Chanthaburi^{P}	6.70	Saraburi^{P}	8.83
Maehongsorn^{P}	2.08	Lampang^{P}	5.82	Rojana^{IE}	6.24
Uthaithani^{P}	1.96			Chainat^{P}	4.23
				IE	6.58
Oct 7–15		**Oct 16–22**		**Oct 23–29**	
Ladprao^{BKK}	31.07	Rangsit^{PT}	19.76	Ladprao^{BKK}	39.13
Ratchada^{BKK}	16.53	Navanakorn^{IE}	13.86	Chatuchak^{BKK}	26.45
Ramkamhang^{BKK}	16.28	Thammasat^{PT}	13.73	Ramintra^{BKK}	14.96
Patumthani^{P}	16.11	Klong I^{PT}	8.32	Dream world^{pt}	14.56
Hitech^{IE}	15.70	IE	25.39	Vibhavadi road	10.49
Rojana^{IE}	15.25			Ramkamhang^{BKK}	9.31
Ayuthaya^{P}	14.82				
Nakornsawan^{P}	14.67				
Rangsit^{PT}	12.15				
IE	23.97				
Oct 30–Nov 5		**Nov 6–12**		**Nov 13–19**	
Ladprao^{BKK}	66.74	Rama III^{BKK}	33.35	Ladprao^{BKK}	27.04
Ratchayothin^{BKK}	43.16	Srinakarin ^{BKK}	23.26	Srinakarin^{BKK}	15.22
Ratchada^{BKK}	34.72	Ladprao^{BKK}	20.71	Ratchada^{BKK}	7.44
Kasetsart^{BKK}	23.03	Ratchada^{BKK}	14.88	IE	14.10
Ramintra^{BKK}	18.98	Pattanakarn^{BKK}	14.71		
Petchkasem road	18.80	Petchkasem road	10.81		
Chatuchak^{BKK}	16.53	Morchit^{BKK}	10.79		
IE	12.69	Ramintra^{BKK}	8.06		
		Victory Mon^{BKK}	7.44		
		IE	14.57		
Nov 20–26		**Nov 27–Dec 3**			
Kasetsart^{BKK}	9.40	Ramintra^{BKK}	6.74		
Ramintra^{BKK}	9.20	IE	4.70		

P Province, *IE* Industrial estate, *BKK* Bangkok, *PT* Patumthani province

4.3.1 Hazard Appraisal

There were only few activities in #thaiflood that were observed in the first two weeks beginning September 16. Most of them indicated the provinces in the northern and northeastern regions that were heavily affected. Some areas in

Ayuthaya, which is close to Bangkok, were also inundated. The few activities in Twitter could be because it is usual occurrence that these areas are inundated, which is why it did not elicit concern and worry from people. It may also be that the majority of the communities in #thaiflood did not perceive a risk to themselves since they were in or around Bangkok, a cognitive bias that proved wrong later on. At the same time, however, there were urgent calls for volunteers and donations (e.g., money, rice, water, medicines, clothes, life jackets, etc.). More alarming was the announcement by the Department of Disaster Prevention that more than seven million people were affected in 57 provinces with 158 reported dead. The perceived vulnerability and severity were high.

In the first two weeks of October, the flood spread from Ayuthaya down to Patumthani, which is adjacent to Bangkok. On the 5th of October, there was a sharp increase in Twitter activity. The term industrial estate had a high TF-IDF score, which means that people became concerned with such infrastructures. We also observed more tweets on warnings and announcements, information, news and reports in other communities during this week as the flood reached Patumthani and its industrial estate. This increase in activity is indicative of people having perceived greater risk and got more concerned since Patumthani, which should have been well protected by flood barriers, had been inundated.

News and reports were retweeted more often as the flood was reaching Bangkok, which is indicative of increased fear and concern. People had to decide whether to stay or move to another place. They also had to move their belongings above the expected water level when they perceived the flood would come to their place as there were retweeted reports of 50 deaths due to electric shock. It was therefore vital for them to closely monitor the situation. When the flood reached some areas in Bangkok, top tweets recounted people leaving the city and causing a big traffic jam, the government announcing evacuations from Bangkok and admitting that all areas in Bangkok were at risk of inundation, the government declaring October 27–31 as public holidays, and even suggesting people to leave Bangkok for vacation. We can expect that people panicked even more with these unusual announcements.

By the second week of November, the flood had already covered a large area of Bangkok. Top results from the TF-IDF scoring confirmed that the most important focus that week was to prevent the central area of Bangkok from being inundated as the central is connected to outer areas via four main roads. By the succeeding week, only few terms related to places had a high TF-IDF score, which suggests that the flood was mostly contained as no new affected area emerged. By the end of November, tweets were about traffic reports, as people were moving back to Bangkok, as well as guidelines on how to cope with post-flood issues (e.g., one of the top tweets was about cleaning out molds in the house), which also suggest that the flood had been contained.

Few weeks after the flood, the activities in Twitter gradually decreased. More tweets about guidelines were observed during the first half of December, which eventually decreased. In the latter half of this month, only few activities were observed in the networks of users. Few discussions were about future plans for the flood prevention systems. Based on the activities and topics tweeted in December, perceptions changed from recovery back to normal situation.

4.3.2 Resilience Appraisal

The numerous urgent calls for volunteers and donations indicated not just the severity of the shock in the affected regions, but also the belief of those who were not affected in the efficacy of these forms of responses. People also believed that posting how-to guidelines and information, and opening hotlines, would be effective in coping through the adverse effects of the flood. The perceived costs of these responses of course differed. While sending donations entailed financial costs, volunteering to be in the affected areas required sending one's self to be used for others. Perceived personal efficacy is significant in instances like volunteering when it could place the person in harm's way. For example, one of the top tweets indicated that five volunteers died on their way to distributing survival kits as their boat sank. At the same time, the mere fact that top tweets were calls for collective action, the perceived collective efficacy was also high—people in social media manifested the belief that in times of disasters people would selflessly act for the welfare of others. True enough, this was evidenced, for example, by the government receiving USD 22 million worth of donations and a TV channel raising a fund worth about USD 15 million. Not to mention the hundreds of volunteers who gave up personal resources, and at certain instances their lives.

The disaster also brought about improvisation as an effective response. When people perceived the watergates and flood barriers put by the government were broken, big bags (i.e., large sand bags) were introduced to replace them, which effectively prevented the rest of Bangkok from being flooded. Another improvisation that was introduced was the use of EM balls to mitigate the effect of polluted water. Also, videos of people creating life jackets by using only ordinary shirts and empty mineral water bottles were retweeted.

4.3.3 Input Perception

The social discourse among the tweeting community centered primarily on the extent of the adverse outcomes of the flood and how people could cope as this hazard ensued. Various information, which included news, guidelines, and warnings were tweeted for situation analysis and awareness. Others, however, are notable in their call for equal sacrifice. For example, one top tweet urged people in Bangkok to let the flood pass through the barriers to lessen the water in Ayuthaya. Another example are the tweets demanding that people who were severely affected should get higher, instead of equal, compensation. Others are notable because they were from international organizations that weighed in. For example, one top tweet indicated that the New York Times reported the disaster as caused by poor water management, forest destruction, and further urbanization without careful planning. Another indicated how CNN admired Thai generosity.

Furthermore, it is clear from the tweets that items, infrastructures, and volunteers consisted the objective adaptive capacity. Monetary donations were sent through banks, SMS, and post offices. Hotlines were installed. Boats, trucks, and buses were used to transport goods. Shopping mall parking lots and fly-overs were used for free parking. Universities and stadiums became evacuation centers. Sandbags and survival kits received considerable tweets as the flood approached Bangkok. At the time of recovery, the Bangkok government issued low interest loans and land tax exemptions to affected people. In terms of response incentives, one of the top tweets during recovery was about a competition that can fund recovery projects for the severely affected communities.

4.3.4 Fear or Empathy Leading to Actual Response

As the situations became more severe, there were instances wherein maladaptation also became rampant. For example, as the flood reached Bangkok, commodities in supermarkets went out of stock as people tried to hoard food, water, and other necessities. This led to an illegal increase of commodity prices. Another is when the water became polluted as the flood became stagnant due to the installed big bags, some people resorted to protesting, and one person even committed violence by throwing an explosive to a group of people who were fixing broken big bags. Clearly, these responses that came out of high perception of the hazard, fear, and/or low perception of collective efficacy, are void of empathy and focused entirely on protecting one's self.

On the other hand, a few top tweets reported emotional contagion with the victims who had no food to eat, as well as sympathy when a significant portion of the donated things (food, clothes, toilets, etc.) were not distributed on time. Other tweets showed how sympathy was extended through prayers. The majority of the tweets, however, empathized emotionally and demonstrated varying degrees of helping behavior by donating, volunteering, and posting guidelines and warnings, among others.

5 Conclusion

We previously argued and elucidated in Legaspi et al. (2014) the notion of perception-based resilience. What we have done here, however, is to make concrete the cognitive, affective, and behavioral processes involved when modeling perception-based resilience. To provide evidence that can support the underpinnings of our model, we analyzed social media contents that were circulated during the 2011 Thai flood.

The social media, such as Twitter, have been used in disaster and emergency management as sources of actionable information that can support situation awareness and decision-making, advise others on how to get specific information from different sources, or provide immediate help to those affected by the hazard (Kongthon et al. 2012; Vieweg 2016; Meier 2016). Social media allows rapid and instant communication while reaching a wide, even worldwide, audience, as well as direct communication between disaster managers and those affected (White 2016). However, every time a social media-based analysis of a critical event is provided, we tend to look for that added insight that is distinct from what we already knew we could get. For instance, another study (Kongthon et al. 2012) also gathered some 64,000 tweets during the 2011 Thai Flood. Their analysis, like other works and ours, led to categories of tweets.

We do not downplay the significance of the conventional contribution afforded by social media-based analysis, but instead, we aim for an alternative way of analyzing that can provide the added significant value. To this end, what we have done in this paper is to move the analyses beyond the conventional value and superficial discussions on the use of social media in times of disasters. Our contribution is a high level analysis, i.e., through our perception-based resilience model, of what drives what kinds of people to post what they post at which time of the shocking or stressful hazard.

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Resilient Community Clustering: A Graph Theoretical Approach

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Abstract Many complex systems can be modeled as a graph consisting of nodes and connecting edges. Such a graph-based model is useful to study the resilience of decentralized systems that handle a system failure by isolating a subsystem with failed components. In this chapter, we study a graph clustering problem for electrical grids where a given grid is partitioned into multiple microgrids that are self-contained in terms of electricity balance. Our goal is to find an optimal partition that minimizes the cost of constructing a set of self-sufficient microgrids. To obtain a better solution accommodating smaller microgrids, we develop an efficient verification algorithm that determines whether microgrids can balance their electricity surplus through electricity exchange among them. Our experimental results with a dataset about Yokohama city in Japan show that our proposed method can effectively reduce the construction cost of decentralized microgrids.

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1 Introduction

After the 2011 Great East Japan Earthquake in Japan, which subsequently shut down the nuclear power plant in Fukushima, we are aware of significant risks of depending on highly centralized electricity power resources. Many researchers who foresee such future threats thus have been proposing decentralized electricity management systems based on renewable green energy.

We consider a distributed electricity system in which solar photovoltaic panels (PVs) supply electricity to microgrids in near proximity. In such a system, an electrical gird is partitioned into several microgrids that are self-sufficient in the sense that their electricity supply and demand are balanced. Our objective is to find a set of partitions that minimize the cost of constructing the resulting microgrids while making them resilient in the sense that each microgrid is well-balanced under time-varying supply and demand.

However, there is a tradeoff between the cost of deploying microgrids and the difficulty of balancing their electricity surplus. As we partition a grid into smaller microgrids, we can reduce their construction cost by removing significant number of transmission lines within microgrids. However, a smaller microgrid contains fewer number of PVs, and it thus becomes more difficult to balance its less aggregated electricity surplus, which fluctuates widely.

To overcome this issue, we propose a dynamic electricity management scheme in which microgrids exchange their electricity in a peer-to-peer way. We consider a microgrid well-balanced if its surplus is under a given threshold after canceling out its surplus or shortage with its neighbor microgrids. Such localized adjustment of electricity allows us to divide a power grid into smaller ones further satisfying the balance requirement. To study dynamic interactions between microgrids, we model an electrical power grid as a weighted graph where computed subgraphs correspond to microgrids.

In this chapter, we describe a new graph partition algorithm (Minami et al. 2014; Yamagata et al. 2015) that guarantees that each cluster's weight is under a given threshold if we properly transfer node weights through capacity-constrained edges. Our algorithm is based the Recursive Coordinate Geometric Bisection (RCB) algorithm (Berger and Bokhari 1987), which supports only vertical and horizontal partitions. We extend it with a new verification algorithm that determines whether it is possible to keep each cluster's weight under a threshold dynamically.

However, this verification task involves high computational cost of solving the combinatorial optimization problem. We thus develop an efficient approximation algorithm based on the maximum flow algorithm by Edmonds and Karp (1972). We apply the algorithm to an aggregated graph where each partitioned subgraph is represented as a node. The basic idea is to compute the maximum flow from clusters of positive weights to those of negative ones and then transfer node weights along the paths of the maximum flow. We extend the original maximum flow algorithm such that it computes a well-balanced maximum flow paths among nodes by iteratively applying the algorithm while incrementing the graph's edge capacity.

We apply our graph partitioning algorithm to a synthesized surplus data for Yokohama city in Japan and examine how our proposed scheme reduces the construction cost of microgrids. We also evaluate the resilience of computed partitions under the presence of time-varying electricity demand and supply over the year.

The rest of this chapter is organized as follows. Section 2 models an electrical power grid as a graph and introduce the graph partitioning problem for constructing a set of microgrids. Section 3 describes our graph partitioning algorithm that extends the existing RCB algorithm. Section 4 shows how we prepare a synthesized dataset of electricity surplus in Yokohama, and Sect. 5 presents our experimental results. Section 6 discusses related work and Sect. 7 concludes.

2 Graph Clustering Problem

In this section, we formulate a graph clustering problem in the context of electrical power grids introducing the metrics and constraints of the system.

2.1 Graph Model

We model an electrical gird as a grid graph $G = (V, E)$ where each node $v \in V$ corresponds to a geographical area and each edge $e_{ij} = (v_i, v_j) \in E$ corresponds to a transmission line between two nodes v_i and v_j. A grid graph is a graph of a mesh topology where nodes are connected via edges vertically or horizontally. We denote by $V(G)$ and $E(G)$ the sets of all nodes and edges in a graph G respectively.

We denote by $w(v)$ and $c(e_{ij})$ the weights of a node v and an edge e_{ij} respectively. Here the weight of node v corresponds to an electrical surplus in v's geographical area and that of edge e_{ij} corresponds to the capacity of a transmission line between two geographical areas of the connected two nodes. We similarly denote by $w(G)$ the weight sum of all nodes in $V(G)$; that is, $w(G) = \sum_{v \in V(G)} w(v)$ and by $c(G_i, G_j)$ the weight sum of all edges that connect two nodes in different graphs G_i and G_j; that is, $c(G_i, G_j) = \sum_{v_k \in V(G_i), v_l \in V(G_j)} c(e_{kl})$.

We now introduce the notion of a graph partition below.

Definition 1 (*Partition*) Given a graph $G = (V, E)$, we say that a finite set $P = \{G_1, G_2, \ldots, G_n\}$ of subgraphs of G is a partition of graph G if

1. $\bigcup_i V(G_i) = V$ and
2. $V(G_i) \cap V(G_j) = \emptyset$ for all $i, j \in \{1, \ldots, n\}$ where $i \neq j$.

That is, a partition P of a graph $G = (V, E)$ is a set of mutually exclusive subgraphs of graph G whose union is equal to V.

2.2 Constraints for Graph Clustering Problem

We introduce a graph clustering problem for an electrical grid. Our goal is to minimize an infrastructure cost for building microgrids whose electricity surplus is under a given threshold. We formulate this problem as a graph clustering program to find a partition $P = \{G_1, G_2, \ldots, G_n\}$ of a given graph G where each subgraph G_i corresponds to a self-sufficient microgrid.

2.2.1 Cost Function

We mainly consider the cost of deploying physical transmission lines for establishing a set of microgrids and simply use the number of edges in a clustered graph as the metrics for the cost function. The number of edges in a partitioned graph varies depending on how a graph is clustered because we require each subgraph to be a complete graph. This requirement represents the fact that each geographical area in a microgrid should have a direct transmission line to the rest of geographical areas.

We define the cost function C for a partitioned graph as follows:

$$C = \alpha \sum_{i=1}^{n} |V(G_i)|^2 + \beta \left| E(G) \setminus \bigcup_{i=1}^{n} E(G_i) \right| \tag{1}$$

where α and β are some coefficients. The first term considers the number of edges in each cluster G_i. A complete graph with n nodes has $\binom{n}{2}$ edges, which is the order of $O(n^2)$. The second term consider the number of edges connecting nodes from different clusters. That is, the former represents the cost of transmission lines within each microgrid and the latter represents the cost of those across different microgrids. We properly choose coefficients α and β to consider the importance of each factor.

2.2.2 Balancing Constraint

We require that a partition $P = \{G_1, G_2, \ldots, G_n\}$ is balanced in the sense that the absolute value of the nodes' average weight in each subgraph $G_i \in P$ is less than a given threshold k. That is,

$$\frac{|w(G_i)|}{|V(G_i)|} \leq k \quad \text{for every } G_i \in P. \tag{2}$$

Note that $|V(G_i)|$ is the number of nodes in graph G_i. This requirement corresponds to the fact that the absolute value of an average surplus per unit area in each microgrid is less than the threshold k.

We now consider the situation where microgrids exchange electricity surplus with each other to distribute their surplus evenly. We model such an electricity flow as a transfer of node weight from one subgraph to another. The flow function f specifies the flow between subgraphs G_i and G_j in a partition P; that is, the function $f : P \times P \rightarrow \mathbb{R}$ takes as inputs two subgraphs G_i and G_j and outputs a real value (an amount of weight) from nodes in G_i to those in G_j.

We extend the balance requirement in Eq. (2) considering such node weight transfers as follows:

$$|w'(G_i)| \leq k \quad \text{for all } G_i \in P \tag{3}$$

such that

$$w'(G_i) = \frac{w(G_i) + \sum_{G_j \in P} f(G_j, G_i)}{|V(G_i)|} \tag{4}$$

where $w'(G_i)$ is an average surplus of G_i after node weights are transferred among subgraphs as specified by the flow function f. Note that the flow $f(G_j, G_i)$ should not exceed the transmission capacity $c(G_j, G_i)$ and that $f(G_j, G_i) = -f(G_i, G_j)$ should hold for every cluster pair G_i and G_j.

Whether a given partition P can be balanced depends on the existence of a proper flow function f. We formulate this decision problem below.

Definition 2 (*k-balanced partition*) Let $P = \{G_1, G_2, \ldots, G_n\}$ be a partition of a graph G. Given a threshold $k \geq 0$, we say that P is a k-balanced partition if there exists a flow function f satisfying Eqs. (3) and (4).

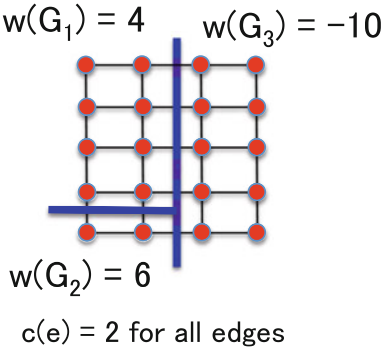

Fig. 1 An example partition $P = \{G_1, G_2, G_3\}$. Each *dot* and each *thin line* represent a graph node and an edge. Each *bold line* represents a border between different subgraphs G_1, G_2, and G_3

Example 1 Consider an example partition P in Fig. 1. Graph G is partitioned into three subgraphs G_1, G_2, and G_3 in which $w(G_1) = 4$, $w(G_2) = 6$, and $w(G_3) = -10$ respectively. Then, G_1 has the average node weight of $|w(G_1)|/|V(G_1)| = 1/2 = 0.5$ and G_2 and G_3 do those of 3 and 1 respectively. That is, all the subgraphs have either some surplus or shortage in average node weight.

However, the partition P is a 0.1-balanced partition because if we consider the flow f such that $f(G_2, G_1) = 4$, $f(G_2, G_3) = 2$, and $f(G_1, G_3) = 8$, we can make $w'(G_1) = w'(G_2) = w'(G_3) = 0 < 0.1$ canceling out their discrepancies.

We finally formulate the graph clustering problem to find a k-balanced partition with the minimum cost below.

Definition 3 (*Graph Clustering Problem*) Given a threshold $k \geq 0$, the graph clustering problem is a problem of finding a partition P of a graph G in which:

1. P is a k-balanced partition, and
2. For any k-balanced partition P', $C(P) \leq C(P')$ *holds where C is the cost function in Eq.* (1)

3 Solving Graph Clustering Problem

In this section, we describe the algorithm for solving the graph clustering problem in Sect. 2. We first introduce the existing Recursive Coordinate Geometric Bisection (RCB) algorithm (Berger and Bokhari 1987) for solving general partitioning problems and then extend it to find a k-balanced partition of the minimum cost.

3.1 Recursive Coordinate Geometric Bisection (RCB) Algorithm

The RCB algorithm (Berger and Bokhari 1987) is a simple graph partitioning algorithm that divides a graph either vertically or horizontally.

Here is an outline of the RCB algorithm:

1. Divide a graph into two subgraphs whose node weight sums are about the same either horizontally or vertically.
2. For each subgraph in the original graph, repeat step 1 to divide the subgraph into smaller ones in a recursive way.

Figure 2 describes how the RCB algorithm works conceptually. A small change in a graph only results in small changes of cluster borders nearby because the algorithm maintains geometric locality of graph nodes. The RCB algorithm is an approximate algorithm, which does not necessarily produce an optimal solution, but it efficiently finds near-optimal solutions in many situations.

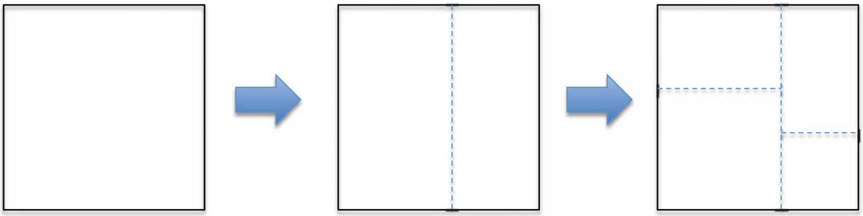

Fig. 2 Example partitioning with the RCB algorithms. The *dotted lines* denote partitions dividing a *rectangular graph*. We omit nodes and edges in the graph

3.2 Extension of the RCB Algorithm

We use a modified version of the RCB algorithm to find a k-balanced partition in Definition 2. The function *partition* in Algorithm 1 shows how we extend the original RCB algorithm. The function *partition* takes as inputs a graph G and a threshold k and outputs a k-balanced partition P with the minimum cost. The major difference from the original RCB algorithm is that we only apply k-balanced partitions, which are checked with the boolean function *isBalanced* in line 10, to divide a given graph.

First, line 4 puts an input graph G to be partitioned into a queue Q, and line 5 initializes the variable *min* that maintains the minimum cost of candidate partitions. The while block in lines 6–25 recursively divides each subgraph g in the queue Q into two. Line 7 obtains a graph g from queue Q, which maintains a list of subgraphs to be partitioned further. Line 8 sets a pair of subgraphs $(\hat{g}_1, \hat{g}_2)$ to *NULL*. This pair maintains a candidate division of the current graph g.

The for loop in lines 9–17 examines all possible partitions of a graph g. Line 10 checks whether a pair of two subgraphs g_1 and g_2 is a k-balanced partition of graph g. If so, the function *compCost* in line 11 computes the cost c of an intermediate partition $Q \cup \{q_1, q_2\}$ in Eq. (2). If the cost c is smaller than the current *min* value, line 13 sets the value c to the new value of *min* and lines 14 sets a pair of subgraphs (g_1, g_2) into $(\hat{g}_1, \hat{g}_2)$. If there is a valid candidate division $(\hat{g}_1, \hat{g}_2)$, lines 19 and 20 put them into the queue. Otherwise, line 22 puts back the extracted graph g into Q again and line 23 breaks out of the while loop. Line 26 finally outputs the partition in Q.

The function *partition* divides a graph in a top-down way without examining all possible graph partitions. Therefore, our algorithm does not guarantee to produce an partition of the minimum cost. However, as we see in Sect. 5, it usually produces good approximate solutions in practice.

3.3 k-*Balance Verification Algorithm*

The boolean function *isBalanced* in Algorithm 1 checks whether a set of subgraphs is a *k*-balanced partition in Definition 2. Since it is infeasible to enumerate and try all possible combinations of node weight movements across subgraphs, we develop an efficient approximation algorithm based on the max flow algorithm by Edmonds and Karp (1972). The max flow algorithm finds an optimal flow of node weights that maximizes the total amount of flow from the source node to the sink node, and we use this algorithm to a set of partitioned subgraphs to find a maximum node weight transfer from subgraphs with positive weights to negative ones. To apply such a flow to the subgraphs reduces the discrepancies of their node weights significantly.

Algorithm 1 Function $partition(G, k)$

```
% Input: a graph $G$, a threshold $k$
% Output: a set $P$ of subgraphs

$Enqueue(Q, G)$ // Put $G$ into a queue $Q$
$min = \infty$
while true do
    $g = Dequeue(Q)$ // Obtain a graph $g$ from $Q$
    $(\hat{g}_1, \hat{g}_2) \leftarrow NULL$
    for each partition $(g_1, g_2)$ for graph $g$ do
        if $isBalanced(Q \cup \{g_1, g_2\}, k)$ then
            $c \leftarrow compCost(Q \cup \{g_1, g_2\})$ // Compute the cost for the set of subgraphs $Q \cup \{g_1, g_2\}$
            if $c < min$ then
                $min \leftarrow c$
                // Add two divided subgraphs $g_1$ and $g_2$
                $(\hat{g}_1, \hat{g}_2) \leftarrow (g_1, g_2)$
            end if
        end if
    end for
    if $(\hat{g}_1, \hat{g}_2) \neq NULL$ then
        $Enqueue(Q, g_1)$
        $Enqueue(Q, g_2)$
    else
        $Enqueue(Q, g)$ // Put $g$ back into $Q$
        break
    end if
end while
return $Q$
```

To apply the maximum flow algorithm to a given graph partition, we define an *aggregated* graph $G^a = (V^a, E^a)$ in which each aggregated node $v_i^a \in V^a$ corresponds to a subgraph $G_i \in P$ and each aggregated edge $e_{i,j}^a = (v_i^a, v_j^a) \in E^a$ corresponds to the set of edges between two nodes in subgraphs G_i and G_j respectively.

Each aggregated node v_i^a has a node weight $w(v_i^a) = w(G_i)$, the weight sum of nodes in G_i and each aggregated edge $e_{i,j}^a$ has a weight

$$c(e^a_{i,j}) = \sum\nolimits_{e_{k,l} \in E \text{where } v_k \in V(G_i), v_l \in V(G_j)} c(e_{k,l}),$$

the weight sum of the edges that connect nodes in G_i and G_j. We denote by $area(v^a_i) = |V(G_i)|$ the number of nodes in the original subgraph G_i. We also add a source node s and a sink node t to V^a. We add edges $e^a_{s,i} = (s, v^a_i)$ for nodes with positive weight and edges $e^a_{j,t} = (v^a_j, t)$ for nodes with negative weight. Each edge $e^a_{s,i}$ has a weight $c(e^a_{s,i}) = |w(v^a_i)|$ to prevent any flow function from making node v^a_i transfer more weight than it has such that v^a_i's weight becomes negative. Similarly, each edge $e^a_{j,t}$ has a weight $c(e^a_{j,t}) = \left|w(v^a_j)\right|$ not to receive too much weight to have positive weight.

Example 2 Figure 3 shows an example aggregate graph obtained from a partition $P = \{G_1, G_2, G_3\}$. A source node s is connected to two nodes v^a_1 and v^a_2 because they have positive weights (i.e., $w(v^a_1) = 4$ and $w(v^a_2) = 6$). A sink node t is connected with node v^a_3 because it has negative weight $w(v^a_3) = -10$. Edge $e^a_{s,1}$ has a weight $c(e^a_{s,1}) = w(v^a_1) = 4$, for example.

However, the max flow algorithm does not necessarily find a flow function that reduces the weight discrepancies of each subgraph the most. The algorithm might find a flow function where most of weight transfer occurs on a particular path between a source node and a sink node without reducing the discrepancies of the remaining nodes. To address this unbalance issue of the flow function, we modify the max flow algorithm so that we can update the flow function iteratively while incrementing the capacity of each edge gradually.

Algorithm 2 shows the k-balance verification algorithm of the function *isBalanced*. The function takes as inputs a partition P, a threshold k, and a delta δ and outputs a boolean value, which indicates whether the partition P can be k-balanced or not. Line 4 first constructs an aggregate graph G from a partition P. Lines 5–8 maintains the original capacity of each edge in G and sets the capacity of each intermediate edge, which does not connect neither a source node s nor a sink node t, to zero.

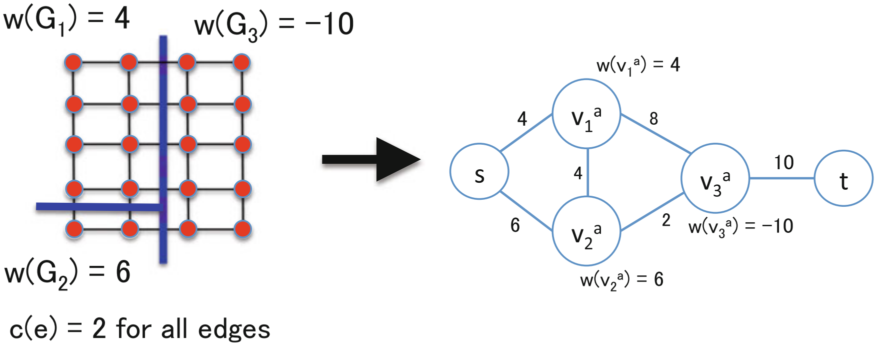

Fig. 3 An example aggregated graph. Each subgraph G_i is aggregated into the node v^a_i and edges between different clusters G_i and G_j is aggregated into an edge $e^a_{ij} = (v^a_i, v^a_j)$. The nodes s and t are virtual nodes which are introduced as a source node and a sink node respectively

The while loop between lines 9 and 36 repeatedly applies the maximum flow algorithm while incrementing edge capacities from zero to their original values. The next for loop in lines 10–16 increments each intermediate edge's capacity by δ until the capacity reaches its original value.

Lines 17–27 pick the node v_i with the largest absolute weight value among the nodes connecting with either a source node s or a sink node t. If v_i is connected with s, lines 19–21 set the capacities of other edges connected with s to zero. Similarly, if v_i is connected with t, lines 23–25 set the capacities of other edges connected with t to zero. Such an arrangement of disabling the sibling edges forces the maximum flow algorithm in line 28 to find a flow function f, which reduces the discrepancy of node v_i most effectively.

Line 29 applies the flow function f in line 28 and obtains another graph G' where the nodes' weight are updated based on the function f. Line 30 checks if all the subgraphs' weights are smaller or equal to a threshold k. If so, lines 31–33 resume the original capacities of the edges that are connected to either node s or t and line 34 returns *true*. Otherwise, the while loop repeats the same procedure again. If all the intermediate edges recover their original edge capacities, line 9 breaks out of the while loop, lines 37–39 resume the original capacities of the edges, and line 40 returns *false*.

Example 3 Figure 4 shows a running example of k-balance algorithm. Directed arrows in each graph indicate a path from the source to the sink node and colored nodes indicate the one with the largest discrepancy in node weight. The number in

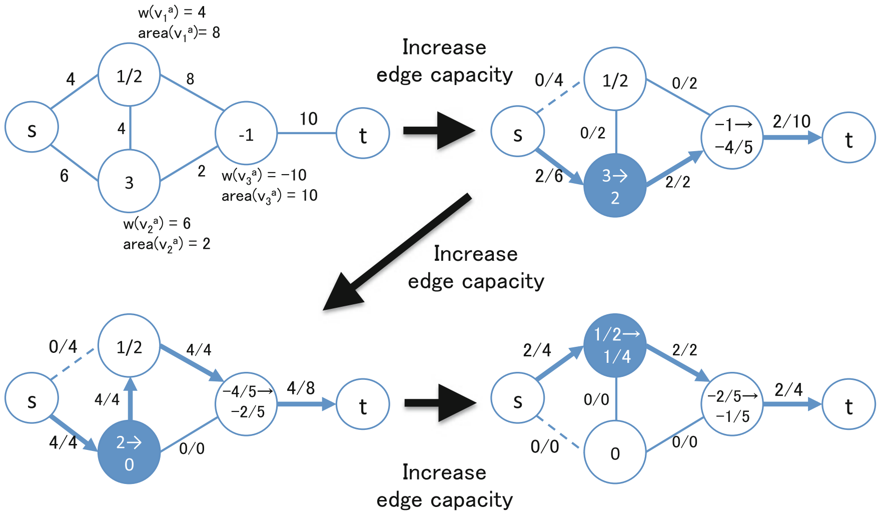

Fig. 4 A running example of the weighted graph balancing algorithm. *Directed arrows* in each graph indicate a path from the source to the sink node, and each edge is labeled with its flow and capacity. The number in each node indicates its weight. Each iteration of the algorithm chooses a single path from the source to the sink node including the colored node with the largest discrepancy

the node v_i^a indicates the average node weight of the nodes in the original subgraph G_i. For each iteration, this algorithm reduces the discrepancies in node weight by repeatedly applying the maximum flow algorithm while incrementing the capacities of intermediate edges. At the first application of the flow function, node v_2 sends outgoing flow of 2 and decreases its weight by $\frac{2}{area(v_2^a)} = \frac{2}{2} = 1$.

Algorithm 2 Function $isBalanced(P,k)$

```
// Input: a partition $P$, a threshold $k$, a delta $\delta$
// Output: Boolean $\{\textbf{true}, \textbf{false}\}$

$G = constAggrGraph(P)$ // Construct an aggregate graph from a partition $P$
for each edge $e_{i,j} \in G$ where $i \neq s \wedge j \neq t$ do
    $c_{max}(e_{i,j}) \leftarrow c(e_{i,j})$ // Remember $e_{i,j}$'s original capacity
    $c(e_{i,j}) \leftarrow 0$ // Set the initialize capacity of each intermediate edge to zero
end for
while $\neg(\forall e_{i,j}$ such that $v_i \neq s \wedge v_j \neq t : c(e_{i,j}) = c_{max}(e_{i,j}))$ do
    for each edge $e_{i,j}$ where $v_i \neq s \wedge v_j \neq t$ do
        if $c(e_{i,j}) + \delta \leq c_{max}(e_{i,j})$ then
            $c(e_{i,j}) \leftarrow c(e_{i,j}) + \delta$ // Increase the capacity of each intermediate edge
        else
            $c(e_{i,j}) \leftarrow c_{max}(e_{i,j})$ // Set the capacity to its maximum
        end if
    end for
    if $\frac{|w(v_i)|}{area(v_i)} \geq \frac{|w(v_j)|}{area(v_j)}$ for all $v_j$ where $v_i$ and $v_j$ are connected either with node $s$ or $t$. then
        if $v_i$ is connected to a source node $s$ then
            for each $e_{s,l}$ where $l \neq i$ do
                $c(e_{s,l}) \leftarrow 0$
            end for
        else
            for each $e_{l,t}$ where $l \neq i$ do
                $c(e_{l,t}) \leftarrow 0$
            end for
        end if
    end if
    $f \leftarrow compMaxFlow(G,s,t)$ // Compute the maximum flow function $f$
    $G' \leftarrow applyFlow(G,f)$ // Create another graph $G'$ by applying the function $f$ to $G$
    if for all node $v \in G'$, $\frac{|w(v)|}{area(v)} \leq k$ then
        for each edge $e_{i,j} \in G$ where $i = s \vee j = t$ do
            $c(e_{i,j}) \leftarrow c_{max}(e_{i,j})$
        end for
        return true
    end if
end while
for each edge $e_{i,j} \in G$ where $i = s \vee j = t$ do
    $c(e_{i,j}) \leftarrow c_{max}(e_{i,j})$
end for
return false
```

4 Estimation of Electricity Affordability for Yokohama City

In this section, we will explain how we estimate the electricity supply and demand for every 250 Sq m region in Yokohama city. We assume that the electricity is supplied from PVs which is installed on the roof for each house, and that it is stored in electric vehicles (EVs) not in use (see Yamagata and Seya 2013 for more details).

First, we estimate the number of cars not in use to estimate the storage capacity of EVs. It is estimated by the following steps:

- Determine the number of cars not in use in each unit area called cho-cho-moku by simulating the daily movements of peoples in Yokohama city using the agent-based transport simulator MATSim.[1] We use the Origin-Destination (OD) trip data (source: the Fourth Person Trip Survey in Tokyo Metropolitan Area) and the road-network data (source: the National Digital Road Map Database) whose attributes include road capacity, road width classification, link length, number of lanes, and travel speed. Note that the OD trip is available only at the distinct-wise level.
- Convert the distinct-wise estimation into those at the 250 m grid level. We apply the standard geostatistical method of Kyriakidis (2004) for converting the distinct-wise estimation.

Second, we estimate the electricity surplus by subtracting electricity household demand from electricity PV supply. The electricity supply $PV_{i,m}$ (kWh/h) in each grid in each month is estimated by using the following formula which is used in Yamagata and Seya (2013) and Yokoi et al. (2010):

$$PV_{i,m} = I \times \tau \times \mathrm{roof}_i^{PV} \times \eta_{pc} \times K_{m,pt} \times T \tag{5}$$

where i is an index of 250 m grids, m is an index of months, I is the total solar irradiance (kWh/m^2) calculated by MTPV-2 database (Itagaki et al. 2003), τ is the array conversion efficiency (=0.1), roof_i^{PV} is the installation area in ith grid (m^2), η_{pc} is the efficiency of power conditioner (=0.95), $K_{m,pt}$ is the temperature correction coefficient set for each month m (e.g., May: 0.92; August: 1.00), and T is the performance ratio (=0.89). roof_i^{PV} is calculated, following (Yamagata and Seya 2012), as

$$\mathrm{roof}_i^{PV} = \frac{B_i \times l \times 1}{\cos(\psi)}$$

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[1] http://matsim.org/.

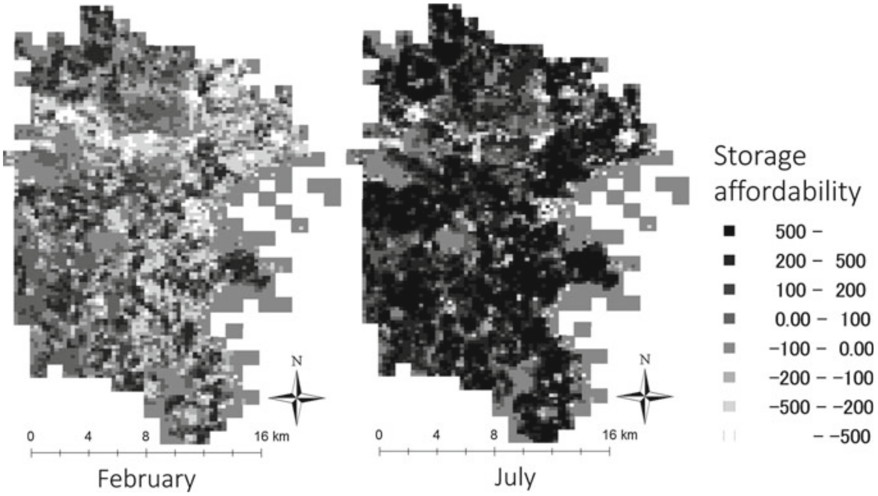

Fig. 5 Electricity affordability in February and July in Yokohama, Japan

where B_i is the building area in ith grid, l is the ratio of possible installation area on a roof (=0.3), and ψ is the optimal angle of inclination (=30°). Electricity demand in each month $D_{i,m}$ is estimated as

$$D_{i,m} = F_i \times w_m$$

where F_i is the total floor area in ith grid, and w_m is the unit electricity demand in each month.

Finally, we can calculate the electricity affordability for each grid for each month by subtracting the electricity surplus from the storage capacity. Figure 5 shows estimated storage affordability in February and July. As shown in Fig. 5, the affordability can vary from month to month.

5 Evaluation

To evaluate the effectiveness of electricity sharing, we apply our graph partitioning algorithm to the estimated surplus data in Yokohama city in Japan that is described in Sect. 4. In this section, we evaluate our proposed method with respect to:

- the number of clusters and the construction cost, and
- the metrics of resilience as described below.

In general, the partition for surplus data in a certain month may not be suitable to that in other months. If the same partition is effective to balance electricity surplus of each cluster through multiple months, we consider that partition resilient against

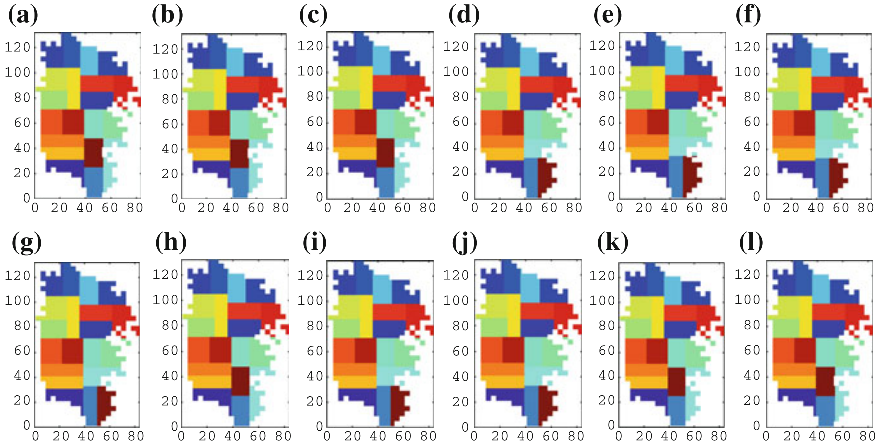

Fig. 6 Clustering results on every month with the RCB algorithm. We use different colors for neighboring clusters to make partitions more recognizable. The algorithm divides the graph into 20 subgraphs. We observe that the partitions change gradually over the year. **a** January, **b** February, **c** March, **d** April, **e** May, **f** June, **g** July, **h** August, **i** September, **j** October, **k** November, **l** December

time-varying electricity surplus. We evaluate the resilience of computed partitions by measuring the maximum discrepancy of portioned clusters.

5.1 Partitions with the RCB Algorithm

We first examine how an optimal partition for an electrical grid changes over the year. We prepare a dataset for each month and divide the corresponding initial graph into 20 subgraphs. Figure 6 shows twelve different partitions for every month. We observe that those partitions change gradually over the year, and this fact motivates us to find a single resilient partition that serves reasonably well over the year since it is too costly to change the partition for the physically deployed microgrids.

5.2 Comparison of the Number of Divisions and the Cost Ratio

We compare the original RCB method and our proposed method that supports electricity sharing in terms of the number of clusters by applying them to the average estimated surplus data over the year. Figure 7 shows the results. The x-axis represents a threshold value and y-axis represents the number of divisions. We

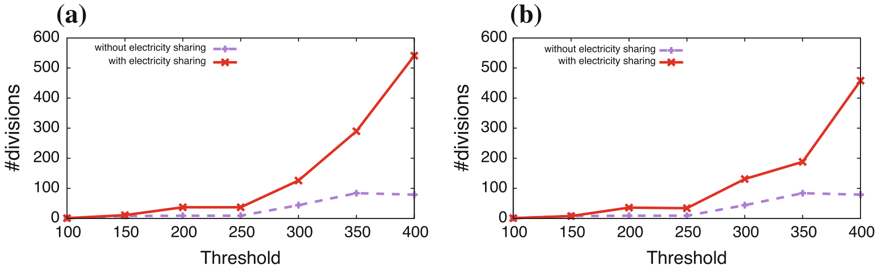

Fig. 7 Comparison of partition results with and without electricity sharing. We use the different combination of coefficients α and β varying the threshold from 100 to 400. The *solid line* represents the results of our proposed method and the *dotted line* represents those of the RCB algorithm. **a** $(\alpha, \beta) = (1, 1)$, **b** $(\alpha, \beta) = (1, 10)$

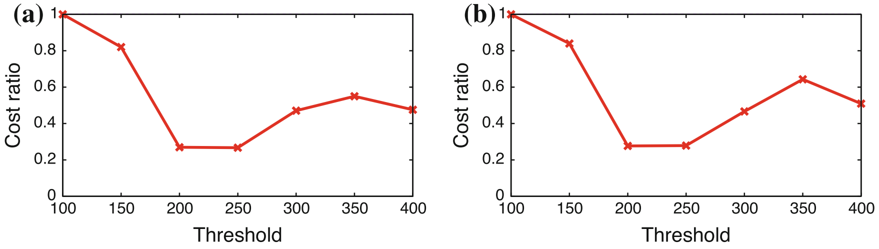

Fig. 8 Cost ratios of RCB with electricity sharing compared with the original RCB. We use the different combination of coefficients α and β varying the threshold from 100 to 400. **a** $(\alpha, \beta) = (1, 1)$, **b** $(\alpha, \beta) = (1, 10)$

examine two different combination of coefficients $(\alpha, \beta) = (1, 1)$ and $(1, 10)$ in Eq. (1) of the cost function. The x-axis represents a threshold and y-axis represents the number of divisions. Our method achieves larger numbers of divisions than the original RCB algorithm in both cases; our method obtains four times larger number of clusters than the original RCB algorithm when a threshold is 400. We next evaluate how our proposed method reduces the cost in Eq. (1) compared with the RCB algorithm. Figure 8 shows the ratio of the cost with our method and that with the RCB algorithm for each threshold. We obtain the ratio by dividing the value with our method with that with the RCB algorithm. The results show that our method significantly reduces the cost than the original RCB algorithm over the wide range of threshold values; our method reduces about 30 % of the cost with the RCB algorithm when a threshold is 200 or 250. We observe that the cost values are highly dominated by the number of divisions especially when the number of divisions is relatively small.

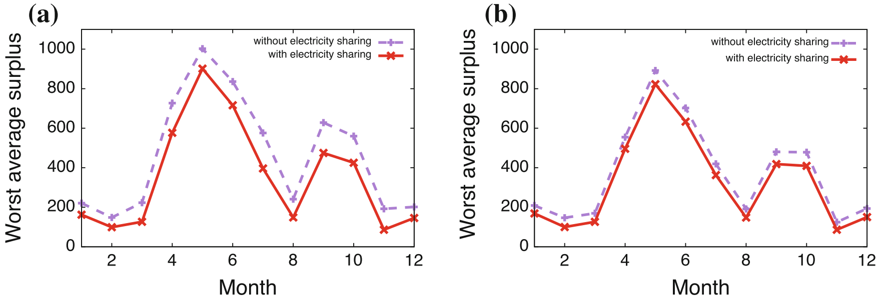

Fig. 9 Comparison of the minimum *GD* with and without electricity sharing for each month. The *solid line* represents the results of our method and the *dotted line* represents those of the RCB algorithm. **a** $(\alpha, \beta) = (1, 1)$, **b** $(\alpha, \beta) = (1, 10)$

5.3 Comparison of Electricity Balance

We next evaluate how computed partitions are resilient by considering the greatest discrepancy of a partition in terms of node weight. The greatest discrepancy function *GD* takes a partition *P* as an input and outputs the greatest discrepancy value defined below.

Definition 4 Function GD. Given a partition $P = \{G_1, \ldots, G_n\}$, the function GD outputs the greatest discrepancy such that

$$GD(P) = \max_{G_i \in P}(G_i)|w'(G_i)|$$

We use a partition *P* obtained from the average surplus during the year by our partitioning algorithm, and apply that partition into monthly data. Figure 9 shows the minimum $GD(P)$ both with the RCB algorithm and our scheme. The x-axis represents months and y-axis represents the minimum *GD* in each month. The solid line represents the results of our method and the dotted line represents those of the RCB algorithm. The figures show that our method reduces the discrepancies of clusters than the original RCB for every month and that that our scheme could produce more resilient partitions under the presence of time-varying electricity surplus over the year.

6 Related Work

There are several previous research on graph partitioning with application to electrical grids. However, none of them considers the possibility of dynamic electricity exchange in the context of graph partitioning.

Yamagata et al. study the spatial clustering problem of minimizing spatial mismatch among clusters in terms of electricity surplus while considering electricity sharing (Yamagata and Seya 2013, 2014; Yamagata et al. 2014) as we do in this paper. Although they develop the clustering algorithm based on a simulated annealing method for finding optimal spatial clusters, they do not study the resilience of computed partitions against time-varying PV supply and demand over the year.

There are several different methods for graph partitioning. Yamagata et al. (2014) used simulated annealing method, which is a general probabilistic metaheuristic for global optimization problems (Van Laarhoven and Aarts 1987; Aarts and Korst 1988). It chooses an initial feasible partition from current wards and randomly modifies the boundary of the clusters according to some probability depending on the total weight of a graph and the circularity constant below.

$$circularity = \sqrt{4\pi \frac{Area}{Perimeter^2}} \tag{6}$$

This method constructs a partition in which each cluster has a circular shape of a given degree although the heuristics for this method requires high computational cost. Arizumi et al. (2014) use the multi-leveled graph (MLG) algorithm that determines clusters by controlling edge connectivity between different clusters (Karypis and Kumar 1995; Hendrickson and Leland 1993; Bui and Jones 1993). It consists of three phases: the coarser phase which summarizes a graph by aggregating nodes and edges, the partitioning phase which performs a partition procedure on the coarser graph, and the propagation phase which propagates the computed clusters back to the original graph. They compare the partitions computed with the RCB algorithm and the MLG algorithm using the surplus for each month and show that the RCB algorithm is preferred for the resilient graph partitioning in the sense that it generates more stable partitions during the year.

There are several studies that solve a resource allocation problem as a linear programming problem. However, their problem settings are different from ours.

Geng et al. (2011) propose a smart parking system that matches a given set of drivers with empty parking spots at a decision point. The goal of the system is to minimize the sum of the distances between the drivers' current locations and their assigned parking spots. They formulate this matching problem as a mixed-integer linear programming (MILP) problem where all the variables are restricted in real numbers or integers. This matching problem is different from our k-balanced partition decision problem in Sect. 3.3 because they use the distance metrics between two points without considering network (i.e., graph) topology in which each edge has a capacity constraint.

The maximum concurrent flow problem (MCFP) (Shahrokhi and Matula 1990) is a similar mathematical problem to our k-balanced partition decision problem. In MCFP, an undirected graph, a set of pairs of nodes to make a flow, and a weight to be transferred for each pair of nodes are given assuming that all the edges have the same capacity. The objective of MCFP is to maximize the ratio of the flow with respect to the demand of each pair. They formulate the MCFP as a linear programming problem and show that it can be approximately solvable in polynomial time. However, our partition balancing problem needs to support edges with different capacities. Also, our goal is to balance node weight of each cluster rather than maximizing the flow among them.

7 Conclusion

An isolation strategy that disconnects failed components from the remaining ones is an effective way to make the system resilient. In this chapter, we consider applying such an isolation strategy to an electrical power grid by dividing it into smaller self-contained microgrids.

To overcome the issue of wide fluctuation of electricity surplus in small microgrids, we take an approach of exchanging electricity surplus among microgrids in a peer-to-peer way. We develop an efficient verification algorithm for checking whether a given partition can be well-balanced by exchanging their electricity surplus, based on the existing maximum flow algorithm.

We experimentally show that our proposed method produces a set of microgrids that are resilient against time-varying electricity surplus with significantly smaller construction cost. We believe that the technique of dynamic resource distribution in a peer-to-peer manner along with the new cluster balancing algorithm is applicable to various systems that adopt the isolation strategy.

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Agent-Based Modeling—A Tool for Urban Resilience Research?

Thomas Brudermann, Christian Hofer and Yoshiki Yamagata

Abstract Resilience-related topics have been gaining importance for urban planners and policy makers over the last decades. In this chapter, we argue that agent-based modeling (ABM) offers a promising tool to assess and test resilience-related measures which are planned and implemented in urban neighborhoods. We demonstrate potentials, but also limitations of the method, using the concept of urban electricity sharing as a demonstration case. Electricity sharing systems are based on decentralized electricity generation and large batteries. The availability of such a system can provide local communities with a back-up system during black-outs, which may occur in the aftermath of catastrophic events such as natural or man-made disasters. When real-world tests are costly or impossible, agent-based models can be used to investigate possible collective behaviors and inefficiencies of such a system. Despite limitations when extrapolating results from simulation runs to the real world, and several other challenges, we conclude that the utilization of agent-based models can very well aid planners and policy makers in designing more resilient cities.

1 Introduction

Resilience-related topics have been gaining importance for urban planners and policy makers over the last decades. Driven by increasing awareness on climate change and increased exposure to natural and man-made disasters, urban planners and policy makers aim for decreasing their cities' vulnerabilities, and building up adaptive capacities. Especially cities with a natural exposure to potential threats,

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such as coastal cities (Smith et al. 2011) have a high interest in adapting to a changing environment, and it is argued that resilience to a wide range of shocks and stresses must be achieved to prepare for climate change (Leichenko 2011). Concepts and frameworks to plan resilient cities exist (Jabareen 2013), but in practice, many cities only implement (simple) parts of such frameworks: Examples are evacuation and emergency management plans which aid minimizing the loss of life during a crisis (Campanella 2006), or more broadly, disaster prevention and disaster management plans. Another example are infrastructural measures that provide redundancy and back-up systems, e.g. for transport, energy and resource supply. A third example is the decentralized organization of crucial systems such as energy provision. Electricity can easily be generated on a small-scale, e.g. with photovoltaic (PV) modules, diesel generators or small wind turbines. A city's electricity demand can be covered with locally available urban resources to a large degree, and in some cases even entirely (Agudelo-Vera et al. 2012); PV and wind offer possibilities for decentralized provision of electricity that can substitute external energy provision and therefore decrease dependency, and increase resilience.

While measures like emergency plans and the build-up of redundant back-up infrastructure can be understood as measures to achieve functional resilience, i.e. maintaining functions in times of disaster and shock, measures like the decentralization of electricity generation, or introduction of novel means of organization, might be considered as transformative approaches.

In any case, risk-mitigation strategies should be developed to assess multifaceted vulnerability and resilience. It is important that these strategies are not being built on too narrow indicators which fail to sufficiently cover various aspects of vulnerability (Menoni et al. 2012). Unfortunately, real-world testing against realistic scenarios is difficult, or even impossible, for most resilience-related measures. A variety of methods allow for assessment of proposed measures; but in a complex system like a city, not only individual system elements, but also the many interactions of these elements need to be considered in order to achieve feasible results. Static methods or top-down modeling efforts often fail to grasp the inherent complexity, and deliver insufficient results.

Agent-based modeling (ABM) offers a promising alternative to assess and test resilience-related measures. The main aim of this chapter therefore is to discuss the potentials of ABM for urban resilience research. We introduce a simple model for a selected case and discuss insights gained from this model, but also demonstrate challenges for and limitations of the method by reference to the introduced model. We furthermore will suggest possible extensions of the model and outline further research.

The remainder of this chapter as structured as follows: In Sect. 2, we will introduce agent-based modeling as an increasingly used method for research on topics related to resilience. In Sect. 3, we will present the concept of local electricity sharing as an interesting case for research with ABM, and describe a basic simulation model. In Sect. 4, we discuss results and insights from simulation runs. In the final section, we elaborate on limitations and challenges as well as potential for further research, and complete the chapter with concluding remarks.

2 Agent-Based Modeling for Resilience Research

Agent-based modeling (ABM, also referred to as individual-based modeling, IBM, or multi-agent simulation, MAS) is a bottom-up modeling and simulation paradigm. Contrary to top-down approaches such as system dynamics, ABM aims to describe a system on the micro level, and to identify so-called 'emergent properties'. Emergent properties are system behaviors which emerge from the bottom-up through agent interactions (Axelrod 2006).

The modeling is done on a micro level: Agents follow certain behavioral rules, and they interact with other agents and with their environment. These interactions might change the properties of the environment or the behaviors and state of agents. While the modeling is done on a micro level, the effects of micro-level behavioral rules and interactions are observed and analyzed on the macro level. Reciprocal effect between micro and macro level might be considered as well.

Simulation in general, and AMB in particular, have become increasingly popular in recent years and by this time can be considered a well-established method in social science research. Applications of 'computational social science' (Conte et al. 2012) include, but are not limited to the study of collective behaviors (Goldstone and Janssen 2005), pedestrian modeling (Crooks et al. 2008), marketing (Brudermann and Fenzl 2010), diffusion studies (Kiesling et al. 2011) ecological economics (Heckbert et al. 2010), investor sentiment in stock markets (Lovric et al. 2010), the study of social dilemmas (Gotts et al. 2003) and many more.

Simulation of agent-based models is done in separate steps; in each time step (or 'tick'), the agents behave according to their programmed rules, i.e. they perform a certain action and/or interact with other agents; the result is a different system state in the next time step/tick. In the next tick, the agents again act and interact based on their rules of behavior and interaction.

Maybe the biggest strength of agent-based models is their ability to connect micro-level behavior with macro-level effects (Cimellaro et al. 2014); an important limitation on the other hand is that the resulting model often is merely stochastic, since it rarely is possible to include the large degree of necessary detail to accurately reproduce real-world phenomena. However, an investigation of underlying principles and basic mechanisms is very well possible, and also valuable.

Agent-based models usually include a certain degree of randomness and uncertainty. To compensate for randomness, simulations are done in Monte Carlo style: Each model is run several times with the same (or a similar) parameter setting, and the simulation outcomes are analyzed on an aggregate level. If necessary for the respective research question, each simulation run of course also can be analyzed separately.

Despite the obvious applicability of ABM for planning and resilience research, it has not been used widely for these specific purposes so far. However, a number of research topics related to the resilience discussion have been addressed with agent-based models. In scientific studies agent-based models have been roughly used for two types of resilience-related purposes, namely the study of short term disaster resilience, and long-term development planning.

Regarding disaster resilience and adaptation studies with ABM, the focus often has been on rather short-term responses to an external shock. For several years, agent based models and related approaches have been used in disaster prevention research, especially regarding the modeling and simulation of traffic (Helbing 2001), of pedestrian flows (D'Orazio et al. 2014) or escape panic (Helbing et al. 2000).

One paper (D'Orazio et al. 2014) for example addresses human behaviors during earthquakes and the first evacuation phases. The proposed model in (D'Orazio et al. 2014) is offering a simulator for earthquake evacuation of pedestrians in an urban environment; the behavioral rules of the agents in the model have been derived from behavioral investigations of real earthquake evacuations. In another paper, ABM has been combined with the application of optimal control theories in order to provide decision support to improve resilience assessments (Cimellaro et al. 2014). The authors conclude that ABM is useful to evaluate the resilience of complex systems in the face of extreme events. On a more conceptual level, a framework for assessing the resilience of an urban community during and after an earthquake has been proposed in (Boston et al. 2014). In this framework, the interaction of people and the (damaged) built environment is modeled with ABM, and the resilience of the community is described as a function of the performance of individual buildings as well as organizations and people within the community.

Regarding development planning, agent-based simulations address long-term developments in communities, cities or regions, often including a discussion of implications for the resilience of these urban or rural systems. ABM has been frequently used in the field of urban geography, e.g. in order to understand settlement developments or urbanization processes. For example, a model to describe the evolution of Soviet urbanization from 1959 to 1989 has been proposed in (Cottineau et al. 2015). This study demonstrated that ABM is well suited for scenario modeling of environmental change, with implications for ecological resilience of the affected area.

ABM has also been used to model and simulate housing choices and residential mobility (Jordan et al. 2014), or to predict future residential demand for housing, and the accompanying pressure on a regional landscape (Fontaine and Rounsevell 2009). On the other end of this line, models have been developed to address urban shrinkage (Haase et al. 2012)—for this particular case, also a combination of different modeling paradigms (ABM, cellular automata and system dynamics) has been proposed to cover main elements of urban shrinkage processes. Other models include the management of urban infrastructure (Osman 2012) or the management of (possibly scarce) urban water resources (Kanta and Zechman 2013). But not only infrastructure and resource management, also the management of urban land as well as urban land use change have been studied with agent-based models (Schwarz et al. 2012), and six type of "players", or agents, have been identified (residents, planners, infrastructure providers, businesses, developers and lobbyists). Since urban systems are complex, and often include a large number of system elements, a metasimulation scheme has been suggested to accelerate agent-based computation of complex urban systems (Zou et al. 2012).

Land use and land cover change often exhibit specific dynamics, and these might very well impact the well-being of inhabitants. Agent-based simulations for the municipality of Koper, Slovenia, e.g. have shown that aggregate resident quality of life increases non-linearly when development density is changed; it also has been shown that clustering industrial development has benefits for human well-being (Robinson et al. 2012).

Agent-based simulations also have been conducted for rural areas, e.g. regarding population-environment interactions in a former agricultural frontier (Walsh et al. 2013). Another application has been landscape-scale management (Cong et al. 2014) to predict different landscape configurations emerging from farm-scale management under different conditions; managing ecosystem services has broad implications for the resilience of agricultural systems, and ABM promises to be a useful method for improving respective policy making and planning.

Agent-based modeling has become an established method in social sciences, and as the examples mentioned in this section show, ABM has been increasingly used in recent years for studying topics related to resilience. We call for continuing and intensifying the use of agent-based modeling, and will illustrate potentials and strengths of the method with one example. Using the same example, we also will carefully discuss challenges and limitations of the method in the following section.

3 Example Case: Agent-Based Modeling of Electricity Sharing

3.1 Electricity Sharing Systems as a Way to Increase Resilience

Resilient systems often are characterized by a rather de-central nature. Even if a large number of system elements fail, a resilient system is able to maintain functionality, as e.g. other system elements replace the failed system elements, or the mode of operation is adapted to the new situation.

In this section, we discuss the basic idea of an electricity sharing system, and point to benefits and challenges when it comes to implementing the concept in an agent-based model.

The basic idea of electricity sharing is to provide a back-up system for electricity provision during black-outs (caused e.g. by a natural disaster), based on decentral electricity generation. For this, three technologies are of specific relevance:

(1) small-scale electricity generation technologies such as PV modules, (2) electric vehicles and their batteries, and (3) mobile phones that are capable of short-range point-to-point communication in the absence of a functioning mobile network.

The increasing popularity of privately-owned PV modules, e.g. on the roofs of detached houses or on the roofs of farm buildings (Brudermann et al. 2013), or also public buildings, or even integrated into building elements (Koinegg et al. 2013), is the main basis for the proposed sharing concept. Small-scale electricity generation can provide inhabitants with electricity even in the absence of functioning grids. Apart from PV, diesel generators, anaerobic bio digesters or small wind plants are of interest for such a sharing system as well, but especially in urban areas of developed countries PV modules are the most wide-spread from of decentral electricity technology.

Mobile phones and smart phones are widely diffused and heavily used; they are the second basis of the proposed concept. We assume that all agents in our model scenarios are equipped with a mobile device that is capable of transmitting and receiving information via point-to-point connections.

The third basis is an assumed availability of electric vehicles; their batteries may serve as electricity storage in post-disaster situations. Electric vehicles are currently still in an early stage of diffusion; for the modeling scenarios we however assume that each house is equipped with one electric vehicle and two respective batteries (one battery in the car, and one battery that can be used for providing electricity to the house).

Based on the availability of these technologies, spatial electricity sharing systems have been proposed for post-disaster situations (Yamagata and Seya 2013). Assuming that electricity grids and telecommunication grids are unavailable for an unknown period of time, the basic idea is to use PV modules for electricity generation, and batteries of electric vehicles for storage, and possibly transport, of electricity. Using batteries to provide households with electricity, at least a basic demand, e.g. for operating fridges, lights and communication and information devices can be met. Charged batteries can be transported to points of demand, and empty batteries can be re-charged at PV sites. Communication devices are sharing important information via point-to-point connections, including information on the availability and location of functioning PV modules.

We aim to develop an agent-based model for the proposed concept, and test different agent behaviors and different parameter settings in simulation experiments. The modeling scenarios described here are limited to PV modules (with respective production curves) and do not include other decentral technologies, which would be conceivable as well.

Note that in a first step, the purpose of the model is not to represent a realistic current situation, but to point to benefits and also challenges of such a system, that prevail in the presence of PV modules and widely diffused electric vehicles. While the challenges for the technical implementation of such a system are well known, behavioral reactions and behavioral patterns are not easy to predict. Experimental investigations are possible, but difficult to conduct under realistic circumstances, especially with respect to the particularity of post-disaster environments.

Experimental results achieved in a ‘normal’ situation, without stress and competition for a scarce good, but with intact infrastructure and functioning communication networks, might not be valid for such exceptional situations.

Simulation experiments are one way of generating insights on collective behaviors in situations that are difficult to study in laboratory experiments or in the field.

3.2 Electricity Sharing in an Agent-Based Model

We designed and implemented a simple model of urban electricity sharing. The conceptual basis for this model has been described in previous contributions (Brudermann and Yamagata 2014a b); in this chapter we describe the model itself and use it to illustrate the potentials and challenges of using ABM for resilience assessments. The prototype of this model has been implemented using the NetLogo (Wilensky 1999) software, which is open access software that has been developed by Uri Wilensky and his team at Northwestern University since 1999 (Fig. 1).[1]

The model consists of a lattice of size 100 × 100 to represent a neighborhood. Each field in this lattice can host one house and several cars. Practically, only a fraction of the lattice is occupied with houses and cars in each time step. There are three types of agents in the model:

- Houses: Houses are characterized by a certain energy demand; they can either be in a state of being provided with electricity, or being not provided. Houses also keep back a minimum reserve to provide their vehicle with enough electricity to reach the next PV module for charging.

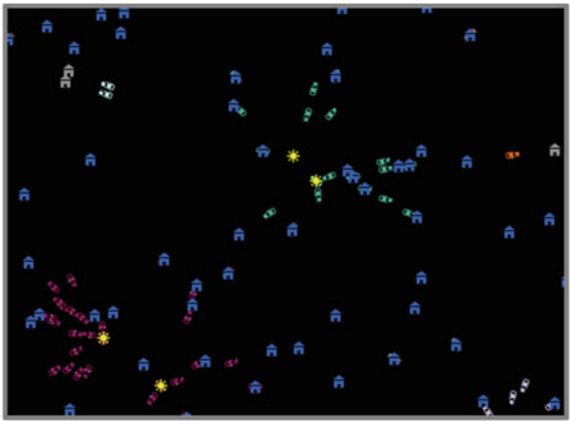

Fig. 1 Example view of the model in the NetLogo platform. Sun icons represent PV-modules, *blue houses* are currently provided with electricity. *Grey houses* are currently not provided with electricity. Cars with the same color currently build an ad hoc mesh network for information exchange (color figure online)

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[1] We used NetLogo version 5.3. There are numerous alternative software packages for implementing ABM, e.g. Anylogic, Ascape, Gama, MASON, MATSim or Repast. Some advantages of NetLogo are free accessibility, beginner-friendliness and easy graphical representation of models.

- Houses with PV modules: These houses also are able to generate and store electricity, and to share stored electricity with vehicles that queue up at them.
- Vehicles: Vehicles are associated with one house (their ‘home place’), have certain electricity consumption when they move, can drive to houses with PV modules to charge their battery there, and transfer the electricity in their batteries to their battery at home. They are also able to communicate with other agents (vehicles) in their proximity to update information on available electricity sources and their current status (queues, available electricity). However, due to the decentral nature of communication, information might be outdated. In every tick, all vehicles within communication range build an ad hoc mesh network to update and share all their available information. Time stamps are used to check which vehicle has the newest information. For reasons of simplicity, potential problems with non-synchronic clocks are neglected.

The following parameters can be changed in the model, and respective adjustments can be analyzed in Monte Carlo simulations:

- Number of cars/houses. Indicates the number of houses in the neighborhood. We assume that each house has one electric vehicle available, and vary the number of houses between 25 and 200.
- Number of houses with PV. Indicates the number of houses that have a PV plant. For the sake of simplicity, each of these small plants has the same capacity. We vary the number of houses with PV between 5 and 80.
- Communication range: The communication range of agents (vehicles); i.e. agents can communicate with another agent if it is within this range. We vary the communication range between 0 (no communication at all) and 20 (given the lattice size, the point-to-point communication can reach out to up to approximately 12.5 % of the lattice area).
- Car capacity: Maximum electricity that a vehicle battery can store. As a simplification, cars are always initialized with a fully charged battery at the start of the simulation run.
- Maximum house capacity: Maximum capacity of the batteries in a house. The batteries are initialized with a random state of charge between zero and maximum capacity.
- Maximum storage capacity of houses with PV: maximum capacity that is available on a PV site. The current capacity is also randomly initialized with a value between maximum capacity and zero.
- Car consumption: Amount of electricity a car is consuming when moving in one tick.
- House consumption: Amount of electricity consumed by one house per time unit/tick.

Simulation experiments are conducted in Monte Carlo style; i.e. parameters are systematically varied to check for interdependencies and effects on model results, but the model is run with the same parameter settings several times, and the aggregate results are being analyzed.

For this model, we conducted 50 simulation runs for each parameter setting; we used NetLogo's built-in 'behavior space' for conducting the simulations. Resulting data was analyzed with descriptive statistics.

4 Results and Insights from the Simple Model

Given the parameter variations above, and 50 simulation runs per parameter setting, we collected and analyzed data from 12,000 simulation runs. Each run simulated a time span of 72 h (1080 ticks à 4 min). We used data from Hoste et al. (2009) to include realistic electricity demand curves and electricity generation curves from PV into the simulation runs.

The dependent variable we measured was the average number of electrified houses over the time span of hours 48–72 in the simulation runs, i.e. we are interested in how well the sharing system works on day three of the simulated case. In each simulation run, the number of electrified houses was counted in each tick of the simulated hours 48–72, and the mean number was calculated. We call this dependent variable 'average electrification' and it refers to the average of calculated means in 50 simulation runs with the same parameter setting. Note that we used NetLogo's built-in function to calculate means and standard deviations (relating to standard deviation for a sample, using Bessel's correction).

The independent variables which we varied were (1) the number of houses (which always corresponds to the number of vehicles), (2) the number of houses with PV modules (and indirectly also the ratio of the number of PV modules to houses), as well as (3) the communication radius of agents. We performed the analysis in two steps: First, we looked for Spearman correlations of each of the independent variables with the dependent variable; and second, we performed automatic linear modeling to find the variable that best predicts the electrification variable. Subsequently, we also made qualitative observations for specific simulation runs.

There is a very weak negative correlation between the number of houses in the simulation and the average number of houses provided with electricity in the (simulated) last 24 h of the simulation runs ($rs = -0.184$, $p = 0.000$, see Fig. 2a). If there are more houses on the lattice, there is a slight tendency that less of them can be provided with electricity in the tested configurations of the model. There is on the other hand a very strong positive correlation between the number of houses with PV and the average electrification ($rs = 0.916$, $p = 0.000$, see Fig. 2b).

Interestingly, the communication radius of the agents does not correlate with average electrification ($rs = 0.001$, $p = 0.943$). This might be explained with the fact that agents a priori know the position of the closest house with PV module for charging their batteries. Even with the information from other agents regarding alternative locations, the closest location is often the most attractive choice due to costly movement—moving the car consumes a lot of electricity—and too far distances. With the configuration of the current model, information exchange therefore has little to no effect on model outcomes. The picture might reverse if agents do not know any locations of possible charging stations.

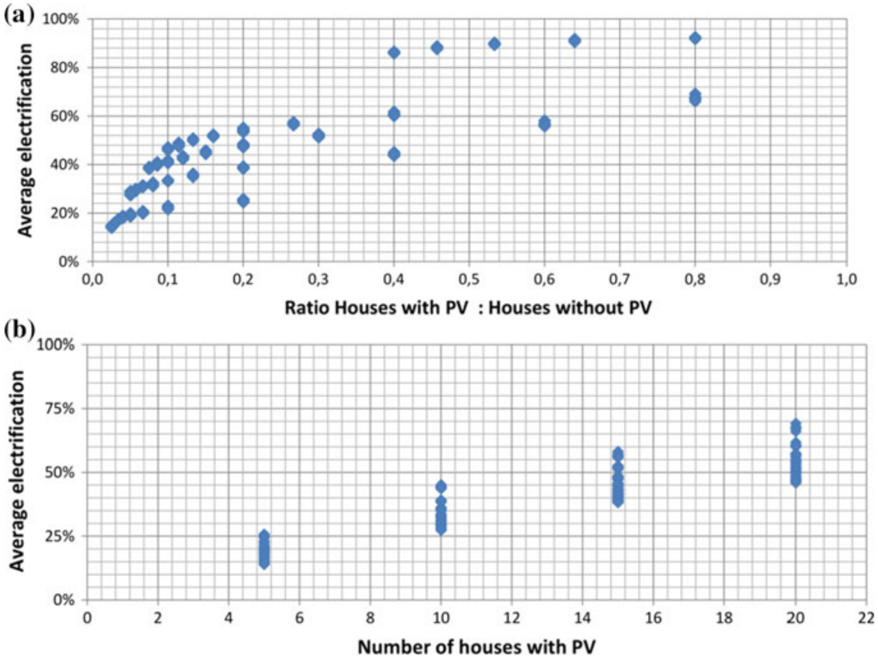

Fig. 2 **a** Scatter plot showing the ratio of houses with PV to houses without PV on the x-axis, and the average percentage of electrified houses in hours 48–72 of the simulation runs on the y-axis. **b** Scatter plot showing the number of houses with PV on the x-axis, and the average percentage of electrified houses in hours 48–72 of the simulation runs on the y-axis

There is also a strong positive correlation of the houses with/without PV ratio and average electrification (rs = 0.688, $p = 0.000$).

In a second step, we built an automatic linear regression model, using SPSS version 20. We used 'number of houses with PV modules', 'number of houses', 'communication radius' and 'houses with/without PV ratio' as parameters, and the average electrification variable as target. The automatic linear model calculated the importance of predictors, and we found that the number of houses with PV has the greatest predictor importance (0.926), followed by the number of houses with/without PV ratio (0.046) and the number of houses (0.028). The model achieved an accuracy of 87.8 % ($p = 0.000$).

These are just two examples for possible quantitative analysis of simulation runs. If necessary, additional data for analysis can be generated without difficulty. For example, different positioning of PV modules and effects on average electrification can be easily tested, or different positioning strategies can be compared with each other (possibly generating implications for funding policies). However, extensive simulation runs and detailed analysis are beyond the scope of this chapter, where the aim is to demonstrate potentials and possibilities instead of studying one case in great detail.

Apart from quantitative explorations, agent-based models also allow for quick and merely qualitative observations. For example, we observe peaks in battery charging activities in the morning hours, when PV modules resume electricity generation and batteries of vehicles and houses are on low levels after evening and night time (Fig. 3).

Another observation is that in simulation runs with high numbers of houses, and relatively few houses with PV, very long queues emerge in front of PV modules (Fig. 4). Even if not programmed in the model, an experienced planner will

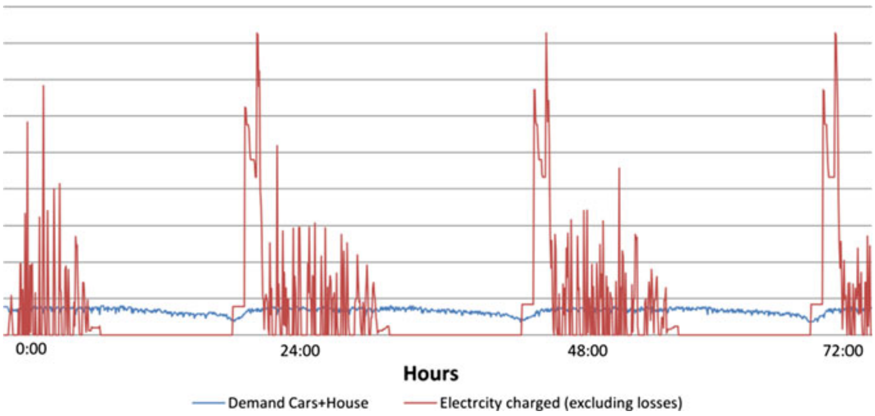

Fig. 3 A typical run over 72 h. The *blue line* indicates the overall electricity demand of cars and houses in the system; the *red line* indicates the amount transferred to batteries in each tick, excluding losses. Electricity transfer is greatest in the morning hours. Note that the simulation run shown here starts at index 0:00, which is a randomly chosen time of the day, and not 0:00 o'clock

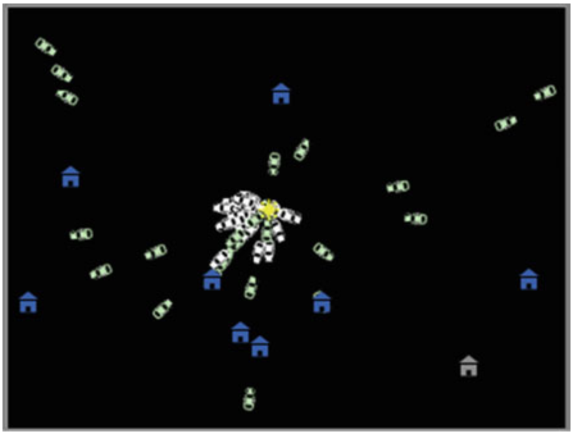

Fig. 4 Cars queuing up for one of the scarce electricity sources in a model run with 400 houses without PV and just 8 houses with PV modules

immediately recognize that such a situation—i.e., a lot of people requiring a scarce good in an emergency situation—might provoke tensions among the competitors, or eventually even lead to civil unrest. Agent-based model thus leave room for interpretation, and might even direct attention to issues that have not been considered in the model itself. In the present case, the question is raised how to design a point-to-point system for information exchange, and how to avoid these without doubt problematic huge queues—questions that again might be addressed with the help of agent-based models.

5 Limitations, Challenges and Further Study

Models always are simplifications of reality, and therefore always underlie limitations. Agent-based approaches have to deal with specific additional challenges. In this section we address limitations and challenges, using the electricity sharing model as an example. We also come up with possibilities for further study.

5.1 Further Study and Model Extensions

As outlined before models need to simplify, and the present case is no exception. The degree of simplification, and which aspects are being simplified, relates to the respective research question. Simplifications in the presented models involve weather conditions, seasonal variations in solar irradiation, differences in house characteristics and consumption patterns, differences in production capacities, individual behavioral traits of groups of inhabitants, and many more. Depending on the purpose of the model, such simplifications are legitimate; if the purpose e.g. is the study of basic mechanisms, and the influence of various parameters on the behavior of the system, exact weather conditions are not necessarily relevant (note that we already include production and consumption curves which reflect varying production and consumption during 24 h of one day).

Moreover, the current model represents a prototypic neighborhood, in which vehicles can move from A to B directly and without any constraints. There is no consideration of a network of streets, possible damages and street blockades, or traffic congestions. In a next step, the model can be applied to a concrete neighborhood based on GIS data. The model then can be used to test the necessary number, capacities and positioning of PV modules to make a sharing system a feasible back-up system for a specific neighborhood. The model might also be fed with accurate data on household electricity consumption, number of electric vehicles per household, exact location of PV modules (including available space for queues), etc.

Another possible extension is to more accurately model collective behaviors. Individual behavior is increasingly understood thanks to suitable methods from social psychology and nowadays neuroscience, and we have learned that human decisions are not necessarily rational or driven by utility maximization (like, e.g. stated by many economic models). In the majority of cases, human decision makers base their decisions on heuristics (rule of thumbs) or intuitive feelings, or they just follow well-established habits, instead of evaluating the utilities of available alternatives, and comparing them carefully (Gigerenzer and Gaissmaier 2011). Despite significant progress in recent decades, modeling individual behaviors remains a tricky challenge, and popular and frequently cited models such as the Theory of Planned Behavior (Ajzen 1991) only succeed to explain a fraction of human behaviors.

Understanding collective behavior is an even more tricky challenge, especially due to methodological limitations. Collective behaviors cannot be explored in the lab, or via simple surveys. Following the popular quote "the whole is more than the sum of its parts", we need to acknowledge that collective behavior also is more than just the sum of individual behaviors. Collective behavior is an aggregation of individual behaviors, of interactions of individuals with each other, interactions of individuals with groups and the environment, and interactions of groups with each other, on various levels. Collective behavior can be seen as a complex system that cannot be dealt with by using simple research methods which are directed to the individual. Here lies a challenge, but also a great opportunity for agent-based models.

A final aspect we need to consider is the difference of regular, every day behaviors, and behaviors in the face of extreme events, when experience and information are lacking. In situations characterized by uncertainty and emotional arousal, people become susceptible to psychological contagion, to suggestion by others. Psychological contagion provides the basis for irrational collective behavior and mass hysteria—which are both difficult to predict. In such situations, behavioral rules change, and usually become more simple on the individual level; and outcomes become more difficult to predict on the collective level. Also here, agent-based modeling promises to be a very useful tool (Brudermann 2010, 2014).

5.2 Potentials, Challenges and Limitations

As we have seen in the electricity sharing example, ABM provides us with a number of potential benefits in studying the resilience of urban systems. Most prominently, we can learn about the basic relevant mechanisms and possible system behaviors, given certain initial parameters, e.g. the role a point-to-point information exchange system can play in disaster aftermaths. We are also able to test interconnections of system elements, e.g. the number, locations and capacities of producers and the number, locations and demands of consumers. Furthermore, agent-based modeling can be a powerful tool to identify possible problems that need to be addressed by planners and policy makers—e.g. congestions and huge queues in front of decentral electricity generators, which might be a result of scarce supply, high demand, and a point-to-point information exchange system, and might even lead to fighting for electricity, or on a larger scale, civil unrest. Agent-based modeling therefore might proof valuable as a tool for transformative planning. Finally, ABM provides us with a method to test research hypotheses, and to derive new hypotheses from the simulation results—which then can be validated against data from real scenarios.

Of course, the agent-based simulation paradigm also comes with challenges for the modeler and user of such models. First, it is not trivial to find the suitable level of abstraction. Simplifications need to be made, and certain details need to be left out. On the other hand, small changes in parameters might lead to entire different results (Brudermann and Fenzl 2010). This leads us to the second challenge: How can we extrapolate results to the real world? Needless to say, a one to one transfer of results achieved in a simulation model to the world beyond this 'artificial laboratory' is problematic. Results need to be interpreted with care and with caution. Especially when we deal with social systems, we need to be aware that we cannot claim predictive power. A certain degree of predictive power might be achieved when agent-based models deal with chemical or physical processes—but the same cannot be true for simplified models of social processes. Nonetheless, agent-based models can direct to certain patterns of behavior in a system, and provide us with important lessons about the behavior of complex social systems.

5.3 Concluding Remarks

In this chapter we discussed the potentials of ABM for urban resilience research. We illustrated benefits, but also pointed to challenges and limitations, using a concrete model as an example.

We believe that ABM can be a useful tool for planners and policy makers, if used correctly. It may support planners and policy makers to transform cities and communities towards resilient communities. In the past, especially agent-based modeling of pedestrians has been used to increase safety for large-scale events, like concerts, festivals or New Year celebrations. Similar approaches can be used for resilience modeling to support transformations.

We chose the case of electricity sharing as an illustration for the following reason: At first sight, such a system merely provides a back-up system with basic emergency functionality, as long as the primary systems of electricity provision fail. Such a back-up can provide functional recovery that bridges the time until the main systems become fully operational again. At a second sight, such a system is more than just a functional back-up: It introduces sharing as an important concept in a social system like a community or city neighborhood. Within a global capitalistic city, people are provided with a sharing system—in an optimistic interpretation, one might consider that as a first transformative step to a society with pro-social "sharing" values instead of ego-centric consumerism values. However, the answer to the question, whether the availability of a sharing system will evoke sharing values, or on the contrary fierce competition for a scarce resource, with 'law of the jungle' prevailing, cannot be answered in simulation runs. But, simulation modeling can help to design such systems in a way that the rise of sharing norms is a more likely outcome when the system is put to the ultimate test in a real case of emergency.

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Urban Form and Energy Resilient Strategies: A Case Study of the Manhattan Grid

Perry P.J. Yang and Steven J. Quan

Abstract The Manhattan grid is known as a testing ground of high-density urban development from the 19th century onward. Its urban form model and regulatory zoning mechanisms provide lessons for global cities in shaping their urban skylines. This chapter describes the physical form and processes that have established and characterize Manhattan's grid, focusing on the grid as a generator and framework for growth. A performance-based urban energy model is used to examine the potential for energy self-sufficiency within the current urban form structure of the Manhattan grid. To make the city more energy resilient, a transformative approach is proposed that centers on the implementation of a performance-based model of urban design, which enhances urban resiliency at the neighborhood level. The concept of panarchy is applied to address complex systems problems such as energy resiliency in cities. To design an energy resilient urban system, it is important to define a community-level action and a medium-scale framework, which allow effective systems integration and coordination among stakeholders. The framework of urban design accommodates finer-scale, bottom-up eco-initiatives, which enable agile responses to unpredictable events, such as climate-induced disasters and environmental changes.

1 Introduction

Urban resilience is becoming an increasingly pressing issue after recent natural or human-induced disasters, such as the Tōhoku earthquake and tsunami that caused the Fukushima disaster in Japan in 2011 and Hurricane Sandy, which led to major flooding and power losses, in New York City in 2012. In this chapter, we address the

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question of how cities should be planned, designed, managed and restructured to be more resilient to future changes caused by potential shocks, using the Manhattan grid as a test case. In order to better prepare for a more tumultuous and unpredictable future, a framework for designing resilient urban forms that adapt to, mitigate or prevent disasters for major cities, like New York and Tokyo, will be needed.

In order to do so, we must understand the urban physical form and structure and the historical and social contexts that have created it. Contemporary cities, however, were not necessarily designed with resiliency in mind. Urban form, street patterns, block structures and building typologies are often produced according to organizational principles other than resilience to climate change, which has only become a major topic in the past several decades. The components of urban form are not only physical, but are also impacted by social, institutional and financial factors. In the case of New York City, the urban grid structure in Manhattan, known as *the Manhattan grid*, was formed through engineering surveys of the land and infrastructure during the early 19th century and formalized in the Commissioner's Plan of 1811 (Bender 2002). Manhattan also created one of the world's earliest zoning ordinances in 1916. The current urban form of the city was influenced by infrastructural interventions, regulatory mechanisms, urban economic developments and real estate finance (see Fig. 1).

However, the events of Hurricane Sandy in 2012 demonstrated the inability of the city's urban form to respond to unexpected shocks, as the city was crippled for several days (see Figs. 2 and 3) by flooding, blackout and other effects of the storm.

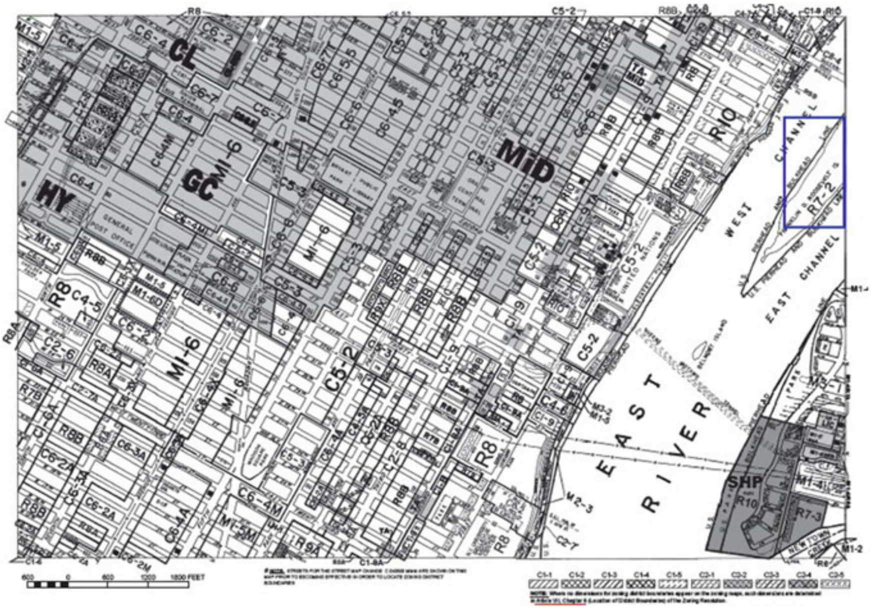


Fig. 1 Zoning map of Midtown Manhattan, New York City (New York City Department of City Planning)

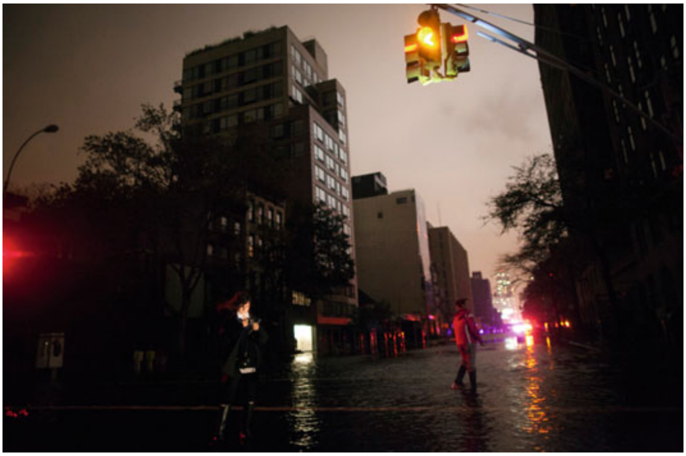
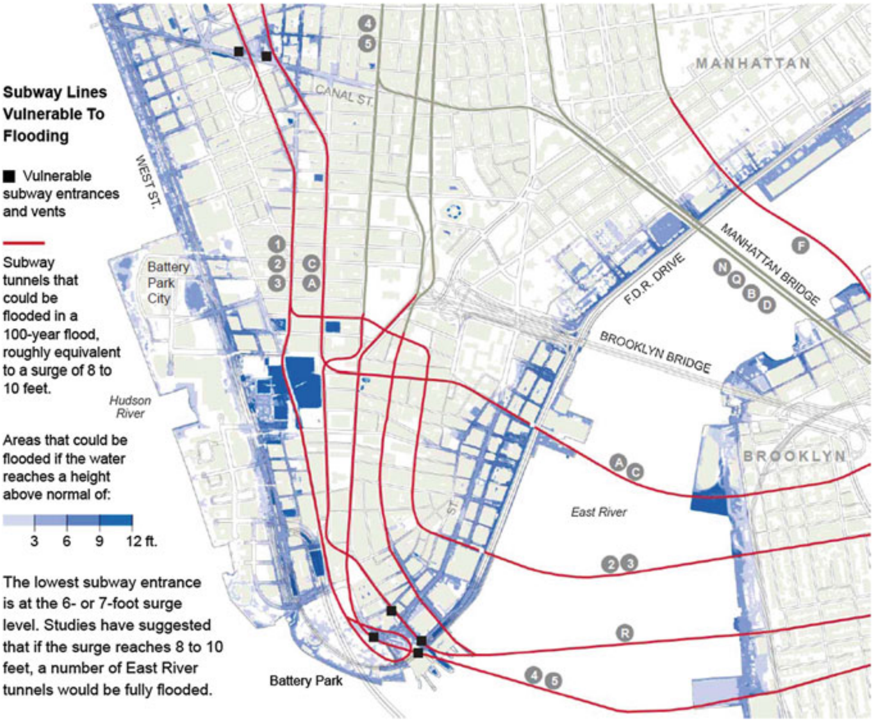


Fig. 2 Black out in New York City (New York Times, October 29, 2012)



The lowest subway entrance is at the 6- or 7-foot surge level. Studies have suggested that if the surge reaches 8 to 10 feet, a number of East River tunnels would be fully flooded.

Fig. 3 Flooding over lower Manhattan during the Sandy Hurricane in 2012 (New York Times, October 29, 2012)

The continued development and increases in density within the Manhattan grid that have occurred over the past 200 years have left the city unable to adapt to unpredictable changes induced by major natural or human-made disasters, such as Hurricane Sandy. In order to transition to more resilient and sustainable systems, new organizational principles and mechanisms must be developed for the existing urban form and structure of cities.

This paper investigates how the urban form of contemporary cities, such as the Manhattan grid, function in energy performance and how urban form can be altered in order to transition to more resilient systems. We provide a brief history of Manhattan's urban grid structure, focusing on how the well-known Manhattan grid generated consequential urban form through regulatory mechanisms, such as the city's 1916 zoning ordinance and setback requirements.

2 Literature on Resilient Cities

The concept of resilience is broadly defined in many research fields including policy, ecology, engineering and planning. There is also a growing body of literature exploring how resilience is defined and connected to other concepts such as sustainability, adaptation, and transformation. Resilience is defined as the capability to absorb disturbances and impacts, e.g., extreme weather events, and the ability to self-adapt to changes (Walker et al. 2004). In other words, resilience is the ability of a system to withstand large perturbations and enable the generalized recovery from within when the system fails. However, the recovery may or may not restore the system to its original configuration; rather, the system can take on a completely new configuration that is also acceptable to the stakeholders (Maruyama 2013).

To make the concept of resilience operational, it must be translated into an operational system in actual urban contexts. *Urban Resilience* can, therefore, be defined as the ability of a city or an urban system to withstand a wide array of shocks and stresses. In order to adapt to and prepare for the effects of climate change, cities must become resilient to a wider range of shocks and stresses and adopt strategies for mitigation and adaptation to these potential shocks (Leichenko 2011). While mitigation aims to reduce the impacts of climate change, adaptation seeks to adjust the built and social environments to minimize the negative outcomes of climate change (Hamin and Gurran 2009).

The above concepts illustrate three approaches to creating a resilient city: First, urban resilience as an ecosystem is the ability of a city or urban system to absorb disturbances while retaining its identity, structure and key processes. Second, urban resilience as risk reduction focuses on enhancing the capacity of cities and infrastructure systems to quickly and effectively recover from both natural and human-made hazards. Third, urban resilience is affected by different types of institutional arrangements, and in response, resilience thinking can influence the development of improved governance mechanisms that promote adaptation to climate change (Leichenko 2011).

Urban resilience contains two other critical attributes: (1) reliability and efficiency and (2) adaptability and flexibility (McDaniels et al. 2008). The first attribute emphasizes the stability and predictability of functions and services provided by urban infrastructure systems, even under extreme or unforeseen conditions. The second attribute stresses continuous adaptation to conditions that unfold and evolve over the long lifecycle of an infrastructure system or a city (Alberts and Hayes 2003). The prominent urban designer Kevin Lynch reminds us that the meanings of both attributes are ambiguous and hard to attain (Lynch 1981).

In order to avoid this pitfall, an operational method of urban resilience is needed to define the interrelationship between urban form and infrastructure systems. The design and operation of urban infrastructure systems, such as energy systems, need to be considered in light of a city's transformation. Conventional approaches of developing infrastructure systems over fragmented, uncertain, and stochastic processes are inadequate in addressing these challenges. In order to transition to more resilient cities, an understanding of the critical interactions and interdependencies between infrastructure systems and urban compositions (such as urban form) is necessary (ASCE 2009).

To tackle the complex challenge of designing urban systems, a network configuration of buildings, infrastructure, information and behavioral systems, we draw on the concept of *panarchy*. This concept was developed by ecologists to account for the dual characteristics of eco-systems—stability and change—and address the interconnectedness across different levels of scales within cities. It deconstructs this interconnectedness by viewing a webbed, interwoven system as multiple layers of components with different levels of detail (Walker et al. 2004). A research approach based on this concept identifies a focal scale that is manageable for analyzing the relationships between sectorial infrastructures and interactions between the focal scale and its coarser scale and finer scale (Yang 2012). The concept of panarchy also provides a perspective that implies a transformative process in the system. By identifying a focal scale, we are able to form a consensus at the community-level and, therefore, make the system transformation tangible.

In this paper, we focus on building an energy resilient city that is both a resource reservoir and producer of secondary resources, rather than a linear resource-to-waste system. The concept of *urban energy harvesting* can be used as a transformative tool for developing more resilient cities (Agudelo-Vera et al. 2012). Urban design provides an interventional approach to connect fragmented elements of landscapes and material resources for enhancing urban energy harvesting capabilities. The objective of designing a resilient place is to create a system in which the urban (metabolic) functions and the urban form are well fitted to each other (Lynch 1983). Resilient urban design is an approach to enhancing the ability of a place, a community or a city to adapt to future changes in urban metabolic and system functions.

3 The Manhattan Grid: From a Non-resilient Form to a Performance-Based Resilient System?

3.1 *The Manhattan Grid as a Generator of Urban Development*

Manhattan's urban grid system serves as a test bed for exploring the issue of urban resilience. The grid is one of the earliest urban form structures and has been studied extensively. The well-known *Commissioners' Plan of 1811* for New York platted the city's urban form from Houston Street in the south to 155th Street on the northern end of Manhattan. The plan superimposed a street grid structure of equal-sized blocks in dimensions such as 70 by 200 m over the previous topography (see Fig. 3) (Bridges 1811). The Manhattan grid can be seen as an urban form generator, which set out the rules for the city's future urban development. The grid of streets and blocks gives the city a regular composition but may also result in monotony (Martin and March 1972). The historical development of Manhattan shows that the grid, however, did not produce a completely uniform and homogeneous urban landscape or social organization, instead it enabled extensive urban experimentation by accommodating a complex urban environment of skylines and skyscrapers (Bender 2002).

The urban grid of Manhattan laid out in the 1811 plan provided a framework of urbanization. It is a controlling factor that dictates how the city was and continues to be built. The scale and pattern of the framework affects the possible building arrangements within it. It supports the growth of overlapping patterns of human activities, which allow for different choices. The grid can accept and respond to growth and change, and accommodates organic growth without turning future urban development over to chaos. It is only through the understanding of the grid as a structuring framework that we can open up the full range of choices and opportunities (Martin and March 1972) (Fig. 4).

In what way does the grid operate as a generator or a controlling instrument in relation to urban form? How does the grid system, as a flexible framework of a city, accommodate urban growth and adapt to future change, both socially and

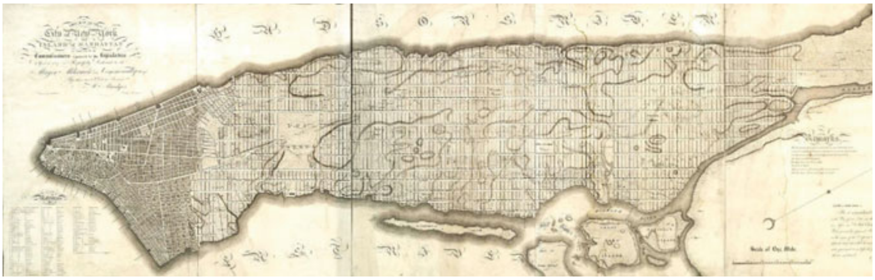


Fig. 4 The Commissioners' plan of 1811, Manhattan, New York City (Bridges 1811)

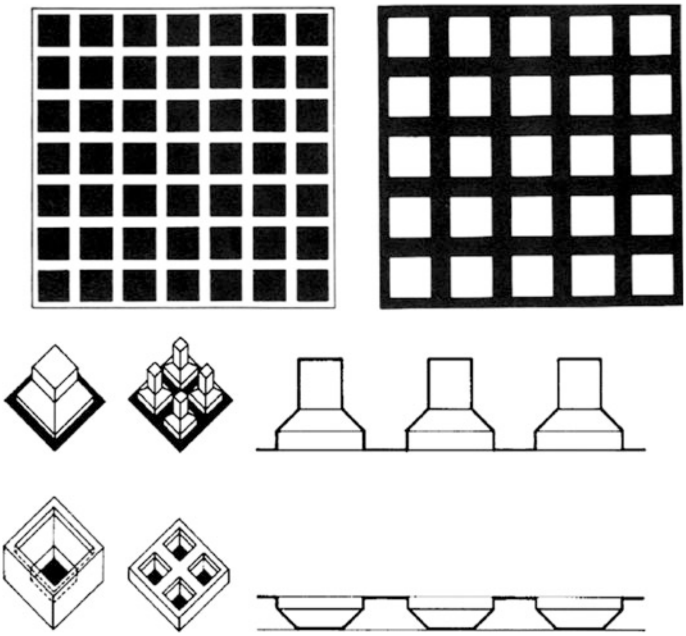


Fig. 5 The forty nine block structure and two building typologies (Martin and March 1972)

environmentally? Martin and March provided an approach to investigating geometric attributes of urban spaces and understanding the relationship between density and spatial typology. Given equal density, various urban typologies generate different effects and consequences. A simple experiment regarding the Manhattan grid was conducted to examine how the grid accommodates two distinct building typologies: the pavilion and the court, based on a fixed building density or floor area ratio (FAR). A grid system of forty nine blocks can be laid out according to the two different building typologies using the same 50 % building cover ratio (see Fig. 5). The relationship among density, urban typology and its social or environmental consequences can then be tested on the performance of urban design.

The simple experiment leads to a question of how the urban grid influences the built form of cities, which, in turn, influences their social and environmental consequences. The current Manhattan grid has developed a specific urban form with a dense skyline of tall skyscrapers from 42nd to 57th Street. What if the same total amount of building floor area were laid out using a different typology, like the courtyard type in which building blocks are arranged around the edge of an enlarged grid. Using this building typology, the original tower blocks could be lowered to an average of 7-story high courtyard blocks that accommodate the same building density (see Fig. 6) (Martin and March 1972).

The hypothetical scenarios for reforming the Manhattan grid reveal the link between urban form typology and its social and environmental impacts. However,

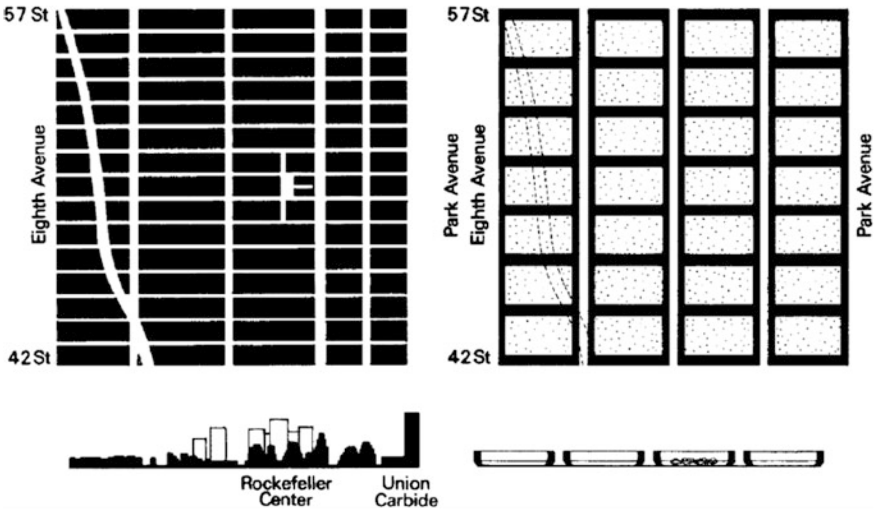


Fig. 6 The Manhattan proposal by Martin and March in the Urban Space Structure book (Martin and March 1972)

the opportunities to redesign the urban form and building typologies in Manhattan are constrained by its grid structure.

What are the advantages of the urban grid in supporting urban energy resilience, in terms of renewable energy harvesting, building energy consumption and energy distribution through the smart grid infrastructure? The form and orientation of urban blocks and buildings affects energy flows in cities, including solar availability, shading and the microclimate that affects the heat transfer between building envelopes. For example, the Manhattan grid contains a large number of east-west oriented blocks, and creates relatively wider south facing building frontage. But the climatic consequences and potential of the grid structure are not fully considered or organized to create a more resilient city.

3.2 Zoning and Setback Controls for Shaping the Urban Street Canyon

Manhattan's urban form is not solely determined by the physical grid structure. Zoning and other regulatory mechanisms also influenced the development of the city's urban form. In the early 20th century, Manhattan was plagued by congested streets, incompatible land uses, and a lack of light and clean air, the results of its intensive urban development. In order for the city to continue to grow and function efficiently, new requirements were needed to address these problems. In response to these issues, New York City created the first zoning ordinance in the United States in 1916. The zoning ordinance established three categories of land uses: residential, business and unrestricted. Zoning demonstrates the ability of regulatory mechanisms, rather than direct architectural design and engineering, to dictate urban form. The principles of zoning, land use control, restriction of building height, setback and building envelopes formed the rules that would determine future urban growth (Loukaitou and Banerjee 1998). Among them, the zoning envelope, or an imaginary spatial envelope beyond which a building could not extend, shapes the three-dimensional urban geometry of New York City. The urban form was determined or affected by the zoning envelope through land assembly and height control.

The setback control, or how building heights are limited in proportion to the width of adjoining streets, shaped the city's urban street canyons, which greatly affect urban climate. The original purpose of setback controls in Manhattan, however, was for aesthetic purpose to create horizontal monumentality within the traditional "five-story building wall" along the streets and to keep towers separate from the street wall (Bender 2002). The setback controls and desire for horizontal monumentality led architects to incorporate decorative bands and ornamental treatments on the buildings' edges, which would become key features of the Art Deco style, also known as "setback style" or "New York style" (Loukaitou and Banerjee 1998). Downtown urban form can be viewed as a container composed of functional cells. The division of downtown into functional cells, defined by zoning, ensured the stable and orderly development of the most prime land in the city, which benefits well established corporations and institutions. As a result, the downtown skylines, streetscapes and canyon-like urban geometries were defined by setback controls in many ways, which produce variation in patterns of microclimate, and would influence total performance of building energy use.

New York City's setback controls, or the width/height ratio (W/H Ratio) to use to width of the road to determine the limit of building heights, act as form-based prescriptive guidelines, and become a global model of urban form control that has been applied to many cities across the globe (see Fig. 7). But the controls impact on buildings' energy performance has received little attention. The performance of the urban form has never been measured in quantitative way or by computing tools until very recently.

Does the current Manhattan urban form contain properties of resilience, e.g. the passive resilience such as redundancy, diversity and adaptability, the active resilience like anticipatory design, modeling or business planning or the capacity for transformative recovery as was defined in the book (Maruyama 2013, 2016)? There is an inconsistency or incompatibility between the historical mechanisms such as the setback control and zoning ordinance that shaped the city's form, and the future mechanisms that will be needed to create a more resilient urban form for adapting to future climate-induced shocks and changes.

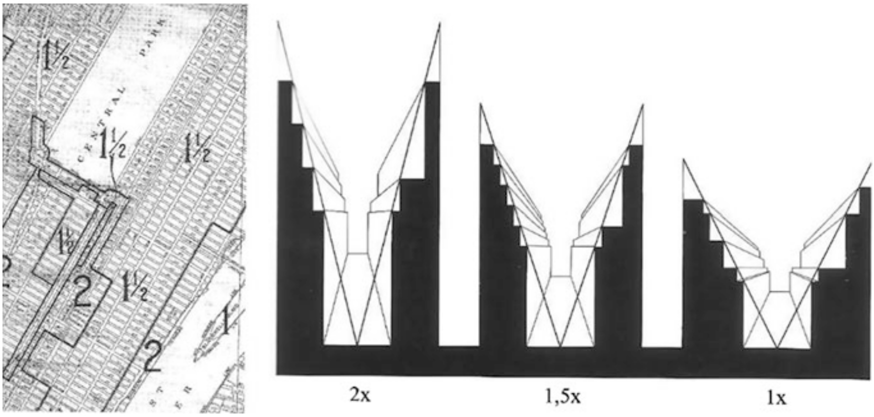


Fig. 7 *Left* Manhattan's setback control map in 1960s; *Right* Street canyons according to the setback ratio (Lehnerer 2009)

4 Urban Energy Modeling of the Manhattan Grid: Moving from a Form-Based Width/Height Ratio to a Performance-Based Energy Resiliency Ratio

4.1 Urban Energy Modeling

Streets, blocks and buildings are the elements of the urban grid system. In Manhattan's grid, the spatial arrangement of these elements reflects similarities and differences, in which the measurability of geometry, scale, performance and their transformation are critical to the making of resilient urban system. How are cities organized in space, time and across different scales? How does the design and organization of cities affect elements of system performance, such as efficiency, complexity and resilience?

We conducted urban energy modeling for the Manhattan grid to test how much total solar energy can be assimilated in the city in different locations and at different times of year. We examined 45,900 buildings within the Manhattan grid to demonstrate how the new modeling assesses each building's energy use, solar potential and energy balance in 2012, using a GIS-based urban energy balance modeling system. This method integrates the building energy modeling and solar potential modeling to provide energy consumption and production estimates and also estimates the energy balance using the self-supply ratio (solar energy production/energy use) and surplus ratio (surplus solar energy/energy use) (Quan et al. 2015b).

This modeling method expands the field of analysis from a single building to many buildings in the urban context. Overall urban energy performance cannot be estimated simply by aggregating individual building performance, as the influence of shading, microclimate changes and occupancy variations must be considered

(Quan et al. 2015b). This model accounts for the interaction between buildings and topographies through obstructions, which influence solar radiation on rooftops, as well as the buildings' energy performance (Ok 1992). Buildings' energy use are also impacted by the building's microclimates. Local air temperature and winds are modified by urban form through the increased thermal storage within buildings and impervious surfaces (Oke et al. 1991). Occupant density and behavioral patterns, which reflects the interaction between buildings and social and economic conditions, also lead to building energy variations (Al-Homoud 2001). This model accounts for all of these factors by developing three engines: a shading engine, a microclimate engine, and an occupancy engine, to estimate hourly variations in building energy use and solar energy production across Manhattan.

The urban energy modeling consists of four models: the Data Integration Model, Urban Building Energy Model, Urban Roof Solar Energy Model and Energy Balance Model. Through these models, the urban scale data are organized and refined to provide inputs for simulations. The resulting data are coupled to examine the energy balance of urban buildings, which leads to the Energy Resilience Ratio, defined as the total solar energy produced by rooftop solar panels divided by the total building energy use (see Fig. 8).

The core *Urban Building Energy Model* is based on a modified EPC calculator (Energy Performance Calculator) in ISO standards. EPC uses simplified calculation to simulate the thermodynamic processes, assuming a quasi-steady-state conditions for heat balance in each hour. It includes heat gain from internal load and solar radiation, and heat loss from ventilation, infiltration and transmission that go through the building envelope (ISO 2006; Lee 2012). Three engines in this model simulated the final inputs. The shading engine generated a set of lines of sight from each sample window point, along which maximum obstruction angles were

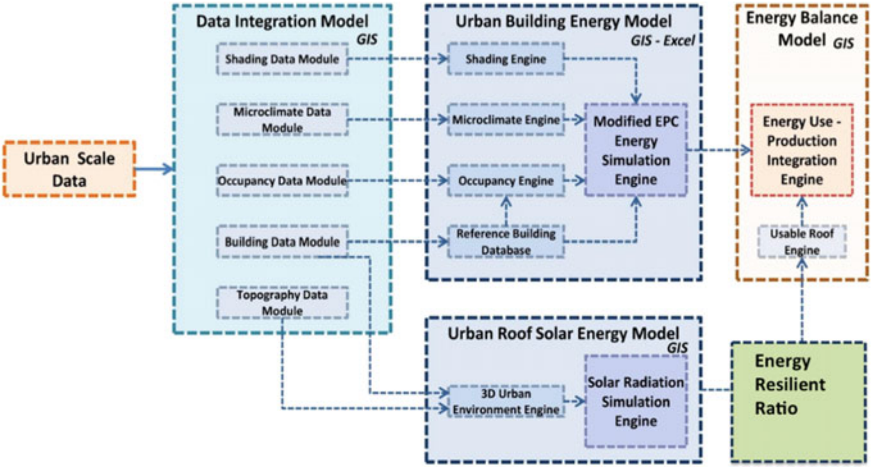


Fig. 8 A process of urban energy modeling for Manhattan grid (revised from Quan et al. 2015b)

Fig. 9 Urban energy modeling in Manhattan. *Left* Annual building energy use mapping; *Middle* Annual solar radiation mapping; *Top Right* Sample window points on the facades and the lines of sight in Gramercy neighborhood; *Bottom Right* Aggregated hourly energy balance of solar buildings in Gramercy neighborhood (Quan et al. 2015a)

calculated according to the intersection between the lines and surrounding buildings, resulting in the shading factor for each facade. The microclimate engine used parameters from the urban canyon and land cover to simulate the hourly temperature representing microclimate for each microclimate zone (Sun and Augenbroe 2014). The occupancy engine used the residence and employment information from census data to adjust the occupant density for each building based on the reference building database. With the output data from those three engines, the modified EPC engine were used to simulate the hourly energy use including electricity use and gas use of each building in Manhattan during a year. The results were then collected and further visualized in GIS to show annual energy use distribution (see Fig. 9).

The *Urban Roof Solar Energy Model* uses the tool of “Area Solar Radiation” based on the Solar Analyst in ArcGIS 10.2 as the core engine. In this model, the 3D modeling engine first transformed the buildings and topography into GIS raster files to represent the 3D urban environment. Then the tool of “Area Solar Radiation” in ArcGIS 10.2 were used to simulate the potentials of solar energy productions from solar PV panels on building rooftops and grounds with different temporal scales from annual, monthly to hourly (see Fig. 9) (Quan et al. 2015b).

Finally, *the Urban Energy Balance Model* examines the balance between the building energy use and rooftop solar energy production. This case study takes the assumption that 50 % of building roofs are used for solar energy production. The usable roof engine first identified the area of 50 % of each roof that has the most solar radiation potentials. Then the potential solar energy production was estimated assuming solar panel efficiency of 20 %. With the solar energy potentials and energy use results, the average building Energy Resilience Ratio through the year was 0.0269, meaning 2.69 % of the overall building energy demands could be met with solar energy from the buildings. However, the energy balance varies at different locations. In the case of the Gramercy neighborhood in Manhattan, the annual Energy Resilience Ratio is 0.0295, which is only a little higher than Manhattan's average as a whole. The model also demonstrates that the Energy Resilience Ratio could increase in the summer with increased solar energy production. For example, during the simulation the daily Energy Resilience Ratio in the Gramercy neighborhood on June 21 was estimated at 0.1015, significantly higher than its average ratio of 0.0295 for the entire year.

4.2 *Moving from the Form-Based Width/Height Ratio to the Performance-Based Energy Resilience Ratio*

The previous results show that the current energy self-supply ratio for Manhattan's grid is still low with the utilization of solar energy. During unpredictable shocks, such as hurricanes that may cause power blackouts and infrastructure breakdowns, the city and its infrastructural systems are unreliable and lack the ability to react and respond to extreme or unforeseen conditions.

How can cities be reorganized and restructured to increase adaptability and resilience? How can the urban form be transformed to be more resilient and robust, given that the current urban grid is far from self-reliant or energy resilient? The urban energy modeling demonstrates that there are variations in energy balance over space of the island and time of a year. Understanding how to exploit these variations, in order to best harvest renewable energy and increase energy performance, will be an important aspect of creating resilient and adaptable cities. The urban grid structure should be adapted to be more climate-sensitive and energy-responsive, rather than simply a form-based structure. The control of urban form making should move from prescriptive urban design guidelines to performance-oriented criteria.

The following analysis uses the previous urban energy modeling to compare the W/H Ratio as the prescriptive form-based guideline and the Energy Resilience Ratio as the performance-based indicator within the Manhattan grid.

The system boundary of the urban district for computing energy balance is defined based on the census tracts and the urban block. Census tract is a geographic unit used for census on demographic characteristics. It links geographic areas with population and societal datasets, but it also reflects the clustering of neighborhoods or districts of homogeneous urban form regulated by current zoning ordinances. The urban block is a physical territory bounded by streets. It is often used to calculate building density such as Floor Area Ratio (FAR). According to the 2010 Census, Manhattan is divided into 288 census tracts and 2870 urban blocks based on the PLUTO (Primary Land Use Tax Lot Output). Given the inconsistency between the two kinds of spatial units, the system boundary of energy performance computing is modified and combined to be 257 district units.

The advantages of defining the above district unit include: (1) the census tract is officially used to document the population change and related to the estimation of occupancy, including the occupant density and occupant behavior (United States Census Bureau 2012) which influence building energy use greatly, and therefore can be used as a spatial unit to cluster building energy use; (2) the census tract was established based on topography, housing and drainage (Krieger 2006). The district unit combines both the census tract and the urban block that imply homogeneous urban geometry, and corresponding microclimate within each district that affect building energy use and renewable energy production; (3) the size of district unit in Manhattan is close to the local climate zones (LCZ) of a classification system proposed by Stewart and Oke that are associated with the homogeneous urban form (Stewart and Oke 2012). It can be linked to wider applications such as the World Urban Database and Access Portal Tools (WUDAPT 2016). The microclimate zone is of great importance in urban building energy performance studies (Li et al. 2015). In this case study, the district unit for analysis serves as the local climate zone to keep the microclimate regime constant within each district. Steward and Oke suggested that the radius of the microclimate zone should be at least 200–500 m so that the boundary layers of adjacent microclimate zones won't overlap with each other (Stewart and Oke 2012), which is equivalent to the minimum area of microclimate zone of 125,600–785,000 m^2. In the total of 257 districts in Manhattan, 76 % of them meet the area requirement of the local climate zone.

The 257 district units are used for calculating the two indicators in those districts: (1) the W/H Ratio measured and calculated in GIS, and (2) the annual Energy Resilience Ratio calculated based on the urban energy modeling described above.

The W/H Ratio computed in our model is based on the existing urban form, in which the discontinuous facades and various building heights in blocks of actual architectural designs are far more complex than the hypothetical envelop controls or the setback controls by the urban design guidelines (see Fig. 9). The computation of the actual W/H Ratio in this study follows the method commonly used in microclimate studies as the average building height in a certain spatial unit (Bueno et al. 2013). In this case study, the W/H Ratio of each district is measured as the average distance between buildings on two sides of all the streets included in the district divided by the average height of buildings of the district (Fig. 10).

As discussed in previous paragraph, the Energy Resilient Ratio is calculated using the above Urban Energy Modeling to simulate how much energy production from rooftop PVs would meet the demand of building energy use within the district over certain period of time. Districts with higher resilience ratio are more self-sufficient and therefore more able to handle and adapt to the effects of unpredicted shocks such as blackouts. Different from the W/H Ratio, the Energy Resilient Ratio varies not only spatially but also temporally, which can be measured based on annual, monthly, daily or hourly average. To evaluate the capability of self-sufficiency and resilience of urban district, the Energy Resilient Ratio should be measured according to when and how long the problems would be caused by the shocks.

The spatial distributions of the W/H Ratio and the annual Energy Resilience Ratio in Manhattan are shown in Fig. 11. The Energy Resilience Ratio was also

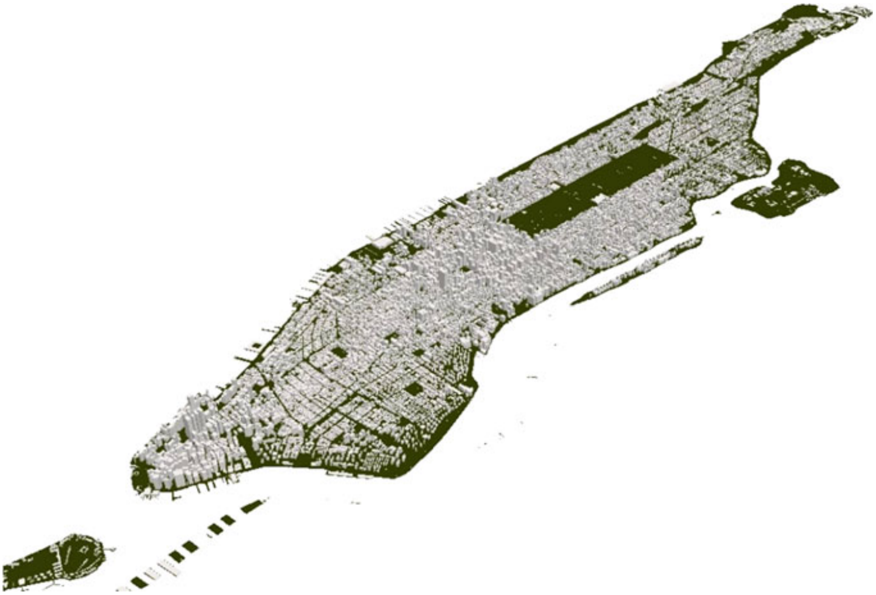


Fig. 10 Highly complex building shapes in Manhattan regulated by set-back and W/H controls

plotted against the W/H Ratio to show their relationship in Fig. 12. Observations from these two figures suggest a seemingly positive correlation between the two variables.

In order to verify this hypothesis, this case study conducted a simple linear regression to test 257 districts with the Energy Resilience Ratio as the dependent variable and the W/H Ratio as the independent variable. The results in Table 1 show that the W/H Ratio is significantly and positively correlated with the Energy Resilience Ratio with the significant level of 0.000, which verifies the hypothesis on the correlation between the two variables. Such result suggests that the W/H Ratio as a prescriptive form-based urban design control can still take effects in addressing the energy resilience variations. However, the R-Square of the regression is only 0.213, which means that the form-based indicator of the W/H Ratio can only explains 21.3 % of the variation in energy resilience. The limited R-square can be observed from the plotting in Fig. 13, in which a number of district units seem to be outliers for the linear relationship between the two variables. It points out that the W/H Ratio as a form-based prescriptive control does not ensure the energy resilience of all district units. The W/H Ratio cannot address the temporal dynamics of the system or the variation of the energy resilience over time. The performance modeling approach proposed in the chapter provides an alternative to addresses the energy resilience problem with better accuracy for adaptable strategies.

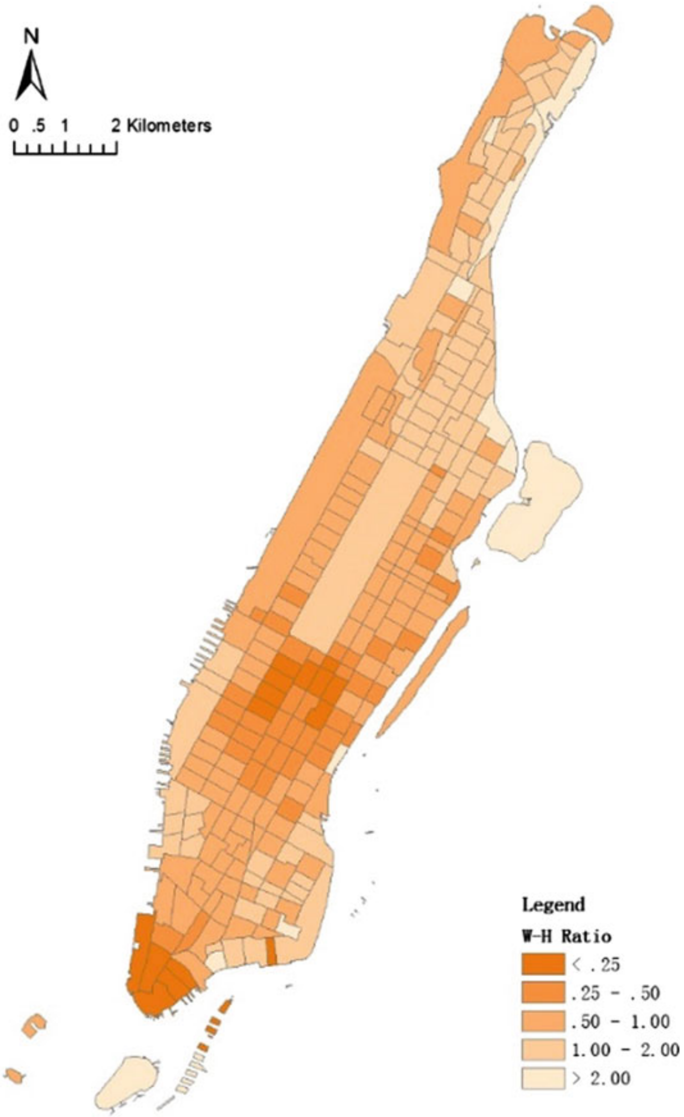


Fig. 11 W/H Ratio mapping in Manhattan

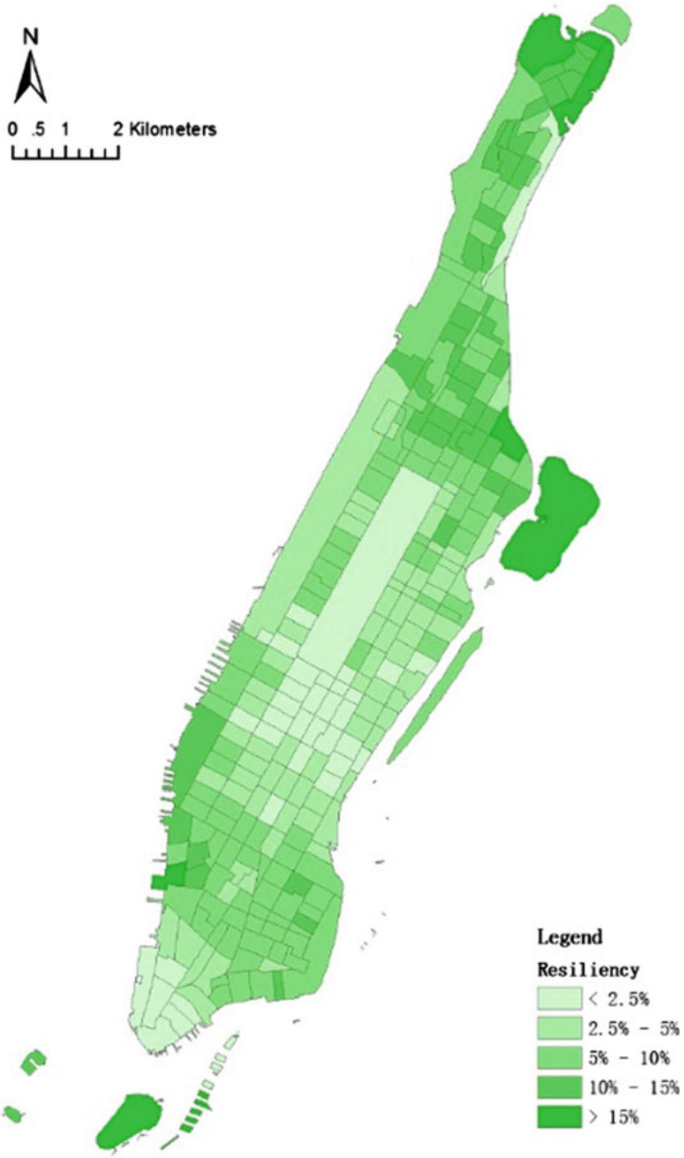


Fig. 12 Energy resilience ratio of defined 257 districts in Manhattan in 2012

Table 1 Coefficients of the linear regression with the dependent variable of the resiliency and the independent variable of the W/H Ratio

Predictors	B	Std. error	t	Sig.
(Constant)	0.045	0.005	9.731	0.000
W/H Ratio	0.026	0.003	8.304	0.000

Dependent variable: energy resilience ratio

R-square: 0.213; std. error of the estimate: 0.056

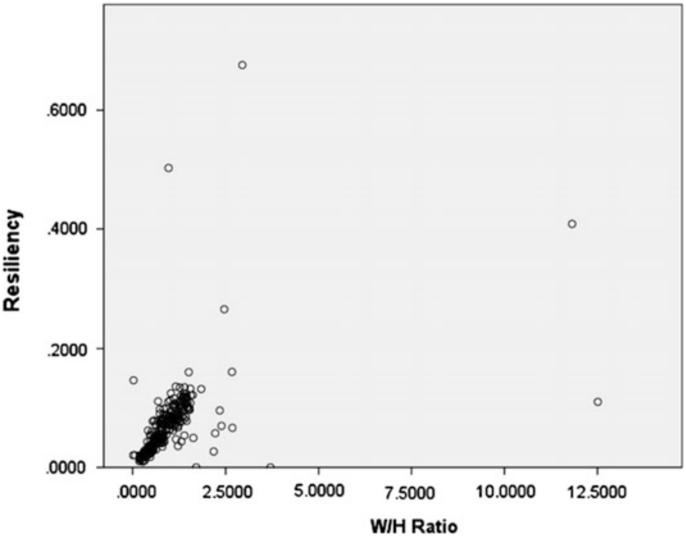


Fig. 13 Plotting of the resiliency against W/H Ratio

5 Conclusion

This chapter investigates the Manhattan grid, a world-renowned high-density urban form structure in place since 1811, and its relationship to resiliency, with a special focus on energy performance. We raise two fundamental questions: (1) to what extent is the Manhattan grid a resilient urban form, and (2) how can the urban form be transformed to create a more energy resilient future city?

The traditional zoning ordinance uses the W/H Ratio, a form-based prescriptive guideline, to form the streetscape and ensured access to sunlight in the case of New York City. The W/H Ratio resulted in the setback control, the setback style or Art-Deco style seen across New York's urban streetscape. The zoning ordinance was intended to control day lighting and ventilation in the urban environment, however, it only indirectly affects buildings' energy performance at the urban-scale.

The above results show that the current Manhattan grid contains very low energy self-supply ratios, which are insufficient for responding to unpredictable shocks, such as hurricanes, that may cause power blackouts and infrastructure breakdowns. A concept of *performance-based* modeling and the Energy Resilient Ratio is proposed to further predict and manage buildings' energy consumption and energy production in real time. There is a need to transition from the current prescriptive-based setback controls, such as W/H Ratio, to a performance-based real time assessment model.

A comparative analysis and mapping of the W/H Ratio and the Energy Resilience Ratio based on 257 districts or local climate zones of the island and over a year in Manhattan are conducted. The result shoes that the W/H Ratio as a form-based prescriptive control does not ensure the energy resilience of all district units. The W/H Ratio lacks the temporal dynamics for responding to the problems of energy resilience over time. By adopting the performance-based model and developing strategies for the increase of energy resilient ratios, the urban form can then be transformed to better adapt to shocks and blackouts caused by the hazardous effects of climate change.

To what degree can the urban form of Manhattan be transformed for more energy resilient, given the physical and institutional constraints of the grid structure? If the current urban form, grid structure and infrastructural systems are not resilient, or was not designed as for being resilient, how do we undo the mistaken parts? What is the reversibility for the system, or in other words, the ability of a system to make recovery? This paper examines a transition from form-based control to performance modeling for strategies to increase energy resilience. Further research should examine transformative paths to increase energy self-sufficient and resilient urban form through linking modeling and urban systems design.

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Disease Outbreaks: Critical Biological Factors and Control Strategies

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Abstract Disease outbreaks remain a major threat to human health and welfare especially in urban areas in both developed and developing countries. A large body of theoretical work has been devoted to modeling disease emergence, and critical factors that predict outbreak occurrence and severity have been proposed. In this chapter, we focus on biological factors that underlie both theoretical models and urban planning. We describe the SARS 2002–2003 pandemic as a case study of epidemic control of a human infectious disease. We then describe theoretical analyses of disease dynamics and control strategies. An important conclusion is that epidemic control will be strongly dependent on particular aspects of pathogen biology including host breadth, virulence, incubation time, and/or mutation rate. The probability, and potential cost, of future outbreaks, may be high and lessons from both past cases and theoretical work should inform urban design and policy. Interdisciplinary collaboration in planning, swiftness of information dissemination and response, and willingness to forgo personal liberties during a crisis may be key factors in resilience to infectious disease outbreaks.

1 Introduction

1.1 Epidemics and Human History

Infectious diseases pose an ever-present danger to human societies. Despite tremendous advances in medical care, roughly one quarter of worldwide human deaths are attributed to infectious and parasitic disease (Mathers et al. 2008).

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Several seemingly unalterable aspects of urban life, including long-distance travel and dense human contact networks, facilitate outbreaks from both known and newly evolved pathogens.

Epidemics are defined as widespread occurrences of infectious disease in a community at a particular time, and the 14th century bubonic plague, or "Black Death", was the most devastating epidemic in human history (Benedictow 2004). Death rates were as high as 25–60 % in Europe, Africa, and Asia from a disease caused by a bacterial infection (*Yersinia pestis*) that persists in rodent populations and is transmitted by fleas to humans. Close contact between humans and rats and worldwide travel contributed to the global impact of bubonic plague which appears to have originated in Asia and traveled to Europe via trade routes (especially rat-infested ships).

The most destructive modern pandemic was the 1918 influenza that infected one third of the world's population (about 500 million) and killed 50–100 million between January 1918 and December 1920 (Taubenberger and Morens 2006). "Spanish influenza", as the disease was named, is caused by the H1N1 virus which is endemic in pigs and birds and often transitions into human populations. The lethality of the 1918 strain was high and showed an unusual relationship between lethality and patients' age: 50 % of deaths were in the 20–40 age group which is the opposite pattern for milder flu strains (higher mortality among the very young and the aged). This partly reflected the impact of WWI where contagion was passed among troops both in training facilities as well as during warfare. However, the strain also had an unusual and lethal property; virulence was enhanced by a human immune over-reaction called a "cytokine storm" which causes the lungs to fill with liquid. Some important aspects of the epidemic were: a deadly pathogen arose from a jump from animal to human (close between-species interactions were important in the origin of the virus), a few mutations were sufficient to confer strong lethality for the virus, and human travel allowed rapid spread (close quarters and massive troop movements helped to spread the virus and allowed new mutations to spread quickly).

This chapter will focus on biological factors that are relevant for understanding and controlling epidemics. We will briefly describe some pathogens that cause human disease and their transmission mechanisms before analyzing the SARS 2002–2003 epidemic as a case study of a modern urban epidemic. Disease models will be discussed with a goal of determining how human societies can prepare to minimize the impact of future disease outbreaks.

1.2 Pathogens and Transmission Mechanisms

Infectious diseases can be classified into two broad categories based on their pattern of transmission (Table 1). "Long-range" infectious diseases are infections that do not require close contact for transmission. For example, water-borne diseases, such as cholera, can rapidly spread throughout the community when the supply of

Table 1 Classification of selected infectious diseases based on their mode of transmission

Long-range		Short-range		
Water-borne	Vector-borne	Airborne	Droplet	Direct contact
Food-borne				
Cholera (*Vibrio cholerae*) Viral gastroenteritis (*Norwalk virus*) Hemorrhagic diarrhea (*E. coli* O157: H7)	Dengue fever (*Dengue virus*) Malaria (*Plasmodium* spp.) Bubonic plague (*Yersina pestis*)	Influenza (*Influenza A virus*) Tuberculosis (*Mycobacterium tuberculosis*) Measles (*Measles virus*)	Severe acute respiratory syndrome (*SARS coronavirus*) Middle East respiratory syndrome (*MERS coronavirus*)	Ebola (Ebolavirus) Smallpox (*Variola virus*) Acquired immunodeficiency syndrome[a] (*Human immunodeficiency virus 1*)

[a] Sexually-transmitted infection

drinking water becomes contaminated with the pathogen *Vibrio cholerae* through poor sanitation or hygiene practices. Food-borne infections follow a similar transmission pattern to water-borne diseases. Transmission through contaminated food and water is also known as “fecal-oral transmission” because fecal matter is often the source of contamination while oral ingestion is the primary route for infection (Mount Sinai Hospital 2007). Diseases transmitted by an animal vector, such as bubonic plague, are also considered long-range infections because a vector facilitates the spreading of the pathogen and direct contact is not necessary. One interesting aspect of some vector-borne infections is that direct contact with an infected individual cannot transmit the infection without the help of the vector. For example, Dengue fever, caused by a mosquito-borne virus, can only be transmitted through the bite of an infected mosquito (US Centers for Disease Control and Prevention 2014). In contrast, plague, caused by bacteria living in fleas of rodents, is primarily transmitted through flea bites, but contact with contaminated body fluids like blood can also lead to plague bacterial infection (US Centers for Disease Control and Prevention 2015a).

In general, fecal-oral and vector-borne diseases are infections transmitted through an environmental (water, food) or a biological (animal) carrier that extends transmission range to large distances, but other routes are also possible depending on the specific pathogen.

Compared to long-range diseases, “short-range” infectious diseases are infections that transmit over limited distances and may require close or direct physical contact with an infectious individual. Examples of short-range infections are pathogens that infect via contaminated airborne particles or expectorated droplets, and diseases that require contact with skin or bodily fluids such as blood or semen. Infections capable of airborne transmission have the widest range among short-range infections and are caused by pathogens that spread through minute solid or liquid particles suspended in the air for an extended period of time (Mount Sinai Hospital 2007). In addition, the pathogen must be resistant to desiccation to remain viable for long periods of time outside its host. Respiratory diseases are commonly believed to spread via airborne transmission of contaminated particles expectorated from coughing and sneezing. However, many respiratory pathogens do not have the capacity to withstand dry environments. Instead, these pathogens transmit via "droplets"—expectorated moisture particles that are too big to indefinitely remain suspended in the air—to ensure ample moisture while outside the host. Transmission occurs when contaminated droplets from an infected individual come in contact with surfaces of the eye, nose, or mouth. This mode of transmission is called "droplet contact". Although diseases spreading via droplet contact have a more limited range than truly airborne infections, in the later sections, we will show how environmental factors can extend the range of droplet transmission. Finally, diseases that transmit via direct contact generally have the most limited transmission range and some have stringent requirements for transmission. In the case of Ebola, the disease is transmissible only via direct exposure of broken skin or mucous membranes with contaminated body fluids like blood, urine and semen, and excretions such as vomit and feces (US Centers for Disease Control and Prevention 2015c). Sexually transmitted diseases like HIV/AIDS are a special form of direct contact infection that requires sexual intercourse or sharing contaminated needles for exposure (US Centers for Disease Control and Prevention 2015b). Thus, short-range infections are characterized by some dependence on distance for infection and can be transmitted directly without a carrier.

Distinguishing between these two classes is important because measures to alleviate and control the spread of long-range infections are not applicable for short-range cases and vice versa. For instance, targeting the carrier or vector of the disease to control the spread of long-range infections (e.g., decontaminating or blocking off access to contaminated water or food) and reducing exposure to vectors of the disease, are irrelevant for mitigating the spread of short-range infections. In contrast, measures to control short-range diseases such as limiting person-to-person contact and imposing quarantine procedures do little to help alleviate the spread of water-borne or vector-borne illnesses. Thus, identifying the mode of transmission is crucial to controlling the spread of any contagious infection. However, we will show that the distinction between long- and short-range transmissions is not always clear-cut.

In this chapter, we focus on the emergence and spreading of Severe Acute Respiratory syndrome or SARS; the first worldwide pandemic in the age of globalized air travel and telecommunications. Through theoretical analyses and data gathered from the epidemic, we examine how globalization exacerbates the problem of containing epidemics and show how urban environments can be especially prone to epidemics. The emergence and control of the SARS epidemic is extensively documented. Research on both the origin and epidemiology of the outbreak as well as the biological underpinnings of the disease making them excellent cases to determine methods to enhance urban resilience to epidemics.

2 The 2002–2003 SARS Outbreak: A Modern Urban Epidemic

The history of the 2002–2003 global outbreak of Severe Acute Respiratory Syndrome (SARS) provides key lessons on biological and policy factors that should be of general importance in designing resilient cities. We will summarize the history of the epidemic, with a focus on biological factors, before our discussion of disease models.

According to the World Health Organization (WHO), over 8000 worldwide SARS cases and over 770 deaths occurred in 30 different countries, mostly over a period of about four months (Kamps and Hoffmann 2003). The severe, "atypical" pneumonia originated in Guangdong Province in southern China in mid-November 2002. Most of the early cases appear to have occurred among those who kill and sell animals and meat as well as food preparers and servers (Breiman et al. 2003). By mid to late January 2003, the disease began to spread rapidly within the province, but a combination of symptoms difficult to distinguish from pneumonia (fever, dizziness, muscle soreness, coughing) and government policy to discourage coverage delayed the reporting of the epidemic until February 11. The initial communication reported 305 cases (including >100 healthcare workers) and 5 mortalities, but claimed that the epidemic was under control (Enserink 2013).

The role of "superspreaders" and amplification in hospitals remained characteristics of SARS as it spread to a worldwide epidemic. The first of several superspreading (generally defined as ten or more transmissions from a single infected individual) events occurred in Hong Kong on February 21, 2003 (Braden et al. 2013). The index case was a physician from Guangdong who stayed at the Hotel Metropole. The physician had treated SARS patients in Guangdong (although the disease was still unrecognized) and showed symptoms before his trip. He stayed only one night at the hotel before being hospitalized with severe symptoms but the short stay was sufficient to spread the infection to 13 or more of the guests from the same floor of the hotel as well as a Hong Kong resident who visited one of the guests. Eventually, over 4000 (almost half) of the documented 2003 SARS cases could be traced to this "index" case. Remarkably, there was no known direct contact in most of the transmissions among the hotel guests and visitors. The Hong Kong resident who visited a friend in the hotel subsequently infected over 140 others at the Prince of Wales Hospital in Hong Kong. Others were business/holiday travelers who spread the pathogen to Canada, Vietnam, and Singapore. As we will discuss below, this high transmission rate with little close contact in the Metropole Hotel remains mysterious.

Rapid recognition of a new epidemic was aided by a WHO disease expert, Carlo Urbani, who was asked to examine patients in a Hanoi hospital. The affected included one of the Metropole guests and roughly 20 hospital staff who became affected not long after his admission. Urbani recognized a severe, and possibly new, disease and warned WHO headquarters as well as the hospital and Vietnam government before contracting, and eventually dying from, the disease (Bourouiba et al. 2014).

Response time is a critical parameter in epidemic control and his efforts played a large role in the effort to subdue the epidemic. WHO designated a new disease, “severe acute respiratory syndrome” (SARS), on March 10 and issued a global health alert on March 12 followed by an emergency travel advisory on March 15. The etiological agent of SARS was later discovered to be a novel coronavirus and was named SARS-associated coronavirus (SARS-CoV). This discovery, in late March 2003, came as a surprise to disease experts as previous human coronaviruses were only known to cause mild illness. In animals, related viruses were known to cause fatal respiratory as well as neurological diseases but coronaviruses are usually highly species-specific (Kamps and Hoffmann 2003).

Forensic analysis of the Metropole Hotel in late April 2003 revealed physical components of SARS in the common areas of the 9th floor including the corridor and elevator hall. However, no bacteria were found inside the guest rooms of the infected guests (the ventilation systems employed positive pressure within the guest rooms so that air was not shared among rooms). Respiratory droplets, or suspended small particle aerosols generated by the index case-patient, are the most likely transmission mechanism (Braden et al. 2013). SARS and other respiratory infections are considered to undergo short-range (approximately 1 m) transmission via pathogen-infected droplets from host coughing or sneezing. Such transmission requires “close contact”, physical proximity between infected and susceptible individuals who can be infected when large droplets spray enter their bodies via air or touch. However, minute droplets or even solid residues that can arise via evaporation (droplet nuclei) may allow potential indirect and/or long-range transmission (Bourouiba et al. 2014). For example, contaminated gas clouds that form during coughing/sneezing may have carried the pathogen and extended its transmission range, removing the distinction between droplet contact and airborne modes of transmission. Aerosol transmission probably caused high infection rates in an airline flight (Air China 112) from Hong Kong to Beijing in which a single 73-year old individual infected at least 20 others (Olsen et al. 2003). This feature of the disease may be highly relevant for medical and urban policy. Long-range aerosol/nuclei transmission does not require direct contact between infected and uninfected individuals and can greatly elevate the number of “contacts” for a given infected individual. Interestingly, genetic analysis showed that several SARS strains entered Hong Kong, but only the Hotel Metropole index case was associated with the subsequent global outbreak (Guan et al. 2004).

A related superspreading event occurred at a crowded high-rise residence, the Amoy Gardens, in Hong Kong. Many of the infected individuals inhabited vertically placed apartments (in contrast to transmissions on a common floor at the Metro Hotel case). Sanitary drainage fixtures that were malfunctioning and allowing air and SARS-contaminated aerosols to flow back into resident bathrooms may have been the main driver of infection spread in the condominium (Stein 2011). The superspreader was likely a medical patient undergoing treatment for a kidney problem including hemodialysis, a medical treatment that inhibits immune capacity (Stein 2011). The index case carried a high viral load and suffered from diarrhea. An important feature of this event was again, a lack of direct contact between the spreader and the individuals he infected, and the "opportunity" for the pathogen to be exposed to a large number of individuals through airborne transmission (Yu et al. 2004). At the Amoy Gardens, more than 300 individuals showed symptoms of SARS almost simultaneously.

High rates of hospital (nosocomial) transmission were an important and disturbing characteristic of the SARS outbreak. The large fraction of infections among healthcare workers probably reflects a combination of contact from respiratory secretions from patients who were at a highly contagious stage (critically ill individuals also were the most infectious) as well as from medical procedures that inadvertently generated aerosol contamination. A single patient appears to have transmitted infections to over 140 hospital staff in a span of two weeks at the Prince of Wales Hospital in Hong Kong (see below).

Two other superspreader events occurred in hospitals in other countries (Braden et al. 2013). One infected patient (the son of one of the Hotel Metropole guests) infected over 100 cases among patients, visitors, and healthcare workers at the Acute Care Hospital in Toronto, Canada. Finally, although Taiwan instituted strict port entry screening and isolation of potentially exposed travelers entering the country, there was an outbreak in the Ho Ping Hospital which spread into the community. In spite of a lock-down quarantine of over 1000 people in the hospital (included a large fraction of uninfected individuals), over 600 cases emerged before the outbreak was contained.

The initial rapid spread of SARS caused widespread concern and panic and the epidemic seemed unstoppable. However, the disease was eventually contained within several months through efforts coordinated by the WHO. Although advances in biomedical science and cooperative efforts among laboratories played key roles in isolating the infectious agent, "classic" epidemiological practices of patient isolation (separation of infected individuals from the general population), contact tracing, and large-scale quarantine (isolation of non-symptomatic individuals who have had contact with the infectious agent) were the main elements that halted the epidemic (Anderson et al. 2004).

2.1 Key Lessons from the SARS 2003 Crisis

The 2002–2003 SARS pandemic was caused by a moderately transmissible viral infection that produced 2.7 new cases for every infection (Riley et al. 2003) and yet it spread to over 30 countries across three continents potentially exposing tens of thousands of people in the span of only a few months. Several studies have shown that the vast majority of infected cases had very low infectivity and that a few outliers were responsible for a disproportionate number of new infections (Anderson et al. 2004; Riley et al. 2003; Lipsitch et al. 2003; Wong et al. 2004). In fact, Riley et al. (2003) and Lipsitch et al. (2003) found that early in the epidemic, an infected individual would only produce approximately three new infections when outliers are excluded. In Singapore, 81 % of the first 201 probable SARS cases showed no evidence of transmitting the infection yet 5 cases appeared to have transmitted the disease to 10 or more individuals (Lipsitch et al. 2003). Shen et al. (2004) found a similar pattern in Beijing where 66 out of the 77 confirmed cases did not infect others whereas four cases were responsible for infecting eight or more.

The rapid spreading of SARS despite only moderate average infectiousness has revived interest in the concept of superspreading events and heterogeneity in pathogen transmission. The transmission potential of an infectious disease is often described by the parameter R, the average number of new infections that infected cases produce over the course of their infection. R_0 is the transmission potential of an infected individual within an otherwise completely susceptible population (Dietz 1993). However, population-based summary statistics may obscure individual variation of infectiousness and other types of heterogeneities. Woolhouse et al. (1997) have shown that heterogeneities in infectiousness exist such that only 20 % of the host population contributes at least 80 % of a pathogen's transmission potential. These individuals who significantly transmit more than the average are called superspreaders. In Hong Kong, apart from the incident at Hotel Metropole, at least two large clusters of infection were attributed to superspreading events (Riley et al. 2003). Data from the SARS pandemic showed the effect that superspreaders and superspreading events could have on the trajectory of the epidemic. Given their crucial role in intensifying an outbreak, we review the risk factors that facilitate superspreading events.

Co-infection and the presence of a comorbid disease could be risk factors for turning infected individuals into superspreaders (Stein 2011). Studies on HIV/AIDS transmission showed that co-infection with another sexually transmitted pathogen increased the urethral shedding of HIV in infected individuals. Moss et al. (1995) demonstrated that urethral HIV infection is associated with gonococcal infection and treatment for urethritis may reduce the risk of HIV transmission. In the case of SARS, Peiris et al. (2003) reported that other viral respiratory pathogens such as human metapneumovirus were detected in confirmed SARS cases. In addition, the index case in the Prince of Wales Hospital superspreading event was described to have a "runny nose" (Wong et al. 2004), an uncommon symptom for a lower-respiratory tract infection such as SARS. These observations have led to the hypothesis that co-infection or presence of a comorbid condition could endow an infected individual with characteristics or behaviors that increases their infectiousness (Bassetti et al. 2005). For example, rhinovirus, the major cause of common colds, can cause swelling of nasal tissues that can elevate airflow speed and contribute to aerosol production (Sherertz et al. 1996). Rhinovirus co-infection with more serious, but less transmissible respiratory ailments, such as SARS, could be an important factor contributing to high infectivity.

Environmental factors also play an important role in facilitating superspreading events (Stein 2011). In the SARS superspreading event at the Prince of Wales Hospital, the index case was placed on a nebulized bronchodilator four times daily for one week (Kamps and Hoffmann 2003). Nebulized bronchodilators are often used to deliver drugs to the lungs of respiratory patients but may have inadvertently aerosolized the virus and left infected droplets in the immediate surroundings leading to extensive dissemination of the pathogen (Tomlinson and Cockram 2003). Tracheal intubation, which involves placing a flexible tube into a patient's windpipe to maintain an airway to deliver drugs, may also have inadvertently spread SARS within hospitals. Patients often emit respiratory secretions during the procedure.

An outdated ventilation system and overcrowding likely also contributed to the spreading of the virus at the Prince of Wales Hospital (Riley et al. 2003; Tomlinson and Cockram 2003). Through a case-control study of hospitals treating SARS patients, Yu et al. (2007) confirmed overcrowding as one of the general risk factors of hospital-based SARS superspreading events. The case-control study performed included 86 wards in 21 hospitals in Guangzhou and 38 wards in five hospitals in Hong Kong and showed that the main risk factors included closely arranged beds (less than 1 m apart), a workload of more than two patients per healthcare worker, hospital staff that continued working despite experiencing symptoms of the disease, and lack of washing or changing facilities for staff.

Despite the explosive growth and global distribution of the SARS outbreak, the pandemic was largely contained through isolation and quarantine, increasing social distance, and social behavioral adjustments (Bell and World Health Organization Working Group on Prevention of International and Community Transmission of SARS 2004). Isolation and quarantine were shown to significantly interrupt transmission of SARS in several countries including Hong Kong (Riley et al. 2003), China (Pang et al. 2003), Singapore (Lipsitch et al. 2003), Taiwan (Twu et al. 2003), and Canada (Svoboda et al. 2004). In general, symptomatic cases were immediately placed in isolation while contacts of confirmed infected cases were placed in some form of quarantine. In some cases, contacts were not immediately confined but instead were monitored for the disease and isolated only when symptoms emerged. Confinement was usually at home but designated facilities were available in countries like Taiwan (Twu et al. 2003). In some cases, individuals under quarantine were allowed to travel with the permission from the local health authorities provided they wore masks and refrained from using public transportation or visiting crowded places. To further reduce the chance of transmission, Hong Kong and Singapore also closed schools and public facilities, and canceled mass gatherings to "increase social distance". People were also required to wear masks when using public transport, entering hospitals, or in jobs where interacting with numerous people is unavoidable such as in restaurants (Bell and World Health Organization Working Group on Prevention of International and Community Transmission of SARS 2004). The concerted effort has been marginally associated with the rapid reduction of new SARS cases in several countries. However, because of the simultaneous introduction of these measures, it is difficult to evaluate the effectiveness of each.

Several characteristics of the infectious agent were important factors in controlling the SARS epidemic. The incubation period from contact with the infectious agent to onset of symptoms was, on average, 4.5 days. Importantly, peak infectivity coincided with clinical symptoms and often required an additional 10 days or more (Anderson et al. 2004). Thus, infectious individuals tended to be hospitalized before peak transmissibility. In addition, the two-week interval from exposure to high infectivity gave epidemiologists critical time to perform contact tracing to identify and quarantine potentially infected individuals before they reached high infectivity. This feature, in combination with moderate transmission rates (except in special cases), contributed to making SARS a relatively controllable outbreak.

In the next section, we present current theories on the emergence and spreading of epidemics and review the theoretical underpinnings behind control measures used to contain outbreaks. We briefly highlight different mathematical models used to describe epidemic dynamics in populations. We explain the factors that govern the emergence and transmission of diseases as well as the evolution of pathogens that cause them. Finally, we examine how control measures such as isolation, quarantine, and vaccination mitigate the spread of infections.

3 Theoretical Models of Emerging Infectious Disease

Mathematical models have played an important role in our understanding of disease propagation. If biological factors can be accurately incorporated, such models may have predictive power to evaluate control strategies and guide policy. A key parameter in epidemic models is the total number of new infections that arise from a single affected host, the reproduction number, R. This value determines the outbreak potential of the infection; if $R = 1$, the infection will be maintained at a constant level (if we ignore random effects). $R > 1$ leads to disease spread and $R < 1$ predicts eventual extinction. However, R is not an intrinsic property of the pathogen. Variability of the reproductive number across pathogens, hosts, and environments over time must be understood to accurately model disease.

In the following three subsections, we discuss theoretical results on three important aspect of disease outbreak: (1) the effect of "superspreaders" on the probability of outbreak, (2) the impact of control strategies such as isolation and quarantine, and (3) factors that affect the evolution of pathogen virulence.

3.1 Superspreaders and Outbreaks

The 2002–2003 SARS epidemic was characterized by the large impact of "superspreaders" on disease propagation. In theoretical models, superspreaders can be treated as individuals with large number of connections to other individuals. Individual-based simulations incorporating network structures can efficiently address this topic and, in this subsection, we introduce three theoretical studies focused on the effect of network structure on disease outbreak.

Lipsitch et al. (2003) studied the effect of superspreaders on outbreak probability using the estimated parameters from the SARS outbreak in Singapore. The authors first estimated the distribution of the parameter R, which expresses the number of new infections from an infected host. Probabilities of outbreak (persistence of

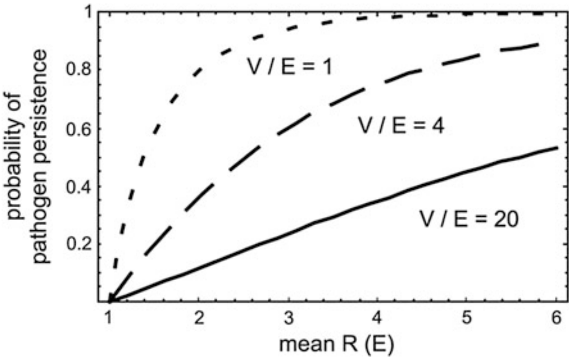

Fig. 1 Theoretically estimated probability that a single introduced pathogen persists after infinite time under a Markov process with different mean (E) and variance (V) in the *R* distribution. In Lipsitch et al. (2003) this persistence probability is considered as probability of an outbreak. Modified from Lipsitch et al. (2003, Fig. 4A)

initially introduced pathogen lineages) were determined for *R* distributions with a fixed mean but differing in variance. The authors found that large variance in *R* distribution greatly *decreased* the probability of outbreak (Fig. 1). Contrary to the expectation of the importance of superspreaders, their result showed that distributions strongly clustered around the mean had higher probabilities of outbreak than distributions that included superspreaders (right-hand tail outliers). One reason of this apparent inconsistency might be the assumption of a fixed mean *R*. Under this assumption, increased variance in the *R* distribution increases both the numbers of individuals with extremely high *R* and low *R*. Individuals with low *R* are essentially "dead ends" in disease infection and high numbers of such individuals will decrease outbreak risk.

A similar result was obtained in Meyers et al. (2005). This study also focused on the case of SARS outbreak in Asian countries and used parameters estimated from the case study in individual-based simulations. Meyers and co-workers examined differences in the probability of outbreak among three different networks among individuals. In the first network, termed "urban", many individuals have numerous contacts at public places including schools, hospitals, shopping centers and workplaces, and have more limited numbers of contacts at their home. The second network was a power law network, in which the distribution of the number of connections has a long right-hand tail. In such a distribution, a small fraction of people have large numbers of connections but most people have only a few connections. The third network was a Poisson network, in which the majority of the people have numbers of connections close to the mean number. If the existence of superspreaders increases the probability of outbreak, then power law networks should show the highest outbreak probability. However, similar to Lipsitch et al. (2003), power law networks showed the *lowest* probabilities of outbreak. The reason might be similar to what we discussed above; in a power law network, the numbers of individuals with extremely small numbers of connection are elevated compared with the other two networks. Pathogens cannot spread if they infect such individuals and will go extinct before they have a chance to infect superspreaders.

The two studies above indicated reduced probabilities of outbreak for populations that include superspreaders, but this conclusion may be strongly sensitive to model assumptions. Networks with more total connections (including superspreaders) may realistically model urban environments (this relaxes the assumption of constant mean connectedness). Fujie and Odagaki (2007) modeled superspreaders as individuals with higher infection rates (strong infectiousness model) or more connections including connections with distant individuals (hub model). They calculated the probability of outbreak under different fractions of superspreaders in a population and showed that, as the fraction of superspreaders increases, the probability of outbreak increases greatly (Fig. 2). They also analyzed several features of outbreaks like speed of disease spread and infection path between the two models and suggested that the hub model is consistent with data from the SARS outbreak in Singapore.

These contrasting results highlight the need to validate model assumptions for applications to human society. Higher outbreak probabilities with larger numbers of connections may seem obvious but this may be a realistic scenario for human society. A key issue is whether the number of connections of one person statistically affects that of others in human society. If not, the comparison between different fraction of number of superspreaders like Fujie and Odagaki (2007) would

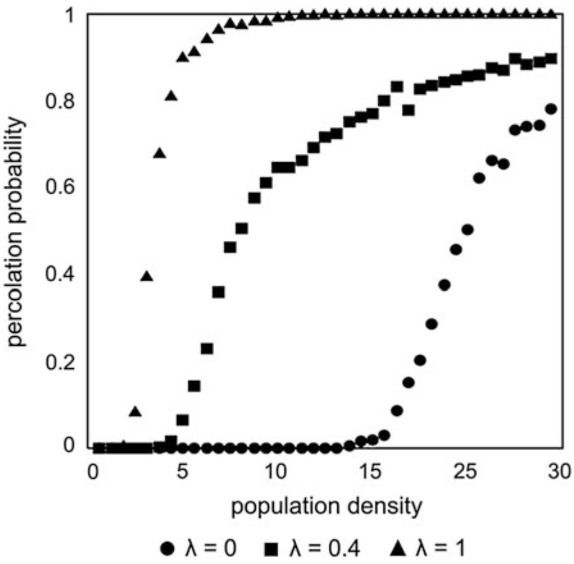

Fig. 2 Theoretically estimated “percolation” probability of a single introduced pathogen under different fraction of superspreaders and population density in a hub model. In Fujie and Odagaki (2007) this percolation probability of percolation theory, in which a pathogen that has infected an individual in the *bottom* of 2 × 2 grid finally reaches an individual in the *top* of the grid, is considered the probability of an outbreak. As density becomes lower, distance between individuals becomes longer. The results for different fraction of superspreaders (λ) are shown in *different markers*. Modified from Fujie and Odagaki (2007, Fig. 4)

more realistically predict the effect of superspreaders on the probability of outbreak. However, if higher number of connections of one person necessitates reduced numbers for others, the results in Lipsitch et al. (2003) and Meyers et al. (2005) could be more applicable for human society. In either case, models should focus on both outbreak probability as well as the nature (explosiveness) of disease spread. Lloyd-Smith et al. (2005) demonstrated that many previous human epidemics appear to have spread through superspreaders (although not to the same extent as SARS). They showed that, although pathogen extinction probability increases with variance in reproductive number, populations with superspreaders experienced more rapid infection spread in cases of pathogen survival. Under their model, host populations may suffer greatly from improbable epidemics.

3.2 Control Measures

3.2.1 Infection Incubation and Infectivity

The first step to control the rise of any infectious disease is to understand how it transmits between hosts. Often, we imagine these infections as readily communicable illnesses that can be caught by even the most fleeting contact. But as we have shown, exposure and transmission depends on the route the infectious disease pathogen takes. This means that some diseases can be transmitted even without direct or close contact with an infected individual. We have also shown how particular conditions can make a close-range disease transmit over extended distances, as is the case with SARS transmission in the Amoy Gardens condominium complex. Aside from mode of transmission, the timing between infectiousness and showing symptoms of the disease is another crucial factor to consider.

An infectious disease is an illness caused by the presence of a pathogen within the host as well as the host's response to the invading pathogen. Upon entry into the host, the pathogen begins to increase its numbers by redirecting resources to itself. After a certain time, its presence and the damage it has done to the host raises an internal host response to thwart the infection. It is at this stage of the infection that overt symptoms appear and the infection can be observed. The time elapsed between exposure to the pathogen and observing the initial signs and symptoms of the disease is called as the "incubation period" of the disease. The length of the incubation period varies among diseases and is affected by several factors such as dose and route of infection, and host susceptibility and ability to respond to the pathogen. Because of these considerations, incubation period is described as a range of values depicting how short or how long it takes before an infection would show symptoms. During this period, the infected individual may or may not be contagious depending on the type of disease and the individual's health state. The disparity between the time we observe the symptoms of the infection and consider an individual ill and the time the individual is contagious are important aspects to consider in modeling as well as in prescribing infection control measures.

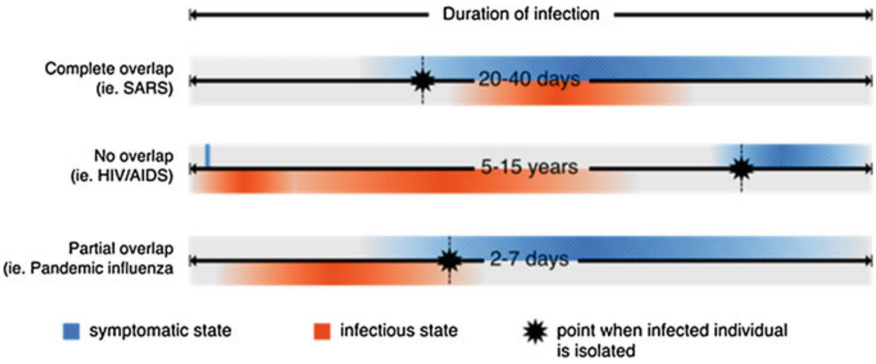

Fig. 3 Timelines for incubation and onset of symptoms for SARS, HIV, and influenza. For each disease, the expected timing when symptoms are observed is shown by the upper shaded region (blue) while the timing of infectiousness is indicated by the lower shaded region (orange). *Marks* indicate roughly when diagnosis and isolation of patients are likely to occur based on the onset of clinical symptoms. Modified from Anderson et al. (2004)

The timings vary widely depending on the infectious disease (Fig. 3). In the simplest scenario, the entire time an infected individual is contagious occurs after the first symptoms of the disease and ends well before the symptoms disappear. A completely overlapping timing where all symptomatic individuals are infectious would simplify identification and make control measures more effective. This timing pattern can be easily modeled by assuming that newly infected individuals simultaneously start to cause new infections to other individuals. And because the disease spreads specifically through a single class of individuals, control measures can simply identify symptomatic individuals to prevent new infections. In the case of SARS, peak infectiousness occurs 7–8 days following the onset of disease symptoms and correlates with viral load over the course of the infection (Anderson et al. 2004). Many believe this pattern helped contain the SARS pandemic (Chau and Yip 2003; Diamond 2003; Fraser et al. 2004) despite exponential growth of the epidemic that quickly spread to multiple continents.

In contrast, diseases such as HIV/AIDS have completely different infectious and symptomatic periods. The first signs of AIDS do not appear until the infecting pathogen has significantly damaged the host yet the infected individual is contagious throughout the asymptomatic phase and peak infectivity occurs before the onset of symptoms (Fraser et al. 2004). Modeling diseases with disconnected infectious and symptomatic periods requires splitting the “infectious” class into “asymptomatic infectious” and “symptomatic infectious” classes to more accurately reflect the clinical characteristics of the disease.

Though SARS and HIV/AIDS have significantly different timing patterns, the relationship between peak infectivity and symptomatic period is clear. However, some diseases exhibit partially overlapping contagious and symptomatic periods that make their outbreaks more difficult to stop. Identifying the precise period that infected individuals are contagious is difficult because the values are affected by numerous factors such as susceptibility of the host, mechanism of infection, and immune response (Baron 1996). Individual variation in incubation periods further complicates the problem. In dealing with diseases that exhibit partially overlapping periods such as pandemic influenza, it is best to rely on conservative measures that consider both exposed and likely infected individuals as targets of containment measures.

Note that it is possible to harbor an infection yet not show any signs or symptoms of the disease. Called a “subclinical infection”, this asymptomatic state may be a result of the pathogen infection strategy and the host’s ability to tolerate an infection instead of purging it (Baron 1996). Asymptomatic cases that are infectious can help spread the contagion despite strict control measures by being misclassified as uninfected individuals. Asymptomatic cases are usually discovered by chance or by reviewing epidemiological data after an epidemic (Baron 1996). Modeling asymptomatic cases requires adding an “asymptomatic infectious” class that is capable of exposing and transmitting the disease. Containing the spread of an infectious disease suspected to have a high proportion of asymptomatic infected individuals is difficult but procedures such as contact tracing may reveal some of these asymptomatic carriers and quarantining of exposed and high-risk individuals can minimize their impact.

3.2.2 Isolation and Quarantine

Most emerging infections have no available vaccine or treatment. Thus the only way to control the spread of these diseases is to prevent exposure and further transmission. Isolation and quarantine are two control measures that help block transmission by isolating the individuals who have, or may have, the contagious disease. “Isolation” describes separating sick individuals (symptomatic) from people who are not sick (naïve) while quarantine pertains to the practice of separating and restricting the movement of asymptomatic individuals who may have been exposed to the disease to see whether they become sick. These control measures aim to progressively reduce the number of new secondary infections until the disease is eradicated from the population. Formally, we can measure the effect of isolation and quarantine by taking a survey of new infected cases and deriving the basic reproduction number R of the infectious disease for each step of the outbreak. Without any intervention, R is expected to eventually decrease as the number of susceptible individuals decreases in a finite population without migration. However, by the time the rate decreases to $R < 1$, a large proportion of the population has already been infected with the disease. By “removing” potentially infected individuals from the population, isolation and quarantine can more rapidly decrease R below 1 by reducing the incidence of the disease, leading to fewer new infected cases capable of transmitting the infection.

Isolating symptomatic individuals prevents new cases by separating individuals spreading the pathogen from the host population. Given a clearly defined set of symptoms to diagnose the disease, this strategy is intuitive and straightforward to implement from a public health point of view. A precise case definition also reduces misdiagnoses and prevents unnecessary isolation of non-target cases. However, many diseases share symptoms and may occur in combination with other infections so case definitions are not always precise. In the SARS epidemic, infected individuals showing atypical symptoms were a major source of transmission, partly because co-infection may have elevated transmission rates (Kamps and Hoffmann 2003). Modern biomedical research may serve to quickly identify new pathogens and providing diagnostic tests may be the most important function of initial research (vaccines and treatments generally require months or years and may not be helpful for new diseases).

Isolating symptomatic individuals is most effective if peak infectivity occurs after observing the first symptoms of the disease and transmission only occurs in symptomatic cases (Fraser et al. 2004). While diseases like SARS have shown such properties, other infections such as influenza appear to be transmissible even prior to showing overt symptoms. When peak infectivity occurs before the onset of symptoms, quarantine for symptomatic individuals may have little impact on dampening the spread of the infection (Fraser et al. 2004). Even for infectious diseases that transmit only after symptoms emerge, infected individuals may not immediately practice self-isolation or report to a healthcare facility. During the lag time between diagnosis and isolation, the pathogen can still spread to susceptible hosts undermining isolation as a way to control the spread of the infection.

On the other hand, quarantining individuals that have been exposed to the disease addresses the shortcomings of isolation as a control measure. Identifying exposure is dependent on how the pathogen spreads from one host to another. If the pathogen transmits via airborne droplets, then people present in the same room with an infected individual are considered “exposed”. However, if the pathogen spreads only through sexual contact, then only individuals who have had sexual relations with the infected case are considered exposed. When the transmission mechanism is unknown, scenarios such as airborne transmission or via physical contact that lead to the most conservative outcome may be used instead. Because the criteria to select individuals are independent of disease status, this strategy sacrifices sensitivity but works regardless of timing of infectivity and does not suffer from the lag time problem. Such a conservative strategy is well suited for emerging infections, especially when the mechanisms of transmission and pathogenesis have yet to be revealed.

In a perfect quarantine, all exposed individuals are expected to undergo quarantine regardless of whether they develop the disease or not, and during the quarantine period, exposed individuals do not transmit the disease. However, tracing all contacts is often problematic especially when an infected individual has traveled to numerous locations and when exposure occurred in public spaces and mass transit. Compared to isolation, quarantine sometimes faces more resistance from expected participants especially from those who have been exposed but appear to be in a healthy condition. During the SARS epidemic, mass quarantines were implemented in many countries. Over 130,000 potentially exposed individuals were quarantined in Taiwan, but in retrospect, the action may have spread panic among uninfected individuals and may not have been an effective strategy (University of Louisville School of Medicine 2003). In reality, quarantines are never perfect. Compliance to the procedures is often problematic: quarantined individuals do not reduce their geographical movement or they only abide by the procedure for a short period. Formal quarantines have good compliance rates but are costly and difficult to manage for a large number of cases. Therefore a majority of quarantines are made voluntarily or with less monitoring than formal quarantines, but these suffer from reduced compliance and are less effective overall. Knowledge about potential superspreaders to identify candidates for isolation can greatly enhance the efficacy of quarantines with much lower numbers of required isolations (Diamond 2003). Although such knowledge may be rare at the beginning of an epidemic, rapid epidemiological analyses may play a critical role in reducing the costs of epidemic control.

3.3 Evolution of Virulence

A critical aspect of human pathogens is their virulence or extent of damage to host. High virulence infectious disease such as HIV, plague or smallpox can be a great threat to human society, and the number of cases of pathogens that have been reported to have evolved virulence and/or resistance against drugs is alarming (Altizer et al. 2003; Holden et al. 2009). Understanding the factors which affect the evolution of virulence in human society is an important issue. If it is possible to control these factors in urban design, human society can be more resilient against serious disease outbreaks.

Several classic theoretical studies on the evolution of virulence concluded that reduced virulence is generally adaptive and should evolve among pathogens. Low virulence allows infected host individuals to survive, and pathogens can have more chance to spread to other host individuals. If pathogens have high virulence, they can propagate within an infected host individual, but risk killing the infected host and limiting their spread to other hosts. Trade-offs between reproduction within a host and transmission among hosts is a well-studied explanation for the evolution of reduced virulence (Anderson and May 1982; Alizon et al. 2009). However, the balance (or equilibrium) of this trade-off can differ depending on biological characters of pathogens. Ewald (1993) discussed how transmission mechanisms of pathogens can alter the predicted trajectory of virulence evolution. Highly virulent diseases tend to immobilize hosts in early stage of infection. Therefore, if pathogens are mainly transmitted by contacts between hosts, higher virulence would greatly decrease chances of new transmission. However, if pathogens can survive outside of the host and can be transmitted by air, water or vectors in which they are not virulent, host immobility should have less effect on the chances of new transmission. Ewald (1993) noted that such pathogens, such as smallpox, tuberculosis or diphtheria, are often more virulent than pathogens that depend more directly on hosts for transmission. Other factors can affect the balance of the trade-off and allow evolution of high virulence (Galvani 2003). For example, if multiple pathogen strains infect simultaneously and compete within individual hosts, high reproduction rate within a host (leading to high virulence) may be favored. In sexually-transmitted diseases, frequent exchange of sexual partners makes transmission of pathogens between hosts easier and as a result cause high virulence. This may be the case of HIV in human society (Lipsitch and Nowak 1995).

Host population structure also affects the transmission of pathogens and therefore, has a large impact on the evolution of virulence. Because urban planning and design can create or alter population structure by its use of the the environment, in the following paragraphs, we introduce two studies focused on the effect of host population structure on evolution of virulence. These studies are based on relatively simple models that may yield general insights. Boots and Sasaki (1999) incorporated a grid-like spatial structure of “sites” at which individuals can exist. Each site can have one of three states: empty, occupied by susceptible individual, or occupied by infected individual. In the spatial structure, connections between individuals were divided into two types, those between neighbors and those between randomly chosen individuals. Randomly chosen individuals can be in distant sites, and in such cases, pathogens can be transferred to distant locations. They found that pathogen virulence is favored as contact between hosts living in distant places becomes more common. In this model, a site becomes empty after death of an occupant. Therefore, higher virulence is more likely to create a situation in which pathogens kill all susceptible hosts around them and can no longer spread. However, long-distance transfer allows pathogens to spread to new locations where they are surrounded by susceptible hosts. Long distance transportation in human society allows contact between distant individuals and may be an important factor that facilitates the spread of outbreaks and favors pathogen virulence.

Boots and Sasaki (1999) did not consider host immunity in their model. Immune (infection-resistant) hosts can block pathogen spread and may have a large impact on the evolution of virulence. This question was theoretically addressed by the same authors. Boots et al. (2004) incorporated the immune state after the recovery assuming a negative correlation between recovery rate and virulence and found that evolutionary trajectories could lead to low, or even extremely high, virulence depending on host population density. In host populations with high density, pathogens can easily find susceptible hosts and therefore, low virulence which increases the opportunity of infection to a new host evolves. On the other hand, in host populations with low density, immune hosts around a newly infected host efficiently block pathogen spread. In this case, highly lethal pathogens which kill infected hosts and make open spaces can spread more efficiently compared with pathogens with low virulence which induce immunity in hosts. Even after killing some hosts, pathogens still have a chance to spread by infecting new susceptible hosts that emigrate to the open spaces. In Boots and Sasaki (1999), infected hosts are assumed to be susceptible just after they recover and therefore, lower virulence pathogens spread more efficiently. However, in Boots et al. (2004), immune hosts block pathogen spread and create scenarios where highly lethal pathogens evolve.

The results in Boots and Sasaki (1999) and Boots et al. (2004) reveal scenarios in which low virulence can evolve to higher virulence depending on the structure of host populations. A key point is that outcomes are sensitive to the scenarios of population structure, transmission mechanisms, and host immunity. Because of their short generation times and high genetic mutation rates, pathogens like RNA viruses may evolve rapidly, even over the course of an outbreak.

Influenza virus, Norovirus or Dengue virus are well known examples of RNA viruses that infect humans. Because these viruses cause epidemics every year, controlling their impact is a very important aspect of urban resilience. As mentioned above, the models in Boots and Sasaki (1999) and Boots et al. (2004) may be too simple to directly apply for particular diseases. Theoretical studies under more realistic conditions based on structures that closely resemble actual human society and biological characteristics relevant to particular pathogens will be valuable to prevent and control outbreaks of high virulent diseases. Important points to consider include parameters and assumption sensitivity for aspects of both host populations and pathogens. In addition, the definition of "connection" differs depending on the transmission mechanism of the pathogen. The concept of "network" must take the view of the pathogen and different networks may need to be considered for different diseases in the same human populations.

3.4 Emergence of New Epidemics

3.4.1 Source of New Human Pathogens

Many of the major human infectious diseases are zoonotic infections that have crossed over from animals into humans (Wolfe et al. 2007). Bubonic plague (Schmid et al. 2015), Influenza (Palese 2004), HIV (Gao et al. 1992), Ebola (Marí Saéz et al. 2015), SARS (Lau et al. 2005; Li et al. 2005b) and MERS (Memish et al. 2014; Wang et al. 2014) have all been shown to have originated from animals before infecting humans. Wolfe et al. (2007) surveyed 25 major infectious diseases ranked by highest mortality and/or morbidity to identify patterns in their animal origins and geographical spreading. All the diseases they surveyed appeared to have originated from the Old World (Africa, Asia, Europe) and a remarkable proportion of causative pathogens arose from warm-blooded vertebrates while the remaining were attributed to birds. Interestingly, the purported geographical origin of the disease was correlated with the type of animal to which the pathogen originally infected. For example, many diseases that trace back to tropical regions have come from wild non-human primates whereas diseases attributed to temperate regions often emerged from domestic animals. Although the exact reason for this pattern is unknown, Wolfe et al. (2007) suggested that, because livestock and pets were domesticated in the Old World, ancestral pathogens had more opportunity to infect humans compared to more recently domesticated New World animals. For the disparity between Old World and New World monkeys, they believe that closer genetic relatedness between human and Old World monkeys may have aided in cross-species transmission. These results stress the importance of considering both environmental and biological factors as key determinants of cross-species transmission of infectious diseases.

Recent spreading of human population by urbanization exposes us to novel pathogens that were previously isolated from human society. The risk of zoonotic infections may be increasing and it is notable that many novel pathogens appear to have high virulence in human (Reads 1994; Schrag and Wiener 1995). During their long evolutionary history, pathogens and their original hosts may have been recurrently co-evolving by which hosts evolve to be resistant against the pathogens, and pathogens evolve to evade the resistant system (Little 2002; Woolhouse et al. 2002). This means if hosts are exposed to a novel pathogen, it is highly possible that the hosts do not yet have immune resistance against the pathogen and are affected by high virulence (Longdon et al. 2015). There are also cases in which infections of novel pathogens cause inappropriate immune response and as a result, increase their virulence (Graham and Baric 2010). As introduced above, these highly virulent pathogens can spread in a host population depending on host spatial structure. However, it is important to note that not all novel pathogens have high virulence for human. Highly virulent pathogens are more likely to be detected and studied and therefore, the patterns may result from ascertainment bias (Alizon et al. 2009; Longdon et al. 2015). In any case, careful surveillance of both human and animal populations in regions of high human-animal contact may be an important component to defending against novel disease (Woolhouse et al. 2012).

Finding the original animal host of a new human pathogen requires scientific rigor but also guesswork and luck. The search for the animal reservoir of the SARS pathogen first identified the Himalayan palm civet (*Paguma larvata*) after SARS-like coronaviruses (SL-CoVs) were isolated from civets in live-animal markets in Guangdong, China (Guan et al. 2003). However, Tu et al. (2004) showed that while civets in live-animal markets were infected with SL-CoVs, civets on farms did not possess antibodies against the virus, which indicated that they have never been exposed to the pathogen. Moreover, palm civets infected with SARS-CoV showed signs of illness contrary to the expectation that animal reservoirs should be clinically asymptomatic (Calisher et al. 2006). This observation and that other animals in the same live-animal markets were also infected by the virus (Guan et al. 2003) indicated that the palm civets were infected in live-animal markets rather than being the ultimate source of the pathogen. Surveillance of wild animals in the region later lead to the serendipitous discovery that Chinese horseshoe bats (*Rhinolophus sinicus*) are the original animal host of the coronavirus that became SARS-CoV (Lau et al. 2005; Li et al. 2005b). The focus on bats may have been inspired by outbreaks of Nipah and Hendra virus a decade before that were also traced back to these mammals (Normile 2013). In addition, Li et al. (2005b) stated that the use of bat products in food and traditional medicine in southern China led them to investigate bats as a potential reservoir. Interestingly, bats appear to harbor many human pathogens and have been implicated as the animal reservoir of Nipah virus, Hendra virus, Ebola virus, and SARS-CoV. Even MERS-CoV, initially transmitted from camels, have been traced back to bat through phylogenetic analysis and biochemical studies (Wang et al. 2014; Yang et al. 2014). While SARS-CoV infection primarily affected the respiratory system, high concentrations of coronavirus were observed in bat feces and recovery from the small and large intestines indicate that replication is primarily through the excretory system (Drexler et al. 2014). Lau et al. (2005) speculated that the use of bats in traditional medicine, especially bat feces, may have played a crucial role in the cross-species transmission of the virus. Bat meat is also considered a delicacy and many Chinese believe it possess therapeutic activity, which led to bat trade in live-animal markets such as those in Guangdong, China.

3.4.2 Environmental Factors

Exposure between the pathogen reservoir and the new potential host species is a key factor dictating the probability of successful cross-species transmission. For example, HIV-1 and -2 seem to have transferred multiple times to humans since 1920 based on phylogenetic analysis, but only after 1970 was there a significant spreading of the infection (Heeney et al. 2006). One explanation suggests that the limited interactions between humans and primates created a barrier for the transference of the virus and insufficient interhuman encounters of infected cases delayed the rise of the epidemic (Parrish et al. 2008). To describe this phenomenon, let us model the underlying host contact network as a network of nodes (individuals) and connections (exposure). Assuming a heterogeneously connected network such as human social network and contact networks (Eubank et al. 2004), we find that the probability of a new infection becoming extinct by chance is very high both because the pathogen may be poorly adapted to transmit in the new host (Parrish et al. 2008; Daszak et al. 2000; Dobson and Foufopoulos 2001) and because cross-species transmission events tend to occur in sparsely connected rural areas (Tibayrenc 2011). The limited connections inhibit emergence of the disease and only the few that avoid stochastic extinction proceed to produce an epidemic in the host population (Lloyd-Smith et al. 2005; Eubank et al. 2004). This may explain why spillover events of animal infections, such as H5N1 avian influenza, fail to take hold in the human population despite the hundreds of human cases and deaths that have been reported (Parrish et al. 2008). While distribution is skewed towards fewer connections in these networks, it is still possible that the cross-species transmission event occurs at a highly connected portion of the network. Such an outcome will only make it more likely that the infection will take hold to produce an epidemic due to the presence of highly connected hubs that can spread the disease to a disproportionate number of hosts (Rock et al. 2014). Lloyd-Smith et al. (2005) expand this concept to show that any type of individual variance, for example infectiousness, produces the same effect. High individual variance increases the probability of extinction of an invading disease regardless of the strength of mean infectiousness. When the host population has a highly heterogeneously connected network, emergence of disease may be rare, but infections that survive stochastic extinction produce “explosive” epidemics similar to the case of SARS in 2002. These findings show that host population structure and demography significantly affects the probability of cross-species transmission as well as the subsequent epidemic that may follow.

3.4.3 Biological Factors

Host factors also play a significant role in determining the success of new infections in novel hosts, especially for viruses. To infect a host, a virus must be able to interact with the host’s cellular receptors to gain entry into cells and hijack the cell’s machinery to replicate itself. At the same time, the pathogen must survive against the host’s defense mechanisms. The initial interaction between the virus and host receptors is a critical step that determines host specificity and host range. For example, in SARS as well as in other coronaviruses, the viral structure responsible for viral entry is the spike glycoprotein, which also appears to be the key determinant of host specificity (Graham and Baric 2010). In humans, the receptor-binding domain on the spike glycoprotein interacts with a cell surface metalloproteinase called human angiotensin-converting enzyme (ACE) 2 to gain entry and infect lung epithelial cells (Li et al. 2003). However, Ren et al. (2008) showed that SL-CoVs found in bats do not interact with palm civet or human ACE2 receptors implying that changes must have occurred to gain this new interaction. In fact, there appears to be a sizeable difference between coronaviruses isolated from the putative bat reservoir and SARS. SL-CoVs from bats were found to be at most only 92 % similar compared to SARS-CoV (Li et al. 2005b). Later, Ge et al. (2013) were able to isolate and characterize a SL-CoV that utilizes the ACE2 for cell entry in bats, palm civets and humans. This finding argues that ACE2 utilization may have evolved prior to any cross-species transmission event.

While gaining the ability to bind to a novel receptor appears to be a complicated process, in some instances, even a few amino acid changes may confer the ability to recognize a new species. Initial studies comparing SARS-CoV isolated at different time points in the pandemic revealed the spike protein of viruses taken from palm civets and early human cases bind less efficiently than those from later on in the epidemic (Yang et al. 2005). Further genetic and biophysical studies demonstrated that two amino acid changes had an enormous effect on the binding affinity of the SARS spike protein to human lung epithelial cells (Li et al. 2005a, c; Qu et al. 2005). In most palm civet samples, lysine at position 479 and serine at position 487 of the spike protein were observed whereas asparagine and threonine were present in human samples. Li et al. (2005a) found that replacing lysine with asparagine removed the electrostatic interference with the histidine residue on the receptor while replacing serine with threonine provided a methyl group capable of filling in a hydrophobic pocket at the interface of the human ACE2 receptor. Although the structural changes appear to be subtle, these substitutions caused a thousand-fold increase in binding affinity to the human ACE2 and lead to enhanced human transmission. However, Li et al. (2005a) also found that some civet specimens have asparagine instead of lysine at position 479 yet this did not affect binding to the civet ACE2 receptor. Changes that are neutral to the original host but advantageous in the new host may have played a critical role in facilitating cross-species transmission between palm civets and humans.

Once a pathogen has evolved to reliably infect the new host's cells, the innate immune response is the host's first line of defense against the infection. When a virus successfully infects a cell, cytoplasmic enzymes that detect the production of double-stranded RNA, a hallmark of virus replication, activate the expression and release of interferons from the cell. Interferons act as an early-warning signal to other cells nearby by activating their intracellular antiviral response to combat viral infection and replication (Roy and Mocarski 2007). Because of the importance of this immune response against viral infection, many viruses have evolved features to subvert interferon signaling. For example, the influenza virus prevents the infected cell from detecting viral replication by using its NS1 protein to sequester double-stranded viral RNA (Lu et al. 1995). Another method to interfere with the innate immune response is to prevent interferons from activating antiviral mechanisms. Nipah virus produces two proteins that prevent STAT1 from translocating into the nucleus as well as another protein that sequesters STAT1 present in the nucleus, obstructing the activation of interferon-stimulated genes (Shaw et al. 2004). In the case of SARS, Kopecky-Bromberg et al. (2007) found that SARS-CoV nucleocapsid and accessory proteins inhibit both the expression of interferon and associated transcription factors, as well as inhibiting cellular response to interferon by subverting the JAK/STAT activation of intracellular antiviral mechanisms. While infection with SARS-CoV did not induce production of interferons, coinfection with another virus did produce interferons. It appears that SARS-CoV does not induce interferon expression, yet does not shut down the whole pathway as interferon signaling continues to work when other stimuli are present (Frieman et al. 2008). By antagonizing the induction and response to interferons, the pathogen blocks the activation of more than 300 interferon-stimulated genes which prevents the cell from going into an "antiviral state" (de Lang et al. 2009). Under the antiviral state, inhibitors are activated to prevent cell division, enzymes that digest proteins initiate programmed cell death, and proteins that present viral particles to activate the adaptive immune response are upregulated. Blocking interferon signaling causes a general decrease of both innate and adaptive immune system response, allowing SARS-CoV to infect cells unimpeded and potentially cause a more serious disease.

The rate at which a pathogen evolves is another biological factor that may determine risk of cross-species transmission. Most recent emerging infections have been caused by RNA viruses such as HIV (Gao et al. 1992), Ebola virus (Gire et al. 2014), Dengue virus (Gubler 1998), SARS-CoV (Lee et al. 2003) and MERS-CoV (de Groot et al. 2013). RNA viruses have an extremely high mutation rate because their RNA polymerase, the enzyme that copies their genome, lacks proofreading activity which leads to error-prone replication. Mutation rates for RNA viruses range from 10^{-6} to 10^{-4} substitutions per nucleotide per cell infection, two orders of magnitude higher, on average, than DNA viruses (Sanjuán et al. 2010). At those rates, about 1 out of 100,000 nucleotide changes every time an RNA virus replicates itself. This may not seem high but note that hundreds of millions of viral particles may be produced during a single infection (Haase 1994), which gives the virus numerous opportunities to explore potentially advantageous mutations. Although high mutation rates helps RNA viruses to rapidly adopt advantageous changes and alter phenotype, deleterious mutations are also produced at an elevated rate. Lauring et al. (2012) have demonstrated that viruses mitigate the effects of deleterious phenotypes by outcompeting and quickly purging these low-fitness variants. The ability of viruses to incorporate functional components made by other functional viruses within the same cell appears to also mitigate the negative effects of high mutation rates (Makino et al. 1988). Indeed, studies have shown that raising the mutation rate through mutagens can be used to create large numbers of dysfunctional mutants that rapidly leads to the extinction of the viral population (Pathak and Temin 1992; Loeb et al. 1999; Domingo 2000). Interestingly, in the case of SARS, the coronavirus that caused the disease did not have a very high mutation rate relative to other RNA viruses. Coronaviruses have the largest genomes (approximately 30,000 nucleotides) among RNA viruses and genome size and mutation rate appear to be negatively correlated (Sanjuán et al. 2010). One reason behind the relative stability of coronavirus genomes could be the presence of proofreading enzymes that guard against mutagenesis. In the case of SARS-CoV, Smith et al. (2013) showed that the exoribonuclease domain in non-structural protein 14 had proofreading activity and was responsible for protecting the viral genome against mutagenesis. Although high mutation rates appear to facilitate adaptation of RNA viruses to new environments, diseases of animal origin are not always caused by the fastest evolving RNA viruses.

4 Summary and Conclusions

The discussions above have introduced how several aspects of urban life, including high connectedness of individuals (including connections among distant individuals) and regions of high human/animal contact, are likely to elevate the risk of future epidemics. Because these properties may be intrinsic to urban life and difficult to alter or control, monitoring and preparedness are critical for urban resilience to disease outbreak.

4.1 Likelihood and Severity of Future Epidemics

Opportunities for the evolution of new or variant human pathogens are difficult to limit and may, in fact, be increasing in modern societies. Each contact between microbe and host can be considered a “trial” for a potential pathogen with random mutations in their genomes that may confer new functions or specificities. Thousands of such trials occur daily in many regions and are likely spawning candidate emerging pathogens with the ability to reproduce within humans and possibly also to transmit from person to person. The trajectory of pathogen evolution depends strongly on the numbers of contacts (potential transmissions) among individuals in the host population as well as on chance. The vast majority of potential new pathogens are likely to be lost early in their histories. However, given continuous opportunities, the chance event of pathogen emergence is simply a matter of time. In Guangdong province, several recent outbreaks of bird influenza (H7N9) have led to limits on live poultry markets, but consumer preference for freshly slaughtered poultry and wild animals remain an impediment to regulating the high-risk concentration of multiple species (pig, poultry, dog, cat, rabbit, as well as reptiles, fish and numerous wild game) in close contact with one another (and often in poor health) as well as with humans. Regions of recent human expansion where wild animal populations are in close proximity to high density human settlements must also be monitored carefully for new zoonotic diseases.

New strains of swine and bird influenza are currently monitored as candidates for outbreaks but pathogen emergence is unpredictable and may come from completely unexpected sources. Regardless of the source of new infectious agents, a major concern is that future pathogens may have properties that will make control much more difficult than SARS. Shorter incubation times and pre-symptomatic transmission strongly limit the efficacy of isolation and quarantine and may allow rapid disease spread.

4.2 Rapid Response

In this chapter, we have focused on biological factors that are central to disease emergence and control. Policy prescriptions have been discussed extensively (University of Louisville School of Medicine 2003; Beaglehole et al. 2003) and we highlight selected topics below. One of the important lessons from the SARS crisis was the need for a rapid and organized response, even in the case of a relatively controllable disease. Recognition of new epidemics through surveillance and global warnings and travel advisories are obvious critical factors but the necessary infrastructure has been difficult to implement, especially in developing regions.

Given the likely lag-time between the start of an outbreak and pathogen isolation and development of diagnostics, well-trained physicians and epidemiologists at the frontlines of the epidemic play a critical role in initial response. For an infected individual, the numbers of contacts and possible and actual transmissions increase rapidly with time so diagnosis and contact tracing are time-critical events. Finally, communicating with, and educating the public and controlling panic are major concerns especially in the context of false reports and rumors. Establishing trusted sources of information prior to emergencies should be a major objective for cities/regional governments. Issues with coordination among government agencies or between medical and government agencies were strong obstacles in the response to SARS in most affected regions (University of Louisville School of Medicine 2003).

4.3 Health Care

High transmission in medical care settings was one of the prominent features of both the SARS and MERS outbreaks. Because infected individuals with weakened immune systems or co-infections may be the most difficult to diagnose and may show high infectiousness, proper training in pathogen containment is a critical element of epidemic preparation. Similar basic techniques (proper use of gloves, gowns, masks, and goggles) were successful for SARS and Ebola suggesting that many practices will be of general value but specifics for particular transmission mechanisms (e.g. airborne versus vector transmission) are also critical. Intervals between outbreak occurrences may be large, so regular confirmation of preparedness is important. Low margins in health care are strongly linked to overcrowding and government and private organization incentives (e.g., increased funding for hospitals that rate highly on infection control training and preparedness) can greatly enhance hospital safety (Committee on the Future of Emergency Care in the United States Health System 2007). The importance of patient isolation in limiting disease spread is clear from recent SARS, Ebola and MERS outbreaks; hospitals must have containment facilities and "surge capacity" to limit superspreading events. Although public health measures were sufficient to eventually control SARS, additional measures including antiviral drugs and rapid vaccine development and production may be necessary for stronger pathogens. The economic impact of epidemics, roughly 200 billion USD (2 % of regional GDP) for East Asia from SARS and potentially over 800 billion USD for pandemic influenza (The Economist 2005) should help to justify the costs of outbreak preparation.

4.4 Interdisciplinary Research and Planning

Informed sanitation (water purification, sewage treatment) and building regulations/inspections (e.g. airflow control) policies can play a key role in preventing disease emergence and spread. The SARS example illustrates the need for extensive interdisciplinary efforts, combining expertise from physics (fluid mechanics), biology (especially understanding mechanisms of disease transmission), and building design for resilience to future outbreaks.

4.5 Personal Liberties and the Common Good

Isolation and quarantine were critical to controlling SARS in Hong Kong, Singapore, Taiwan, China, Vietnam and Canada. Compliance rates appeared to be high in all regions (University of Louisville School of Medicine 2003) perhaps partly because the "cultural" value placed on solidarity and cohesion was relatively high in these regions. More severe movement restrictions may be necessary for more transmissible and/or virulent pathogens. It is unclear whether similar measures can be employed with success in other regions where personal liberties are emphasized and/or government is less trusted. Biological studies can help to determine the necessity and guide planning for future epidemics, but social and economic issues may be the more critical limiting factors in developing preparedness for disease outbreaks. Understanding the social, psychological, and economic costs of previous and potential disease outbreaks among both citizens and government officials will be central to planning for resilient communities. The ability to overcome economic and psychological barriers (e.g., normalcy bias) to implementing such plans may require a fundamental transformation in human society.

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Part IV
Measuring Urban Resilience

Approaches to Measurement of Urban Resilience

Leena Ilmola

Abstract Measurement is a prerequisite for systematic development. Resilience measurement approaches have been developed for assessment, planning and follow up resilience development. In this chapter I will review several different resilience assessment systems that either measure resilience performance (past incident and the urban system's reaction in that) or resilience as competence (city's perceived capability to adapt, recover and benefit of shocks). The methods analyzed are Rockefeller Foundations 100 resilient cities measurement framework, UN Habitat disaster measurement system, New Zeland based method, the system produced by the Strategy Alliance and the method developed in the Global X Network. None of these approaches are 'good' or 'bad' but they have been developed for a specific purpose, they have different objectives, principles, methods and data used. The analysis framework consisted of five systems theoretical dimensions: structure, interaction, coordination, renewal and resources. The analysis revealed that the approaches can be divided into three clusters; firstly survey based method that collect perceptions, second existing statistical data based methods and third multimethod approaches. One of the main conclusions was that none of these methods paid any or thorough attention on interaction between urban system components. Even if the methods try to assess resilience, the main source of adaptation—interaction dynamics—is not covered. But even if the existing resilience measurement methods have weaknesses, I think that the comparison presented in this chapter provides resilience developers a conceptual framework for assessment criteria for deciding which method they should use.

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1 Background

1.1 Measurement Necessary for Investment

Several organizations (over 30 milj. Google hits on December 20, 2015) are investing in the developing resilience measurement system. Why had this enthusiasm? Any investment decision requires two kinds of basic information; why investment is needed and what is the return on investment? This applies both to the public and private sector. In such situations as recent hurricanes on the east coast of the US, this causes a strong motivation for investments in preventing, mitigating and adaptation even without specific calculations. The challenge emerges when we try to convince decision makers to improve resilience for potential future shocks. So we have to have a way to diagnose a city's current resilience, and to compare it to the optimal level. Then if we find that improvements are needed, we should be able to present solid investment plans and even to calculate the benefits of the increased adaptation and agility.

This chapter is concentrating on the diagnosis, the first of the problems described above. Without good diagnostic tools, a development decision is based only on the most recent experience that we remember and thus produces a very short term solution to the problem at hand. The resilience measurement community, practitioners, and researchers are working to help decision makers. The ambition is to find a diagnosis and measurement system that meets the requirement that Briguglio (2014) presented as criteria for a resilience index or measurement system: "the measurement system should be simple and transparent, it should be redundant (several ways to measure one feature), and it should facilitate comparisons of results of one organization in different time periods, or comparisons across similar organizations." As Briguglio (op cit.) state, the measurement system should be affordable.

The trip has just begun. Several different methods are under construction. When the development contexts and objectives are divergent, it is interesting to see, how these approaches are different and what the areas are that all of the analyzed measurement initiatives cover. If any.

1.2 Operationalization of the Resilience Concept

The review of the recent literature and resilience measurement initiatives reveal first that operationalization of the resilience concept is not easy to do. The resilience concept was developed by ecosystems theorists, such as Holling on 1970s, Levin and Ulanowicz in 1990s and 2000s for a better understanding of the adaptation of ecosystems (for example Ulanowicz 2000). Their approach was based either on general systems theory or the Complex Adaptive Systems (CAS) theory. The Urban system is a complex adaptive system so it is natural that the CAS framework will be used as a scaffolding structure where we will "hang" our findings of different resilience measurement approaches.

Urban system is a complex adaptive system

First a few words about complex systems and then more about the specific nature of one of its four applications (Morel and Ramanujam 1999); complex adaptive systems.

Systems are called complex if they meet six requirements. First a system is complex if it consist of a large number of elements. A large number of elements is necessary, but not a sufficient feature. To constitute a complex system, the elements have to interact, and this interaction must be dynamic. So typical for a complex system is that it changes with time. All this applies to an urban system, citizens, citizen groups, businesses, city authorities are interacting in a system, where energy, food, water, labor and capital flows from one agent to another, and the dynamic city is changing all the time.

First, the interaction of the elements of the complex system does not have to be physical. Second, elements can interact by transferring information or energy. Third, the interaction should be rich, i.e. any element in the system influences, and is influenced by, quite a few others. Fourth, these interactions are non-linear. This means that that a small cause can have large results, and vice versa. Fifthly the interactions usually have a fairly short range, i.e. information or feedback is received primarily from immediate neighbors. The effect of any actively can feed back onto itself, sometimes directly, sometimes after some intervening stages. This feedback can be positive (enhancing, stimulating) or negative (detracting, inhibiting). Both kinds are necessary. Information is the fuel of the social system, political decision making and for example for shopping behavior. As we have seen lately, an unlucky incident where a policeman kills a young (innocent) boy. This can escalate into riots in the social system and destroy both the physical urban environment and the trust of authorities as well.

Moreover, the sixth typical feature is that complex systems usually are open systems, i.e. they interact with their environment. As an urban system does when it imports energy, food, water or labor from surrounding environment and applies national level legislation to govern the city's operations.

CAS in the urban environment

Complex adaptive systems are special cases of complex systems. The complex system is adaptive when it is composed of interactive, adaptive agents (Morel and Ramanujam 1999). The system, as well as agents, adapt, change and learn (Holland 1995). The agents are constantly acting and reacting to what the other agents are doing. The control of a CAS is typically dispersed and decentralized. The overall behavior of the system is emergent as the result of a huge number of decisions made every moment by many individual agents. The system has an order, but it is an emergent property of individual interactions at a lower level of aggregation (Anderson 1999, pp. 219–220).

Agents are connected to one another by feedback loops, and each agent observes and acts on local information only. Increased flexibility is gained when no single partner of the network dictates the collective behavior of the system and the sub-systems be coevolving. Adaptability is maximized at the state of non-equilibrium (Anderson 1999; Anderson and McDaniel 1999) when a system is self-organizing on the edge of chaos (Brown and Eisenhardt 1998).

Each agent adapts to its environment by trying to increase a payoff or its fitness function over time. When all the agents are adapting, the landscape—a perception of the operating environment—is constantly shifting. The equilibrium is dynamic, small changes in behavior can produce small, medium or large changes in the next set of outcomes. To maintain the state of non-equilibrium, that produces the maximum capability of adjustment, the system has to import energy. According to CAS, there are attractors or strange attractors (Anderson 1999) that keep the complex system changing within the certain amplitude or an area.

What does all this theoretical elaboration imply to resilience measurement? When we summarize the features that according to the systems and the Complex Adaptive Systems theory has an impact on resilience we end up listing four primary features. Adaptation depends on

1. systems structure that is modifying itself all the time
2. interaction patterns of the agents within the system
3. self-organization that is not controlled by anyone
4. staying on the edge of chaos, or in the vicinity of attractors until the system transits from one state to another

The systems tradition that focused on ecosystems ended up a bit different articulation. We will use Folke's (2006) list the features of the resilient ecosystem as an example of this approach. Folke has recognized 11 different features that have an impact on social-ecological systems resilience:

- spatial heterogeneity
- sustained diversity
- continual adaptation
- diversity
- dispersed interactions
- far from equilibrium dynamics
- the transition from attractor basin to another
- variability of responses and response diversity
- overlapping characteristics
- dynamics across spatial and temporal scales
- renewal of the system

According to Folke resilience can be measured as a degree of absorption without transition, degree of self-organization and its degree of adaptation and learning. However, these are very difficult features to operationalize as we see later on when the diagnosis approach of the Resilience Alliance will be described.

Now we summarize what we have learned from CAS and ecosystems resilience into four dimensions of resilience, that consist of several features.

1. Structure—diversity of agents, heterogeneity, connectivity, spatial scales, time scales
2. Interaction—Interaction patterns, dispersed interactions, variability of responses, Coordination—self-organization, no central coordination
3. Resources—sustained diversity, overlapping characteristics
4. Renewal—continual adaptation, far from equilibrium state, transitions from a basin to another

The above is our summary of the general systems and ecosystems resilience, but a city is a social system. So let us look at the social systems more closely.

Social system and resilience

Once again, some words about the theory, then some examples of the urban social system.

The main purpose of the social system (SS) is to distinguish itself from the other systems (Berger and Luckmann 1966), from its environment. For this purpose, the social system is building, maintaining and defensing its identity (Luhmann 1995). To enforce itself, the social system develops shared perception of identity, internal rules of operation and the idea about the nature of its environment (Anderson 1999). The process is intersubjective and is based on communications (language) (Stacey 1995).

The identity of a New Yorker and a Parisians strongly follows a specific code of behavior. Our interpretation is that the urban social system that produces this identity emerges in public spaces; streets, cafes, parks and squares of the city. The typical features of the city's social system are that the formation of the identity is based on visual stimuli (fashion, behavior) and is enforced by short moments of communications. This is a typical autopoietic intersubjective process (Nicolis and Prigogine 1989) that produces a common perception of the elements that constitute a New Yorker or a Parisian. During years, the city identity develops and institutionalizes until it forms the social construction of reality. Especially if the city has been able to be successful (attractive to outsiders) the identity, rules and perception of the uniqueness of the city are not challenged. Newcomers perceive the framework as the reality that is close to impossible to change.

In Complex Adaptive Systems (CAS) theory, the phenomenon has been described as schemata (Anderson 1999). They consist of identity, internal rules, and recipes, the perception of the external environment and rules of coevolving in this environment.

Cognitive theory speaks about a set of shared mental models (Hodgkinson et al. 1999; Hodgkinson 2003). These mental models do not define only the rules of co-operation within an organization but filter the observations of the external environment (Ilmola and Kuusi 2013). In principle, a social system will focus its attention on those issues that it perceives essential for its operations. Luhman calls this choice as indication and distinction rules; Igor Ansoff (1979, 1984) speaks about filters, and Weick (1995, 2001) sense is making process.

Same applies as well to ecosystems (Holland 1995). In the ecosystems theory Holling (Holling et al. 1998) presents the Panarchy, a process where an ecosystem is growing and stabilizing until even a small change can trigger a dramatic change in the organization.

The common denominator of all the frameworks presented above is that a social system has a strong need to support its identity (decrease uncertainty) by seeking information that is confirming its current perceptions. This process will stabilize the social system and increase its feeling of security.

This does not happen without tensions between numerous subsystems of the city. The socioeconomic mixture contains very rich elite and poor homeless, and many ethnical, religious and ideological groups. This variety generates tension and one of the ways to decrease tension is to have strong shared identity, to look and behave like a Parisians in spite of all of these differences.

A typical feature of social systems is that this process will continue untill the social system is too rigid to adapt to its environment, and a small trigger can push the organization from its development trajectory. When the perceptions of reality are very homogenous, the social system will easily get surprised even shocked. What did Nassim Taleb say about black swans?

Social systems are by their nature goal oriented, and they have the capability to make conscious changes in their structure, resources and operations. These changes are called strategies, plans or perceptions of social system's norms, values, and rules.

The urban system is a complex social system, so we include some features typical for social systems to the resilience dimensions defined earlier. As we notice, even if the wording is different the principles are close to systems' and ecosystems' resilience. The main difference emerges from the coordination; to understand the resilience of the social systems we have to add some specific elements: identity, control system, culture, schemata, and one more typical feature of a social system; planning and goal setting.

1. Structure—diversity of agents, heterogeneity, connectivity, spatial scales, time scales
2. Interaction—Interaction patterns, dispersed interactions, variability of responses,
3. Coordination—self-organization, no central coordination, **identity, control system, culture, schemata, objectives, planning**
4. Resources—sustained diversity, overlapping characteristics
5. Renewal—continual adaptation, far from equilibrium state, transitions from a basin to another

Competence and performance metrics

At the beginning of the chapter, we referred to past disasters and their power as motivators for resilience improvement. As stated earlier, our aim is to be prepared for future incidents, so the focus of this chapter is on resilience as a competence or a capacity of an urban system. However, before we analyze the different approaches in this field, a few words about another measurement approach; the performance analysis. Performance metrics is measuring resilience by analyzing the data collected from previous shock situations and measuring the speed and time of recovery as described in Picture 1. The systems engineering researchers are using this approach a lot. Ramirez-Marquez (Henry and Ramirez-Marquez 2012; Hosseini et al. 2016) has conducted with his research group a comprehensive review of different resilience performance metrics applications.

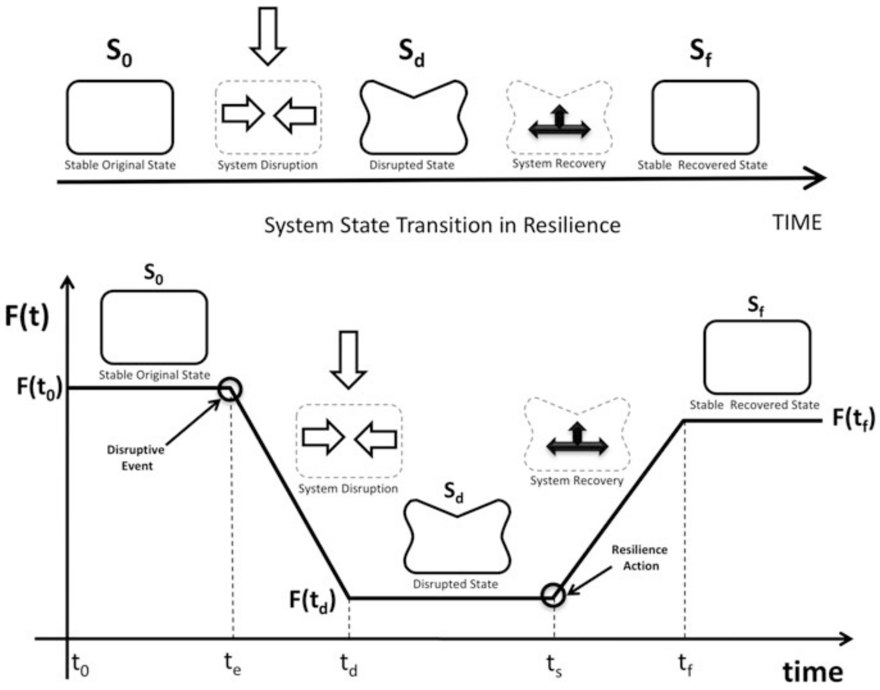
Dalziel and McManus (2004) use key performance indicators (KPI), to compare the shocked performance to the target level and measure the time to discovery. The Marquez approach follows this line of thought; resilience is measured by the time needed for recovery/loss (td). Even if performance based measurement system is attractive, it has two major features that can be considered as weaknesses. All of these indicators are data intensive and context dependent. Even if the recovery performance has been good, it does not automatically indicate that the city's performance will be as good in the future contexts.

The special challenge with an urban system is its great openness and high complexity. When engineering systems' design and functions are well known, the urban system is a typical complex adaptive system that emerges from the behavior of independent agents (Picture 1).

2 Different Urban Resilience Measurement Approaches

Fast scan of Google Scholar shows 6650 links to the publications published in 2015 (the situation in 11.9.2015) about urban resilience measurement. Plenty of words about an interesting subject. To arrange this abundance, we will try to cluster the approaches and look more closely at different resilience capacity measurement initiatives to understand what is done, why and how the results are used.

We have chosen four different approaches for the comparison. The 100 Resilient Cities, the most well-known urban resilience initiatives are promoted by the Rockefeller Foundation, so it is natural to use that one as one of the examples. In addition to Rockefeller project, there are not so many global approaches that would have an intent to produce generic resilience metrics for cities. Private companies such as Swiss-Re and Grosvenor have their approaches that are based on the analysis of the existing statistics, but these methods are not widely applied. The direct information from UN Habitat indicates that they are in a process of developing their indicators, but the results have not been published yet. To cover one global, widely used approach (Rockefeller has not reported any results yet), we will analyze resilience measurement metrics presented by a UN organization; UNDP launched their resilience index two years ago. New Zealand and Australia have been pioneers in the field of pragmatic resilience work, especially in the context of natural disasters; our third approach is a hybrid of New Zealand and Australian measurement frameworks, which we have collected from various sources.



Picture 1 Delivery function transition in resilience. From Henry and Ramirez-Marquez (2012)

Resilience Alliance is emerging directly from the ecosystems resilience framework. Even if the need for urban analysis is articulated (http://www.resalliance.org/) it is not properly addressed yet. Our motivation for presenting a Resilience Alliance diagnosis system in this context is an attempt to operationalize the systems theories we promoted earlier in this chapter.

The last example is the framework that was developed in the Global X-Network. The network is a self-organizing cross-discipline group of researchers that are studying uncertainty and surprise. Resilience development is one of the strategies that an organization can apply to meet the challenges of a global environment dominated by uncertainty.

Description of each of the methods consists of the definition of resilience applied the strategy and principles of resilience measurement, nature of data and methods used for data collection. Additional elements are the structure of the resilience measurement scores or index, analysis methods and what and how the results of the analysis are reported. The last item we try to cover is related to the usage of the measurement results; how the results are guiding resilience planning and implementation.

2.1 Rockefeller: the 100 Recilient Cities Project

Rockefeller Foundation has worked since December 2013 in helping cities around to the world in helping cities to become more resilient, physical and social and economic challenges. 100 Resilient Cities project aims to help individual cities to become more resilient and simultaneously to facilitate the building of a global practice of resilience among governments, NGOs, the private sector, and individuals. The latest city resilience framework material is brief but the three studies conducted by a consultant, the ARUP Group, provides us with a better insight. First the team conducted a desk study, which led to a preliminary 'the city resilience framework'. In the next stage, the team collected primary data from six cities and based on these both sources the final RC100 resilience concept was formulated (see City Resilience Index Research Report Vol 2[1]).

Definition
Urban Resilience is the capacity of individuals, communities, institutions, businesses, and systems within the city to survive, adapt, and grow a no matter of chronic stresses and acute shocks they experience.

Strategy Principles
The 100RC measurement is collecting data and analyzing the resilience competence of a city by assessing eight key functions of an urban system. These key functions are called as the resilience dimensions:

- to deliver basic needs
- safeguard human life
- support human relationships and identity
- promote knowledge, education, and innovation
- enforce the rule of law, justice, and equity
- to protect, and maintain assets
- to support livelihoods
- to stimulate economic prosperity

The 100RC approach is pragmatic and based on the city's operations in different conditions. The primary objective of the method is to reveal improvement areas but to compare different cities as well. The index should (the material available does not describe how) measure reflectiveness, robustness, resourcefulness, redundancy, flexibility, inclusivity and integration of the city systems.

Structure
The Rockefeller framework is built on four essential dimensions of urban resilience: health and wellbeing; economy and society, infrastructure and environment, and leadership and strategy. Each of the dimensions is divided into three more detailed drivers. Leadership and strategy are looking at leaderships, inclusive decision making, empowered stakeholders, and integrated planning processes. Health and wellbeing

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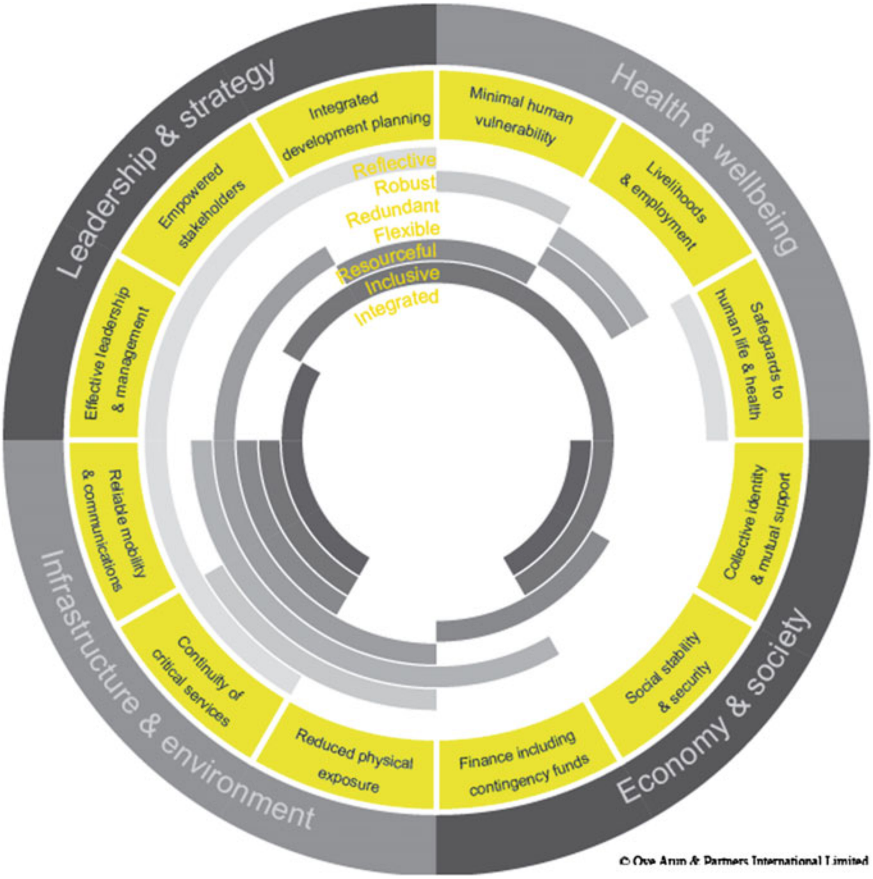
[1] http://www.arup.com (Nov 2015)

are analyzing the urban capability to meet basic needs, support livelihoods and employment and to ensure that the public health services are available also in the crisis. Economy and society are focusing on community building social stability, security, and fostering of economic prosperity. The man-made and natural systems that provide critical services and enable the flow of goods, services, and knowledge are clustered under combined infrastructure and environment dimension (Picture 2).

Data Collection

We do not have information about details of the current data collection praxis; we can only assume that it follows similar procedure than applied in the development



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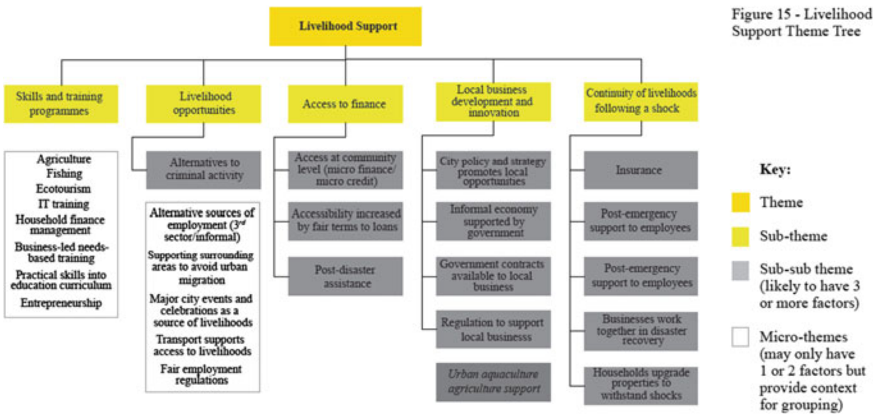
Picture 2 The framework describes four dimensions and 12 subdimensions of resilience designed by the Arup Group and funded by the Rockefeller Foundation. *Source* Rockefeller Foundation City-Recilience-Framework1 2014 http://www.100resilientcities.org Nov 2015



Picture 3 Form the Arup Group's website you can find the 100RC research report Vol 2 field data analysis, the picture on page 36 describes one of the factors, Livelihood support, and its subthemes

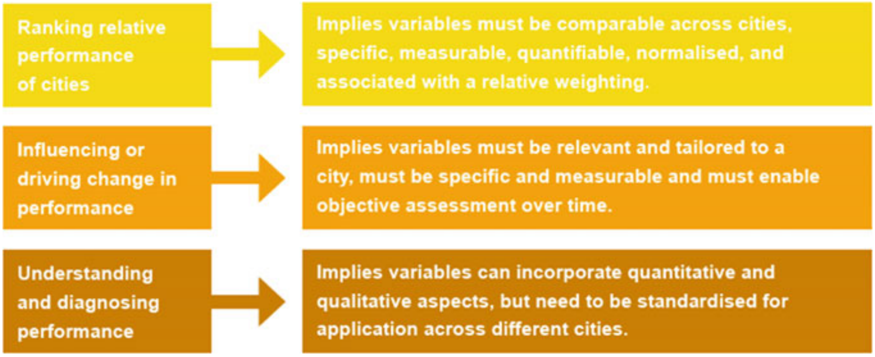
phase. When the measurement system was developed the primary data collection was based on interviews, focus group discussions and workshops (Picture 3).

Analysis

Qualitative data was coded according to predefined scales, and the material was clustered into 1546 factors, which were analyzed with factor analysis. We could not identify any detailed description of the current line of analysis that should have been piloted in 2015.

How the results are guiding planning and implementation

The 100RC framework is focused on driving performance improvement, and the user of the report should be the city leadership (Picture 4).


Ranking relative performance of cities → Implies variables must be comparable across cities, specific, measurable, quantifiable, normalised, and associated with a relative weighting.

Influencing or driving change in performance → Implies variables must be relevant and tailored to a city, must be specific and measurable and must enable objective assessment over time.

Understanding and diagnosing performance → Implies variables can incorporate quantitative and qualitative aspects, but need to be standardised for application across different cities.

Picture 4 The 100RC measurement system development is motivated by the need for comparison between different cities, driving change and need for diagnosis. *Source* Arup Group http://www.arup.com (Nov 2015)

2.2 Grosvenor Style of Resilience Measurement

Grosvenor is a commercial enterprise that is developing and investing in real estate around the world. The company has investments in 17 cities, and their aim is to use resilience measurement as a tool for risk and yield assessment. The reason we would like to present their approach is that it is very comprehensive, and it integrates both vulnerability and adaptive capacity into one resilience index.[2]

Definitions
Resilience is defined to be an ability of a city to avoid or bounce back from an adverse event—and it is generated in an interplay between vulnerability and adaptive capacity. Thus, a city that can maintain itself as a center for production and the same time it can provide its citizens with a decent standard of living (Grosvenor report pp. 2–8).

Strategy, *Principles*
The vulnerability is assessed by a city's exposure to shocks, shocks frequency, and magnitude. Adaptive capacity describes both capabilities and resources of a city. Resilience is a combination of these both.

Data
From each of the cities, the Grosvenor collected the best possible sources of data. Each of the data sets were different; that is why the Grosvenor team did use ranking as a means for arranging the cities according to their vulnerability or adaptive capacity.

Structure
Vulnerability emerges in the Grosvenor's study from climate, environment capacity, resource capacity, infrastructure's state and community. Adaptive capacity is based on governance, institutions, technical adaptation and learning, planning system and funding structure. The setting can be different for each of the cities, due the type of vulnerabilities they are exposed on and the capacities they have built for resilience.

Adaptive capacity:

- Governance: Democracy, freedom of speech and community participation to decision making. Leadership to look at long term issues.
- Institutions: the capacity of delivering by city governance bodies and community groups.
- Technical and learning: This is vague in the material available. Partnerships in international and national bodies, technical universities…
- Planning systems: Disaster planning and rehearsals

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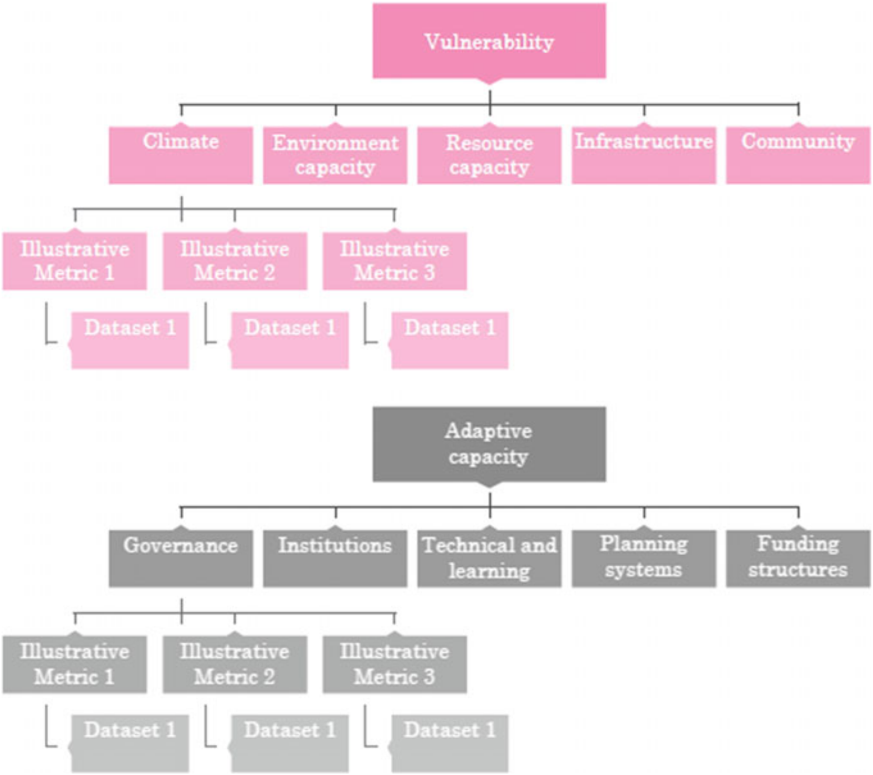
[2] http://www.grosvenor.com (Nov 2015)

- Funding structures: Access to funding, good bucget resources, loans or acces to international and national funding.

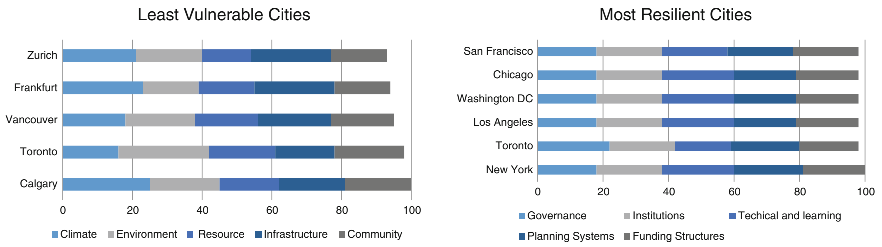
Vulnerability:

- Climate change, vulnerability to sea level rise, storms and droughts. Risky housing locations.
- Environment: pollution, overconsumption of natural resources and land use
- Resources: Access to energy, water, and food.
- Infrastructure: Level of housing, transport infrastructure and access to basic utilities.
- Community: Access to housing, education, and health care. Freedom of religion and honesty of city governance and businesses (Picture 5).

Data collection:
After the city specific measurement structure is defined, the available data is acquired from various statistical sources. Data availability will define the final city specific dimensions to be measured.



Picture 5 As the structure chart form the Grosvenor report p. 6. shows the system consist of 10 dimensions, which are assessed by the best possible illustrative data



Picture 6 Grosvenor index is one of the rare exceptions; its results are published. *Source* http://www.grosvenor.com (Nov 2015)

How data is analyzed:
For the comparison purposes, the different data sets of cities are arranged with an ordinal ranking system, where the distributions and units are harmonized. These ordinal rankings are added together and then averaged. Then each of the cities is ranked according to each of the components to know the relative position of the city by a component.

What are results, *what is reported*:
The measurement system is developed for real estate development and investment purposes. Where to invest and how to manage risks? The material claims that resilient cities provide the best yields for the investors in the long run. The cities with the fastest development of resilience are providing investors with a high yield potential (Picture 6).

How the results are guiding planning and implementation
The analysis results are used for the definition of the investor's portfolio. Details are not available.

2.3 Resilience Measurement in New-Zealand

New Zealand has been one of the pioneers of the disaster resilience development. Even if the primary focus of the resilience measurement is not on cities, the approach is justified to present in this context as well. The articulated focus is on communities[3] so the approach could be applied to the urban context as well. The literature that has been used as a basis for this description of the New Zealand approach is from two sources: scientific papers and the material that is available in the New Zealand Resilience Organization's web-site.[4]

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[3] http://resorgs.org.nz (Nov 2015)

[4] http://resorgs.org.nz (Nov 2015)

The scientific material has been produced by the team of John Vargo, Erica Seville and Amy V. Lee (earlier Stephenson) from University of Canterbury. The literature analysis of the group is comprehensive (based on Amy Stephenson's doctoral thesis, Stephenson 2010).

Definition

The New Zealand approach applies the definition published by McManus (2008): 'resilience is a function of an organization's overall situation awareness, management of keystone vulnerabilities and adaptive capacity in a complex, dynamic and interconnected environment.'

Strategy, *Principles*

Objectives of the work of the New Zealand team (Lee et al. 2013; McManus et al. 2007, 2008; Stephenson 2010) was to develop a measurement system that measures community's or organization's resilience by operationalization of the different dimensions into survey questions. The basis of the development was McManus work reported in the 2008 paper (Picture 7).

Data

The development started in New Zealand with a literature analysis as well. The first dimensions of the indicator were literature based, but the final structure was completed in a workshop where a group of managers discussed resilience and potential resilience indicators. Out of this material the team developed four factors that they operationalized into 23 indicators. The questionnaire contained over 100 questions that covered the dimensions. Out of over 1000 invited organizations, only 68 responded to the survey, and the average number of respondents per organization was four.

The survey questionnaire presents a statement/claim, and the respondent is asked to define how well the statement fits the organization.

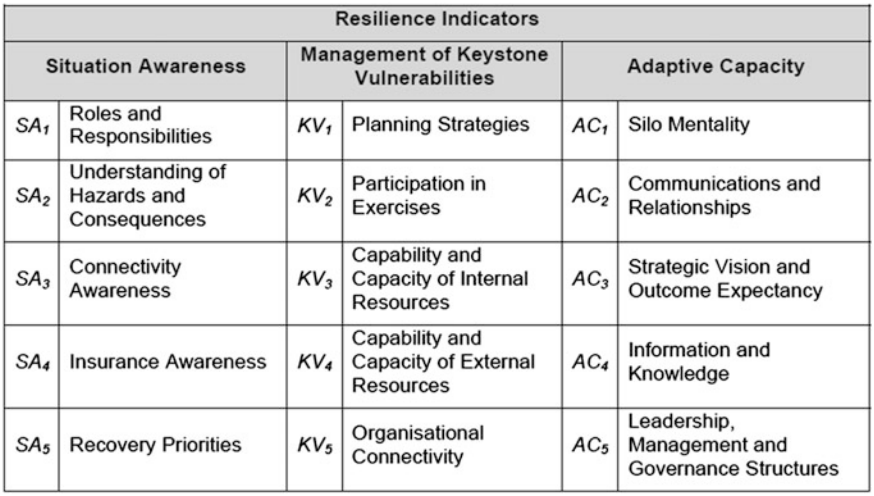
Structure

The statistical analysis of the material led the team to choose the model, with only two factors; Adaptive capacity and Planning. Adaptive capacity is including elements of organization structure (silos), resources, involvement, knowledge, leadership, creativity, decision making and situation monitoring and reporting. The Planning factor consists of planning strategies, the participation in exercises, proactive posture, access to external resources and recovery priorities.

The New Zealand resilience measurement framework has been modified for resilience benchmarking, as well. The structure of the benchmark exercise follows the same resilience indicator structure (Picture 8).

Data collection, *analysis*, *and reporting*

As stated earlier, data is collected by the survey questionnaire from the organizations managers and employees. Data analysis is easy because the average of the collected values tell how advanced the organization is. Closer the average value is five, better is the resilience of the organization measured.



Resilience Indicators					
Situation Awareness		Management of Keystone Vulnerabilities		Adaptive Capacity	
SA_1	Roles and Responsibilities	KV_1	Planning Strategies	AC_1	Silo Mentality
SA_2	Understanding of Hazards and Consequences	KV_2	Participation in Exercises	AC_2	Communications and Relationships
SA_3	Connectivity Awareness	KV_3	Capability and Capacity of Internal Resources	AC_3	Strategic Vision and Outcome Expectancy
SA_4	Insurance Awareness	KV_4	Capability and Capacity of External Resources	AC_4	Information and Knowledge
SA_5	Recovery Priorities	KV_5	Organisational Connectivity	AC_5	Leadership, Management and Governance Structures

Picture 7 Resilience indicators according to McManus (2008)

How the results are guiding planning and implementation
The survey will provide an organization a simple way to identify potential weaknesses and strengths and when the presented alternatives are such as in the Picture 10 the question setting leads to obvious improvement ideas (Pictures 9 and 10).

The strength of the approach is its pragmatic nature. Easy to copy, easy to use and analyze. The challenge is here reliability. Even if the literature review was extensive, and the statistical processing of the data was rigorous, the process cannot show that the two dimensions are the best and right for resilience measurement. McManus approach was developed in an interview process, and the perspective of resilience was disaster focused. For example, the requirement of strong leadership is supported in the crisis management literature, but not by complex adaptive systems theory, where capability for self-organization is the key competence of adaptation. The paper commented potentially interesting link between resilience and business performance but did not report any results of this part of the survey.

2.4 The Global X-Networks Resilience Measurement System

The Global X-Network[5] (www.globalxnetwork.com) is a self-organized network of Asian, European and North-American researchers that are studying uncertainty and

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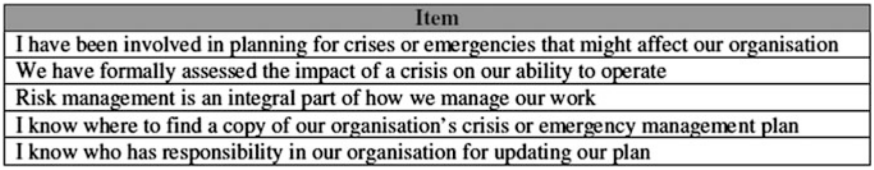
[5] The writer is a member of the GXN.

	Indicator	Definition
Adaptive Capacity	Minimisation of Silo Mentality	Minimisation of divisive social, cultural and behavioural barriers, which are most often manifested as communication barriers creating disjointed, disconnected and detrimental ways of working.
	Capability & Capacity of Internal Resources	The management and mobilisation of the organisation's resources to ensure its ability to operate during business-as-usual, as well as being able to provide the extra capacity required during a crisis.
	Staff Engagement & Involvement	The engagement and involvement of staff who understand the link between their own work, the organisation's resilience, and its long term success. Staff are empowered and use their skills to solve problems.
	Information & Knowledge	Critical information is stored in a number of formats and locations and staff have access to expert opinions when needed. Roles are shared and staff are trained so that someone will always be able to fill key roles.
	Leadership, Management & Governance Structures	Strong crisis leadership to provide good management and decision making during times of crisis, as well as continuous evaluation of strategies and work programs against organisational goals.
	Innovation & Creativity	Staff are encouraged and rewarded for using their knowledge in novel ways to solve new and existing problems, and for utilising innovative and creative approaches to developing solutions.
	Devolved & Responsive Decision Making	Staff have the appropriate authority to make decisions related to their work and authority is clearly delegated to enable a crisis response. Highly skilled staff are involved, or are able to make, decisions where their specific knowledge adds significant value, or where their involvement will aid implementation.
	Internal & External Situation Monitoring & Reporting	Staff are encouraged to be vigilant about the organisation, its performance and potential problems. Staff are rewarded for sharing good and bad news about the organisation including early warning signals and these are quickly reported to organisational leaders.
Planning	Planning Strategies	The development and evaluation of plans and strategies to manage vulnerabilities in relation to the business environment and its stakeholders.
	Participation in Exercises	The participation of staff in simulations or scenarios designed to practise response arrangements and validate plans.
	Proactive Posture	A strategic and behavioural readiness to respond to early warning signals of change in the organisation's internal and external environment before they escalate into crisis.
	Capability & Capacity of External Resources	An understanding of the relationships and resources the organisation might need to access from other organisations during a crisis, and planning and management to ensure this access.
	Recovery Priorities	An organisation wide awareness of what the organisation's priorities would be following a crisis, clearly defined at the organisation level, as well as an understanding of the organisation's minimum operating requirements.

Picture 8 Amy Stephenson added new dimensions to the McManus framework (Stephenson 2010, p. 245)



Item
I have been involved in planning for crises or emergencies that might affect our organisation
We have formally assessed the impact of a crisis on our ability to operate
Risk management is an integral part of how we manage our work
I know where to find a copy of our organisation's crisis or emergency management plan
I know who has responsibility in our organisation for updating our plan

Picture 9 Questionnaire is built on multi-choice options, the example covers planning strategies indicator (Stephenson 2010, p. 251)

About Resilience

What is it that makes some organisations able to not only survive, but also to thrive in the face of adversity?

Picture 10 The resilience indicators as they were presented in Autumn 2015 on the Resilient Organization's web-site http://www.resorgs.org.nz/

surprise. Resilience development is one of the strategies (the other strategy is to invest in anticipation of changes) that can be applied to uncertainty. The network has studied resilience in national, regional and organizational level. The measurement system described below is mainly based on the four pilot studies that were conducted with global corporations. The GXN is adapting the material to the urban resilience measurement.

Definitions
The GXN defines resilience by introducing four A's: awareness, adaptation, agility and active learning. Resilience is not bouncing back, but bouncing actively forward (Picture 11).

Strategy, *Principles*
The GXN measurement system is based on participatory analysis of resilience with several scopes and the analysis of results from national, regional or organizational perspective. The aim is to detect those features that build generic resilience. The research has been case driven, and exploratory, so the theoretical frameworks have been very generic, such as CAS.

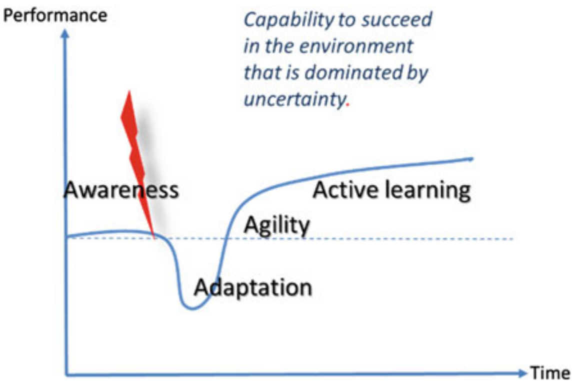
Data and data collection
Data has been collected on different case studies, with several different methods such as surveys, structured participatory analysis or by stories about previous shock incidents (Picture 12).

Structure
The resilience indicator consists of four main dimensions; operations, structure, planning, and resources. Each of the dimensions is divided 3–4 factors. Operations dimension consists of culture, the speed of reaction, trust, experience (or exercises) of disruptive incidents. The structure is divided into City structure, infrastructure and number of layers between a citizen and the Mayor of the city. Planning/strategy dimension consists of citizens' perception of the environment, the vulnerability of key strategies, and the focus (vision/mission) of the city. Resources are divided into a mix of competences, redundancy, diversity and mobility (Picture 13).

How data is analyzed
Data analysis methods are described in the Picture 12. In principle, a respondent will assess and code her own response. This is the way to minimize the impact of the researcher's perceptions.

What is reported and used for improvement
The system described above is producing a report of the city's sources of resilience and its vulnerabilities. The city resilience profile is reported as well, but its role is merely internal; it is a way to follow up development.

Picture 11 The GXN defines resilience by looking at performance in time



2.5 UNDP: City as an Economic System

United Nations have contributed the generic discussion about resilience in multiple ways (disaster management,[6] climate resilience,[7] financial risks,[8] agriculture risks[9]). The special theme of economic resilience has been addressed as the part of the Millenium Development Goals.[10] The report is studying human systems resilience from an economic perspective, and the approach is national economy level, but still applicable to the city system. The main differences between a national economy and a city are:

- the city is more open system than a national economy
- the city has a limited centralized power in the shaping of the institutional environment (no legislative power, no taxation power, no currency)

In the UNDP report,[11] the economic resilience is defined as ex ante resilience and expost coping strategies. Ex ante: diversifying sources of income ex post various forms of insurance and savings.

Many of the goods that improve household resilience are public goods: education, health service, provision of basic goods and services, education, public infrastructure, protection of property rights. 'Systemic resilience requires weakening of the drivers of macro-economic vulnerability, which is not household-driven, but determined by structural economic conditions.'

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[6] http://www.unisdr.org (Nov 2015)

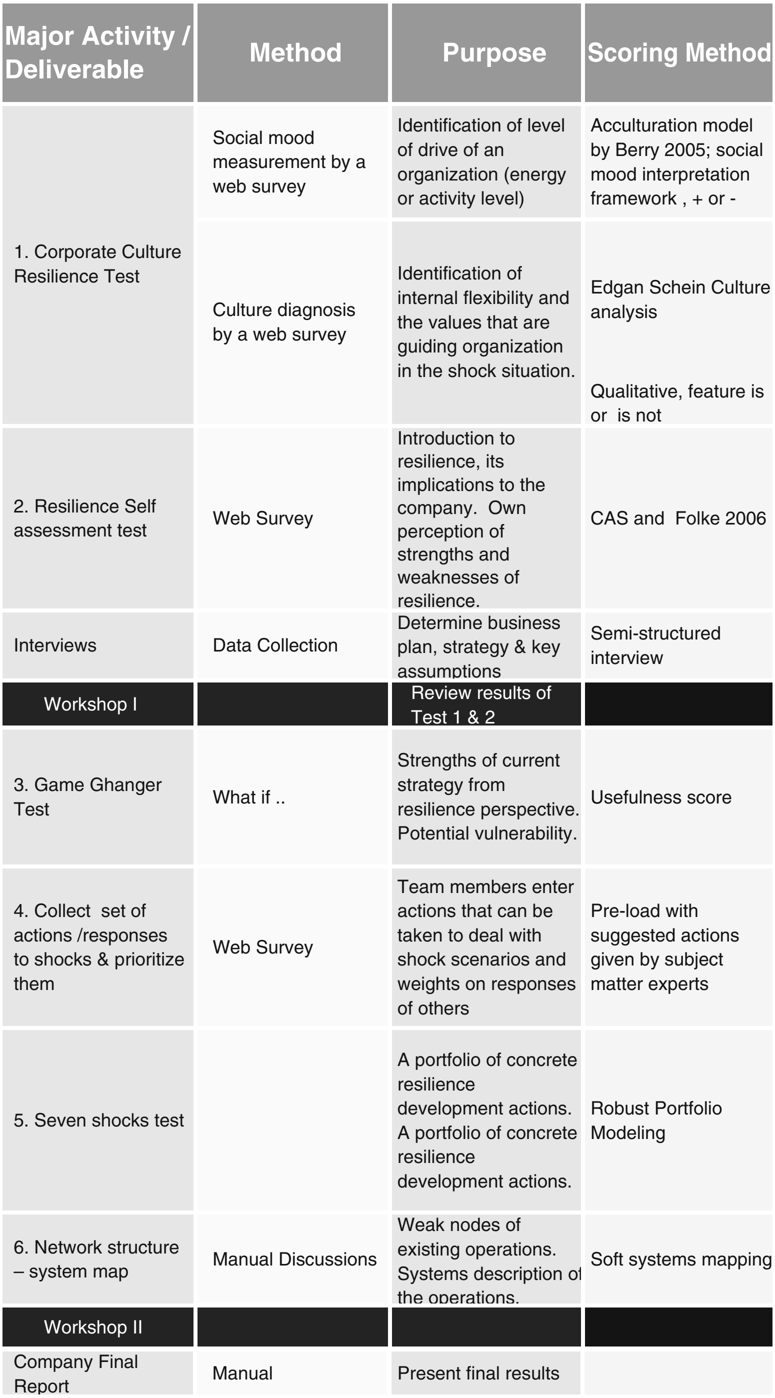
[7] http://www.undp.org (Nov 2015)

[8] http://blogs.worldbank.org (Nov 2015)

[9] http://www.fao.org (Nov 2015)

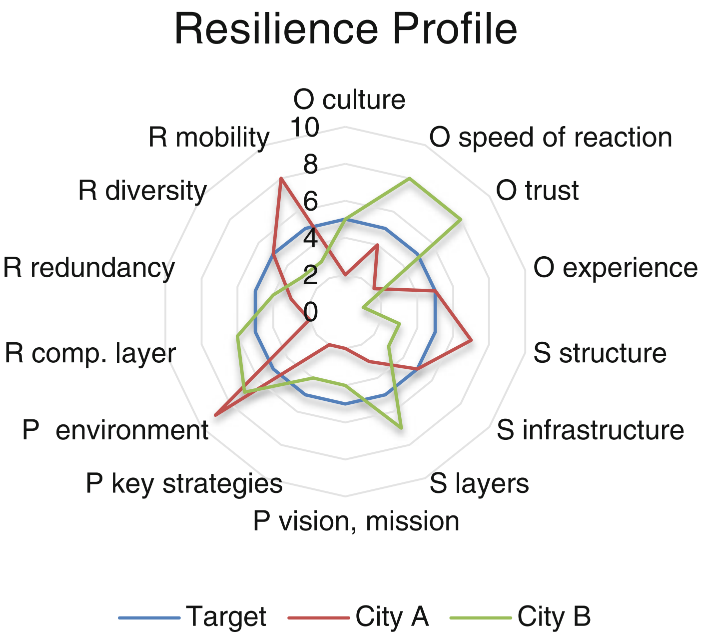
[10] http://www.undp.org (Nov 2015)

[11] United Nations Development Program: Disaster Resilience Measurements, edited by Thomas Winderld, February 2014.



Major Activity / Deliverable	Method	Purpose	Scoring Method
1. Corporate Culture Resilience Test	Social mood measurement by a web survey	Identification of level of drive of an organization (energy or activity level)	Acculturation model by Berry 2005; social mood interpretation framework , + or -
	Culture diagnosis by a web survey	Identification of internal flexibility and the values that are guiding organization in the shock situation.	Edgan Schein Culture analysis Qualitative, feature is or is not
2. Resilience Self assessment test	Web Survey	Introduction to resilience, its implications to the company. Own perception of strengths and weaknesses of resilience.	CAS and Folke 2006
Interviews	Data Collection	Determine business plan, strategy & key assumptions	Semi-structured interview
Workshop I		Review results of Test 1 & 2	
3. Game Ghanger Test	What if ..	Strengths of current strategy from resilience perspective. Potential vulnerability.	Usefulness score
4. Collect set of actions /responses to shocks & prioritize them	Web Survey	Team members enter actions that can be taken to deal with shock scenarios and weights on responses of others	Pre-load with suggested actions given by subject matter experts
5. Seven shocks test		A portfolio of concrete resilience development actions. A portfolio of concrete resilience development actions.	Robust Portfolio Modeling
6. Network structure – system map	Manual Discussions	Weak nodes of existing operations. Systems description of the operations.	Soft systems mapping
Workshop II			
Company Final Report	Manual	Present final results	

Picture 12 The pilot case studies consisted of six phases that used several different methods such as systems mapping, surveys, and Robust Portfolio Modeling



Picture 13 The GXN is dividing the 14 specific features into four dimensions: *O* operations, *S* structure, *P* perception and *R* resources

Definitions
Resilience refers to the country's ability to cope with or recover from a shock: ability to counteract, or absorb the impact of a shock.

Strategy, *Principles*
The report is looking at the structure of the economy as a source of vulnerability or resilience. The structure can drive macroeconomic vulnerability. The report distinguishes two type of channels for resilience improvement: fiscal and economic growth channels. Higher economic growth improves reduces income poverty and improves living conditions. The fiscal channel is related to economic growth as well; if the GDP is reduced, the tax revenues, are sharply smaller. Fiscal hole is opening.

Indicators:

- foreign trade profile, investment profile, the extent of integration into the global economy
- level of exposure for shocks

Measures:

- fiscal capacity measure: the ability of a country to finance programs that create jobs, ensure the delivery of core services, infrastructure and safety nets. > countercyclical spending

- institutional strength measure: country's capacity to efficiently and effectively scale up public expenditures and also ability to protect vulnerable groups and reduce poverty, to cushion the impact of the crisis
- the level of social development: inequality the economic resilience index (Briguglio et al. 2009)

Data

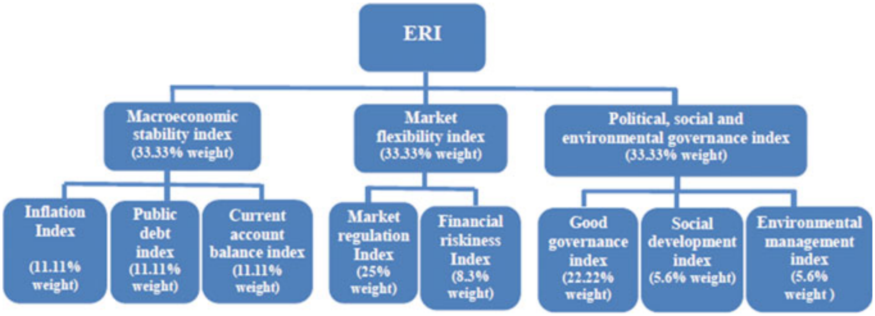
- Macroenomic statistics.

Structure
The structure is based on Briguglio et al. 2009 report where the five dimensions are two macroeconomic stability, market efficiency, good political governance, social development and environmental governance (Picture 14).

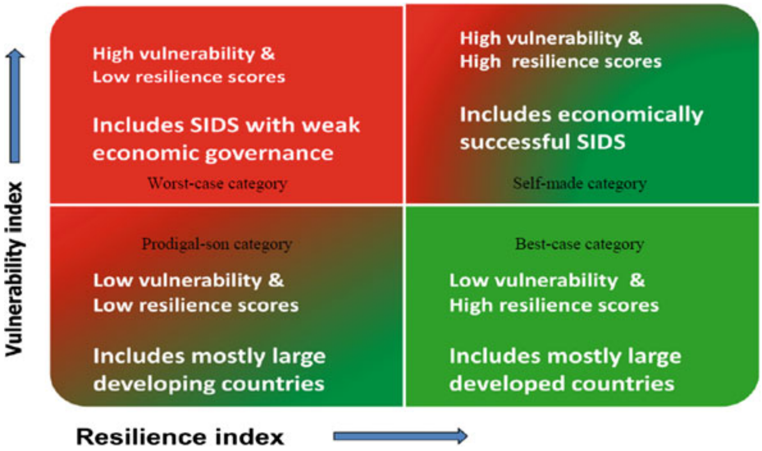
Data collection
No specific data collection, the method exploits the existing national accounting data and statistics.

How data is analyzed
The data defines the city's position on the vulnerability-resilience quadrant (Picture 15).

What are results, *what is reported and how they are guiding improvement*
The approach is aiming at building systemic resilience. Systemic resilience is built by reducing dependence on volatile sources of income and growth, by stabilizing incomes of commodity producers and by addressing the volatility of private capital flows and leverage innovative financing options. According to the UNDP, the export dependency is an important driver of vulnerability. Export concentration (share of dependency of primary commodity exports) and price volatility of primary commodities are stressing the system. Production structures where key sources of revenue and growth are highly volatile are the principal channel that makes countries especially vulnerable. Investments play a similar role. According to the UNDP report, volatile sources of investments (such as private capital flows, foreign direct investments) are increasing the need for resilience. It also seems that rising income inequalities are creating a vicious cycle, which leads to lower resilience.



Picture 14 Economic resilience index is based on Briguglio's (2014) report page 52



Picture 15 The connection between resilience and vulnerability is presented on page 26 on Briguglio (2014)

2.6 *Resilience Alliance's Measurement Framework*

Resilience Alliance http://www.resalliance.org/ is an international, multidisciplinary research organization that explores the dynamics of social-ecological systems. The origin of the thinking is based on Holling's (Gunderson and Holling 2002) work. Resilience Alliance (RA) has no specific system scope focus (such as urban resilience), but they are looking the specific features of urban social-ecological systems as well. The key question they pose is how much and which kinds of disturbances can urban areas absorb without shifting to alternative less desirable system regimes? The RA does not present (December 2015) any particular measurement system, but merely an analytical framework that is radically different from those presented earlier in this chapter.

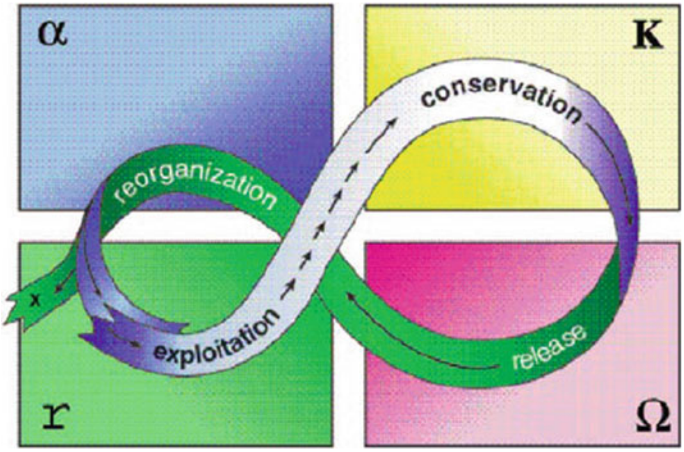
The key for the resilience improvement is to understand what is the state of the system is right now and what is the trajectory of the system. Few words about Holling's (Gunderson and Holling 2002) concept of the adaptive cycle that is called as Panarchy (Picture 16).

Definitions

Resilience is defined by the ‘regime topology; resilience is the capacity of a system to absorb disturbance and reorganize with undergoing a change so as to retain still essentially the same function, structure, identity and feedbacks (Holling 1973; Walker et al. 2004) page 16 of the Practitioners' Handbook.

Strategy, *Principles*

The approach is focusing on analyzing the social-ecological system, and it is interested in regime-shifts, situations when the system is changing its structure,



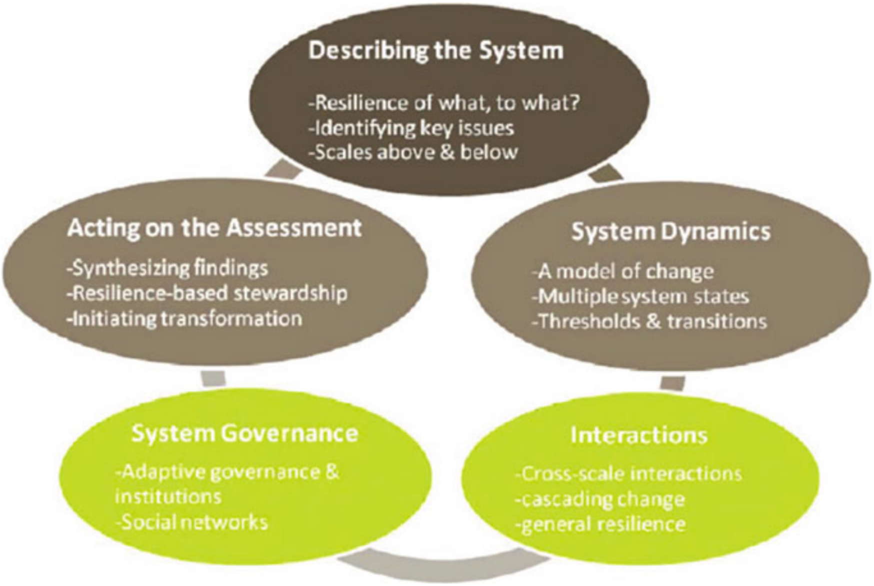
Picture 16 The system's performance is at its peak on the top of the conservation phase (K) of the adaptive cycle. The efficiency of the system emerges from the increase of the order. Increasing order will stabilize the system so that even a small trigger will push it into chaos and collapse, to the O (omega) phase where the previous structures are disappearing and the system—to survive—reorganizes itself (alpha phase). *Source* Practitioners' Handbook, Resilience Alliance 2015

function, feedbacks and its identity. The approach is based on a set of questions that help a group of people/analysts to understand the system.

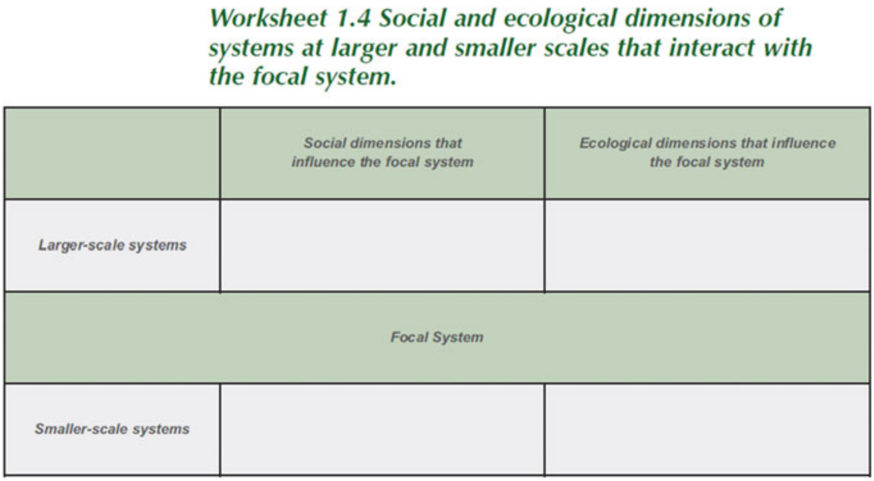
Data
Data is based on workshops' materials, and it is qualitative by its nature.

Structure
The first phase of the process is to describe the system, system scales, and the potential issues (concerns) from participant's perspective and then define the context dependent systems boundaries. The approach focuses on potential disturbances and the past behavior of resource flows, especially in the shock situation. The Past supports system drivers and disturbances identification. The method distinguishes fast and slow drivers and identifies critical variables. The analysis also defines key people involved in ecosystem service management and the political system that defines governance, regulations and control systems. The resilience assessment is based on conceptual models of the physical and social system, alternative tresholds and tipping points and their potential transitions that lead to major change is the system (change of the system regime) (Picture 17).

Data collection
The conceptual model is the main objective of the analysis. The sources of data are historical statistics, qualitative descriptions of the historical events and descriptions



Picture 17 The analysis process is divided into 5 phases. *Source* Practitioner's Handbook



Worksheet 1.4 Social and ecological dimensions of systems at larger and smaller scales that interact with the focal system.

	Social dimensions that influence the focal system	*Ecological dimensions that influence the focal system*
Larger-scale systems		
Focal System		
Smaller-scale systems		

Picture 18 The screenshot is from the Practitioner's Handbook p. 20

of mental models of key people and researchers. The main part of the work is qualitative, and the most of it should be participatory (workshops or surveys) (Picture 18).

How data is analyzed
The aim of the process is to identify what is the phase of the adaptive cycle (see the Picture 10) and how fast the system is moving into the next phase. The scenarios are developed for different transitions and potential interventions defined.
What is reported and how the results are guiding improvement
The Handbook for Practitioners focuses on improvement of ecosystem services management by proposing a set of interventions that should arise during the analysis.

3 Results

At the beginning of this chapter, we discussed systems theory and social systems features to be able to review these very different methods and compare them within one framework. As our conclusions, we defined five dimensions to describe an urban system. These dimensions should help us in assessing resilience measurement methods: structure, interactions between members/variables of the system, coordination mechanisms, dynamics of renewal of the system and resources that flow from a system's node to another (Picture 19).

The six methods reviewed had a strong urban substance focus. To distinguish differences of the methods from substance perspective, we will look the substance of systems flows, systems outputs and urban systems' different system levels.

All the measurement systems were focusing on generic resilience and resilience capacity/competence. The definition of resilience was mostly the 'bouncing-back' type, but the 'bouncing-forward' was represented as well.

The main disagreement—according to the material analyzed—seems to be in what to measure. All of the methods were different, even if some overlap was possible to identify.

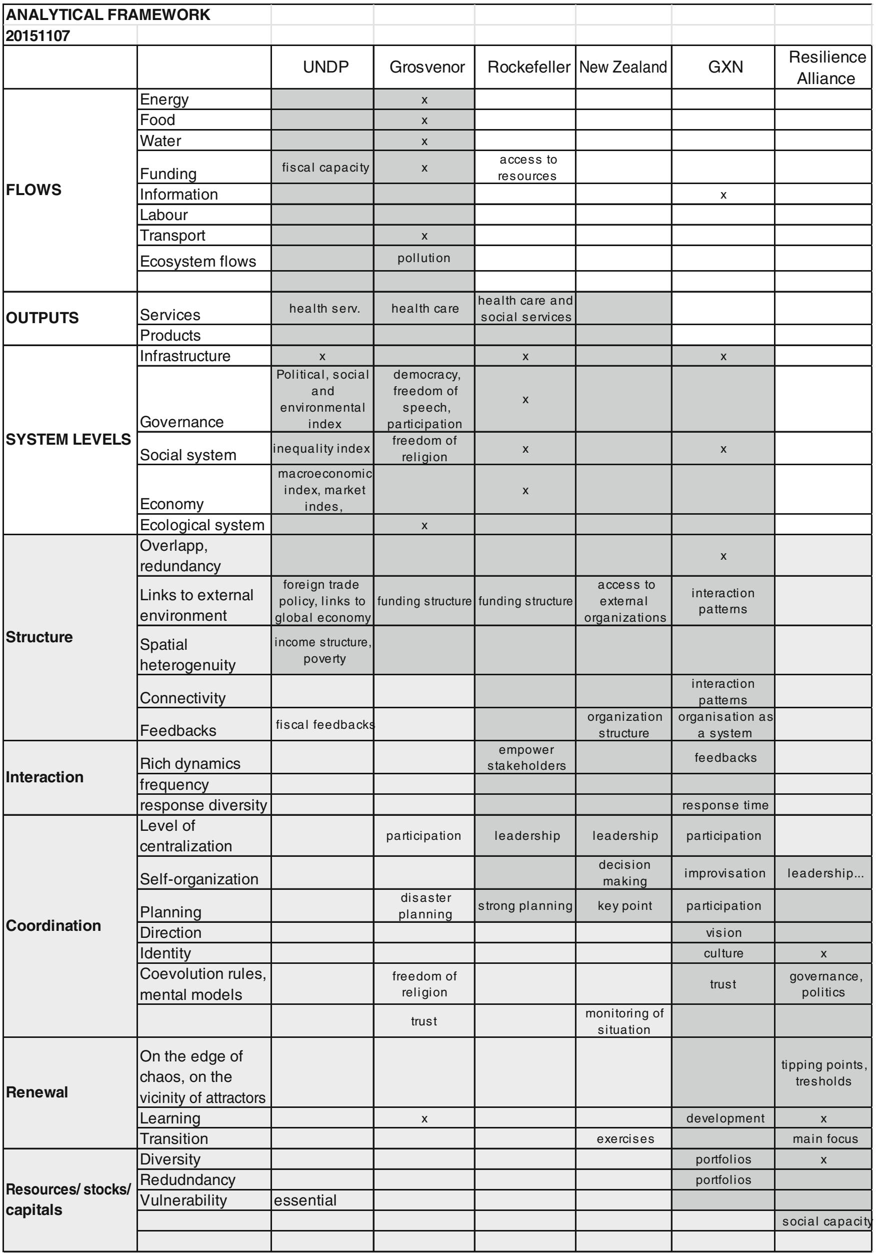
When the measurement systems are reviewed in the framework developed for the purpose, we see that there are three different groups of approaches.

The first approach is heavily substance driven (that is the reason we had to add substance flows to our framework), and data used is statistical data. The Grosvenor and UNDP resilience measurement system belong to this group. These methods are pragmatic and easy (depending on the data available) to apply.

The second group can be described as participant's perception driven (the 100RC, the New Zealand and the GXN), due the fact that according to the information available in the public sources the data is collected by using surveys and workshop discussions. The focus of these three methods is very different; the 100RC mostly measures the city's government, the New Zealand approach is taking the perceptions of people into consideration, and the GXN method aims to cover both the structure and resources but culture and planning as well. These methods are relatively easy to implement if respondents of surveys have a strong motivation to respond.

ANALYTICAL FRAMEWORK					
		CAS	**Holling**	**Folke**	**Social Systems**
Structure	Overlapp, redundancy	x			
	Links to external environment				x
	Spatial heterogenuity			x	
	Connectivity	x			x
	Feedbacks	x	x		
Interaction	Rich dynamics	x		x	
	Frequency				x
	Response diversity			x	x
Coordination	Level of centralization	x		x	
	Self-organization	x			
	Planning				x
	Direction				x
	Identity				x
	Coevolution rules, mental models	x	x		x
Renewal	On the edge of chaos, on the vicinity of attractors	x	x	x	
	Learning				x
	Transition		x		x
Resources	Diversity			x	
	Redudndancy			x	
	Vulnerability		x	x	

Picture 19 Four systems theoretical frameworks define a set of features that have an impact on systems' resilience



ANALYTICAL FRAMEWORK							
20151107							
		UNDP	Grosvenor	Rockefeller	New Zealand	GXN	Resilience Alliance
FLOWS	Energy		x				
	Food		x				
	Water		x				
	Funding	fiscal capacity	x	access to resources			
	Information					x	
	Labour						
	Transport		x				
	Ecosystem flows		pollution				
OUTPUTS	Services	health serv.	health care	health care and social services			
	Products						
SYSTEM LEVELS	Infrastructure	x		x		x	
	Governance	Political, social and environmental index	democracy, freedom of speech, participation	x			
	Social system	inequality index	freedom of religion	x		x	
	Economy	macroeconomic index, market indes,		x			
	Ecological system		x				
Structure	Overlapp, redundancy					x	
	Links to external environment	foreign trade policy, links to global economy	funding structure	funding structure	access to external organizations	interaction patterns	
	Spatial heterogenuity	income structure, poverty					
	Connectivity					interaction patterns	
	Feedbacks	fiscal feedbacks			organization structure	organisation as a system	
Interaction	Rich dynamics			empower stakeholders		feedbacks	
	frequency						
	response diversity					response time	
Coordination	Level of centralization		participation	leadership	leadership	participation	
	Self-organization				decision making	improvisation	leadership...
	Planning		disaster planning	strong planning	key point	participation	
	Direction					vision	
	Identity					culture	x
	Coevolution rules, mental models		freedom of religion			trust	governance, politics
			trust		monitoring of situation		
Renewal	On the edge of chaos, on the vicinity of attractors						tipping points, tresholds
	Learning		x			development	x
	Transition				exercises		main focus
Resources/ stocks/ capitals	Diversity					portfolios	x
	Redudndancy					portfolios	
	Vulnerability	essential					
							social capacity

Picture 20 The summary of the analysis matrix indicated that there are three different approaches that are merely complementary than exclusive

The pure systems approach for city resilience comes from Resilience Alliance. The method is looking at the most of the systems features by addressing a set of questions to workshop participants. The RA method is not a measurement system in that respect, that even if the improvement of resilience is possible to identify, it does not produce any profile that would facilitate cross city comparison (Picture 20).

The most surprising outcome of this study is that we can say that these methods do not pay any attention (except the GXN approach in a very limited way) to the nature of the interaction within an urban system. This is the key development field for the next generation of city resilience measurement initiatives.

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Computational Framework of Resilience

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Leena Ilmola and Katsumi Inoue

Abstract Many researchers have been studying the resilience in urban cities. However, due to the complexity of the system involving human activities, it is difficult to define the resilience of an urban area quantitatively. We introduce an abstract model that represents an urban system through a set of variables and a utility function (or dually, a cost function) evaluating the "quality" of the states of the variables. This cost function depends on the criterion of interest for evaluating the resilience of the system, and can be easily defined in a succinct way. Then, our contribution is mainly twofold. First, we propose several performance metrics that evaluate how resilient a given system has been in some specific scenario, that is, in the past. Second, assuming we are given some knowledge about the dynamics of the system, we model its possible evolutions by embedding it into a discrete state transition machine, and show how we can adapt the performance metrics to this framework to predict the resilience of the system in the future. Such an adaptation of a performance metric to our dynamic model is called here a *performance-based competency metric*. This new kind of metric is useful to validate existing competency metrics (Ilmola in Competency metric of economic resilience. Urban resilience: a transformative approach. Springer, 2016) by aligning these competency metrics with our performance-based ones.

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1 Introduction

Evaluating the resilience of an urban city has been an increasingly important issue in our society as we have been experiencing many natural and man-made disasters. However, it is not obvious how we can improve the resilience of an urban area. Indeed, on the one hand it is a large-scale complex system involving many different stakeholders and decision makers, and on the other hand its state and structure evolve in time, which is a direct effect of the actors evolving inside of the system and the dynamic nature of our environment. This chapter introduces a set of properties, allowing one to evaluate a specific scenario that has been followed by a given system *in the past*. A scenario consists of a series of system state "snapshots," where each snapshot is associated with a given utility function (e.g., the GDP per capita) or conversely, a cost function (e.g., the unemployment rate in a given city.) The choice of the particular utility/cost function depends on the context, i.e., it depends on which indicator we want the system to be resilient to. As discussed in the previous chapter key indicators of an urban system are, for instance, the capacity of a city to deliver basic needs, to safeguard human life, to promote knowledge, education and innovation, etc. Our properties are based on numerical parameters, thus they quantitatively assess how resilient a given system has been in the past. These properties are called *performance metrics*. However, what we really need is to evaluate the resilience of a system in the future, given the system's current state, specifications, the assumptions on the environment and the possible decisions at hand. Several context-dependent properties have been proposed for this purpose (Ilmola 2016). These properties evaluate how resilient one can expect the system to be in the future, and are called *competency metrics*.

There is a clear distinction between a performance metric and a competency metric. Chomsky (Chomsky 1986) emphasized the difference between performance and competence in the field of linguistic theory, though the concept can be applied to a large number of areas, including the topic under consideration in this chapter. In linguistics, Chomsky describes competence as an idealized capacity that is located as a psychological or mental property or function, and performance as the production of actual utterances. Stated otherwise and speaking generally, competence involves *knowing* the field of interest and performance involves *doing* something. Then, while competence seems to be a key tool to assess the performance of a given system in the future, it is very difficult to assess competence without assessing performance, which leads to a contradiction. What we propose here is an alternative way to define a competency metric from the resilience viewpoint. We take advantage of the performance metrics which we will introduce first, and we provide a way to derive a competency metric from a performance metric, which we call a *performance-based competency metric*. Such a metric considers all possible futures on the system, given the uncontrollable effects of the environment of the system, and given the possible actions the government can take over the system. Then, each possible future scenario is evaluated using the same given performance metric. Last, the set of such evaluations is aggregated to a single value, which defines our performance-based competency metric. Therefore, the model proposed here provides a theoretical tool to validate the accuracy of standard competency metrics by aligning them with our performance-based ones.

The model we present in this paper can be viewed as a simplified version of the one introduced in (Schwind et al. 2016). Before introducing it, we would like to stress an important point concerning what this work is and is not about. The very purpose of this chapter is to provide a formal framework that can be applied to urban systems, but at the same time that can be used in other domains such as engineering systems, computer networks, financial systems, civil infrastructures, organizations and society; it is used for resilience-checking purposes, i.e., we want to be able to *assess* the resilience of a given system through the performance-based competency metrics we introduce. By no means this chapter provides some specific or general resilient strategies or methods for the design of a resilient system (this is, for instance, a topic addressed in (Maruyama 2016)). In other words, we focus on the verification of the behavior of a system, which is nevertheless a crucial stage in the design of a reliable urban system.

2 Formalization of an Urban System and Its Past Evolution

As stated in (Ilmola 2016), an urban system is a complex system, which means that it involves a large number of components. We propose a simple, though general structure for representing a system, its components, and its dynamics. Our intention is to simply introduce step by step the formal structures involved in the abstract definition of an urban system.

Intuitively, each component of the system is represented through a variable whose value ranges over a domain that may be specific to this variable. An assignment of each variable to a specific value leads to a *system state,* which represents a specific situation in which the system is at a given time.

Formally, a *system state* is the complete description of a system S at a given time step. It involves a certain set of variables $X = \{X_1, \ldots, X_n\}$ representing the components of the system, where each variable X_i is assigned to a certain value from a given domain D_i. Such an assignment will be represented by the (possibly indexed) symbol ω in the rest of the chapter, and in a given assignment ω, for each variable $X_i \in X$, $\omega(X_i)$ denotes the value from D_i assigned to X_i in ω. A system state is denoted by the pair (S, ω), where S is the system and ω is a specific assignment of all variables into their domain.

Let us consider the example representing the workforce distribution across economic sectors in a given city of m citizens from the workforce. One can consider the following simple formalization of this problem. Let $X_1, \ldots, X_m$ be m variables representing the employment status of each citizen, and X_{m+1}, X_{m+2}, X_{m+3} be three additional variables representing the available number of positions in, respectively, the primary (raw materials), secondary (manufacturing) and tertiary (services) sectors. One can set $D_1 = \ldots = D_m = \{un, sec1, sec2, sec3\}$ where for each $i \in \{1, \ldots, m\}$, the assignment $X_i = un$ stands for "Citizen i is unemployed," and $X_i = secj$ stands for "Citizen i has a position in the jth sector," where $j \in \{1, 2, 3\}$. Additionally, since the available number of positions in each sector is a non-negative integer number, we set $D_{m+1} = D_{m+2} = D_{m+3} = \mathbb{N}$.

As in any complex system, the components involved in an urban system are likely to interact with each other. We distinguish two types of such interactions, static ones and dynamic ones:

- Static interactions are called here *integrity constraints*. These constraints restrain the possible states of a set of components at a given time step. For instance, when one intends to represent the organization of a public transportation service, one obviously cannot assign two trains at the same platform of the same station at the same time; more formally, if at a given time a component *Train X* is assigned to a certain value *Station Y—Platform Z* then no other component *Train Y* (different from *Train X*) can also be assigned to the value *Station Y—Platform Z* at the same time. Integrity constraints are part of the formalization of an urban system and will be given through a set C of formulae (or a single formula.)
- Dynamic interactions between the components of the system will have a delayed influence on the system. The consequences of these interactions are more complex to predict since events that are not within the boundaries of the system and its components (such as natural disasters or intentional, exogenous attacks) may force the state of some system's components to change. These kinds of dynamics will be dealt with in the next sections.

Our example of workforce representation involves a set of integrity constraints (the static interactions between the components) that must be satisfied and that restrain the set of "feasible" assignments. Indeed, in a given system state and for each sector $j \in \{1, 2, 3\}$, no more than X_{m+j} positions can be assigned to the citizens. Formally speaking, one can define the constraint C as follows [1]:

$$\forall j \in \{1, 2, 3\}, X_{m+j} \geq \#\{X_i \in \{X_1, \ldots, X_m\} \mid \omega(X_i) = secj\}.$$

The set of *feasible assignments* is the set of all system assignments ω that satisfy the constraint C.

Additionally, we assume that we are given a utility (or cost) function which associates with each system state a value characterizing the quality of the state with respect to some indicator of interest such as employment rate, safety degree, Gross Domestic Product (GDP), GDP per capita, average income, pollution (air/water quality), ratio of educated people, etc. From now on, our framework and our metrics will be based on a *cost* function, rather than a utility one. Stated otherwise, each

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[1] Given a set E, the notation $\#E$ stands for the number of elements in E.

indicator under consideration evaluates the state of a system with a value such that the lower the value the better. This choice is made without loss of generality, since any utility-based indicator can be converted to a cost-based indicator (e.g., when we are given an employment rate of a city, one can easily convert it into an unemployment rate.)

In our example, several indicators can be easily derived, associating a cost value with any feasible system state. For instance, we will focus on the following cost function *ur* corresponding to the unemployment rate of the city under consideration:

$$\forall \mathit{feasible}\, \omega,\ ur(\omega) = \frac{\#\{X_i \in X \mid \omega(X_i) = un\}}{m}.$$

Depending on the indicator of interest for evaluating the resilience of the system, one may consider other indicators, e.g., the number of unassigned positions in some specific sector. Additionally, with richer domains for the variables considered in our example, the indicators can be easily refined. For instance, in addition to the employment status of each citizen one can easily store her gender and age, for instance, by defining each domain $D_1, \ldots, D_m$ as the following Cartesian product $D_i = \{un, sec1, sec2, sec3\} \times \{Female, Male\} \times \mathbb{N}$. Doing so, one could derive indicators such as the unemployment rate by sex and age.

Based on the notions we introduced in this section, we are ready to formalize the notion of a *system*:

Definition 1 (*System*) A *system S* is characterized by a tuple $\langle X, D, C, cost \rangle$ where:

- $X = \{X_1, \ldots, X_n\}$ is a set of variables representing the components of the system;
- $D = \{D_1, \ldots, D_n\}$ is a multiset of non-empty sets: each D_i is the domain of the variable X_i, i.e., the set of values over which the variable ranges;
- C is the (set of) integrity constraint(s);
- *cost* is a cost function, that is, a mapping associating each feasible assignment of S (according to C) with a non-negative real number $\mathbb{R}^+$.

Because our environment is dynamic by nature, an urban system naturally changes over time: not only its state (i.e., the actual state of each one of its components and the cost associated with each system state), but also its specifications. Indeed, from a time step to the next one, the set of variables forming a system may change (some components may be added or removed from it), as well as the domain for each variable, the integrity constraints and even the cost function. Therefore, Definition 1 above serves a characterization of a system *at a given specific time*.

In our example of workforce analysis, let us assume that the considered time granularity is of one month between two consecutive time steps. Naturally, the workforce, i.e., the set of variables $X = \{X_1, \ldots, X_m\}$ is likely to be modified from any time step to the next one. Moreover, the cost function may also change when for instance one wants to combine several indicators and the relative importance given in each one of these indicators separately is altered over time.

Therefore, one can represent the past evolution of a given urban system as a series of "system snapshots," that is, a sequence of system states:

Definition 2 (*System state trajectory*) A *system state trajectory* $SST = ((S_1, \omega_1), \ldots, (S_q, \omega_q))$ is a finite series of pairs (S_i, ω_i), where for each $(S_i, \omega_i) \in SST$, S_i is a system (according to Definition 1) and ω_i is a feasible assignment in S_i.

A system state trajectory represents the precise description of a specific scenario that has occurred in the past (from some time step 1 to some time step q), for the urban system into consideration. Then, given a system state trajectory $((S_1, \omega_1), \ldots, (S_q, \omega_q))$ one can naturally associate with it a sequence of values representing the series of costs induced in each pair (S_i, ω_i). We call such a sequence a *system cost trajectory*:

Definition 3 (*System cost trajectory*) Let $SST = ((S_1, \omega_1), \ldots, (S_q, \omega_q))$ be a system state trajectory. The *system cost trajectory SCT* associated with *SST* is defined as the sequence $SCT = (cost_1(\omega_1), \ldots, cost_q(\omega_q))$, where each $cost_i$ is the cost function in the system S_i.

An example of system cost trajectory is given in Fig. 1. It depicts the unemployment rate in Finland from January 2010 to November 2015 according to (Statistics Finland 2016).

We are now given the formal tools to define an existing urban system, derive in a simple way a system state trajectory describing the system's evolution in the past, as well as its system cost trajectory that depends on an indicator of interest. The next section deals with the evaluation of such trajectories, that is, we intend to provide an answer to the following question: can we say that our system had a resilient behavior so far?

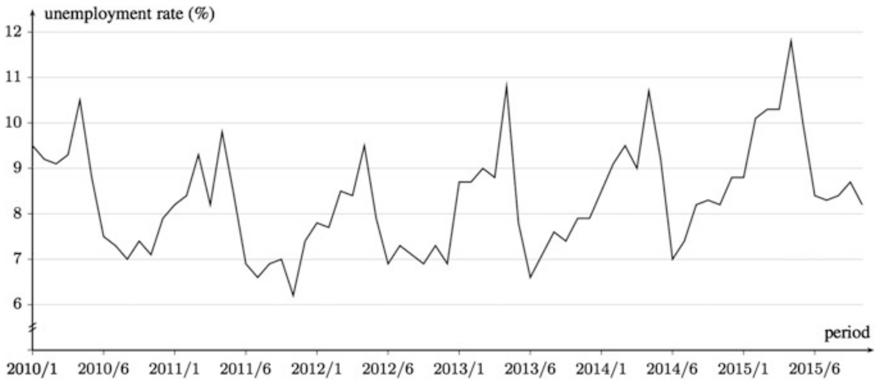

Fig. 1 An example of system cost trajectory: the unemployment rate in Finland from January 2010 to November 2015

3 Resilience-Based Performance Metrics: Evaluating a Past Scenario

A performance metric associates with a system state trajectory or a system cost trajectory, a single number. But before providing a set of specific (resilience-based) performance metrics, let us introduce a recent real-case resilience scenario that motivates the need for such performance metrics.

In the city of Oulu, Finland, Nokia and its networks venture had employed about 5000 people in Oulu, more than three times the next biggest private sector employer before 2014. In April 2014, Microsoft acquired Nokia's Devices and Services division, and made it Microsoft Mobile, a wholly owned subsidiary of Microsoft. Following this acquisition, more than 1000 jobs were eliminated from the former Nokia sites in Oulu. The city's unemployment rate topped 16 percent in the summer of the same year, a level not seen since the Finnish financial crisis of the early 1990s. The jump of unemployment rate was sudden, but showed a reasonably "quick" recovery. The question is, can we say that the city of Oulu has been resilient against the shock, namely, the shutdown of the former Nokia sites and loss of so many jobs? Qualitatively, the answer probably is yes, but how can we quantify the resilience? How can we compare whether a specific scenario from the past had a more resilient behavior than another scenario? When looking back at Fig. 1, at the country level can we say that Finland has been resilient in terms of employment rate? These questions clearly call for the definition of relevant performance metrics, since one wants to evaluate the resilience of a past scenario.

Several well-known indicators exist to interpret such system state/cost trajectories, e.g., the mean or variance of overall costs. But none of these "traditional" measures evaluates the curve from the resilience point of view. We intend to fill the gap.

3.1 Cost-Based Performance Metrics

We recall several metrics that have been proposed in (Schwind et al. 2013, 2016). These metrics are crucial to assess the resilience of a state trajectory. They are inspired from Bruneau's work (Bruneau 2003) who reconciled a number of concepts underlying resilience within two main characteristics: the *absorption* of shocks when they occur, and the *recovery* after a shock, i.e., the capability to establish back a normal performance.

In (Schwind et al. 2013, 2016), three properties evaluating a system cost trajectory have been introduced: resistance, functionality and recoverability.

Resistance is the ability exhibited by the system to absorb by itself some perturbations. Intuitively, when a system is resistant, the potential, challenging attacks are actually not visible in its system cost trajectory. This notion of "direct shock absorption" appeared in the literature within various qualitative variants.

(Grimm and Calabrese 2011) considered the same notion under the term "persistence" as the ability for a system to stay essentially unchanged despite the presence of disturbances. (Bruneau 2003) referred to the term "robustness" as the capability for a system of services to keep a certain level of demand without directly suffering from a degradation. Moreover, the notion coincides with the initial qualitative characterization of resilience proposed by Holling (1973), as a system's inherent ability to absorb the external shocks. In (Schwind et al. 2013, 2016), resistance is assessed under the ability for a system to maintain some underlying costs under a certain "threshold," such that the system satisfies some hard constraints and does not suffer from irreversible damages. The quantitative definition of resistance is then very simple, though it provides us with a first performance metric:

Definition 4 (*Resistance*) The resistance of a system cost trajectory *SCT* is the maximal cost in *SCT*.

In other terms, resistance associates with a system cost trajectory a single value corresponding to the worst case the system has ever encountered within its trajectory. In Fig. 1, the resistance of the system is 11.8, that is, from 2010 to 2015 Finland never had an unemployment rate worst that 11.8 %, or stated otherwise, Finland has been resistant to the tune of 11.8.

Functionality, like resistance, relates to the system's capacity to absorb the shocks. However, resistance evaluates the cost of the system at each single time step within its trajectory and considers the worst case encountered; on the contrary, functionality evaluates the system in its whole trajectory, by considering the average of all values:

Definition 5 (*Functionality*) The functionality of a system cost trajectory *SCT* is the average of costs in *SCT*.

Looking back at Fig. 1, the system's functionality corresponds to the average of unemployment rates along the considered trajectory, that is, 8.33.

Obviously enough, resistance and functionality are not sufficient metrics to evaluate the resilience of a system in its past trajectory.

Recoverability is the ability to reach an admissible state within a given time interval after potentially damaging modifications. This property allows the system to express temporarily the consequences of some external disturbances, but then it should be able to return to a satisfactory state (Schwind et al. 2013, 2016). This system's behavior has been widely discussed in various fields, though the same notion is often named differently depending on the field. For instance in physics, this notion is identified by the term *buoyancy*, and is described as "the quantity of work given back by a body that is compressed to a certain limit and then allowed freely to recover its former size or shape" (The New International Webster's Comprehensive Dictionary 2016). Additional domain-dependent characterization of the notion of recoverability can be found in other disciplines such as environmental sciences and risk management (Haimes et al. 2008; Wohlgemuth 2014), computer networks (Stoicescu et al. 2011; Smith et al. 2011; Linkov et al. 2013), psychiatry (Cicchetti 2010), sociology and material sciences.

The recoverability metric we are going to introduce is a parameterized metric: it relies on a number p that corresponds to a certain given cost threshold. If the cost of the system state is beyond this threshold, then it is considered as being an "unstable" state, otherwise it is "stable." Under this interpretation, the recoverability of a system cost trajectory corresponds to the cumulative extra cost associated with an "unstable sub-trajectory" in the worst case. This calls first for the definition of an unstable sub-trajectory.

Definition 6 (*Unstable sub-trajectory*) Given a system cost trajectory $SCT = (cost_1(\omega_1), \ldots, cost_q(\omega_q))$, a *subtrajectory* $SCT' = (cost_a(\omega_a), \ldots, cost_b(\omega_b))$ of SCT is a series of consecutive values from SCT such that $1 \leq a \leq b \leq q$. We denote $SCT' \sqsubseteq SCT$ when SCT' is a sub-trajectory of SCT. Given an additional non-negative number p, SCT' is said to be p-unstable if each value in SCT' is strictly greater than p.

Let us assume that for Finland, an unemployment rate above 8.5 is considered to be unsatisfactory. Figure 2 emphasizes the set of all 8.5-unstable sub-trajectories of the system cost trajectory introduced in Fig. 1.

We are ready to introduce the performance metric capturing the notion of recoverability, parameterized by a cost threshold p:

Definition 7 (*Recoverability*) Given a system cost trajectory $SCT = (cost_1(\omega_1), \ldots, cost_q(\omega_q))$ and a non-negative number p, the p-recoverability of SCT corresponds to the value $+\infty$ if $cost_q(\omega_q) > p$, otherwise it corresponds to the following value:

$$max_{SST' \sqsubseteq SST} \left\{ \sum_{i=a}^{b} (cost_i(\omega_i) - p) \mid cost_i(\omega_i) \in SST', SST' is\, p - unstable \right\}.$$

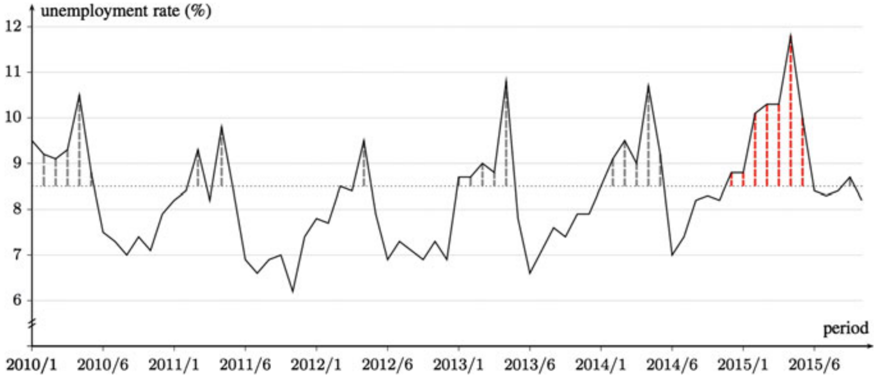

Fig. 2 The set of all 8.5-unstable sub-trajectories of the evolution of the unemployment rate in Finland from January 2010 to November 2015. The 8.5-recoverability of the whole system cost trajectory is equal to 10.6 (color figure online)

Figure 2 depicts in red the "worst situation," i.e., where the cumulative extra cost of an 8.5-unstable trajectory is maximal. This situation corresponds to the period between December 2014 and June 2015. In this case, the 8.5-recoverability of the system cost trajectory is equal to 10.6.

Schwind et al. (2016) have then proposed a more general property simply named *resilience*. We provide below an adaptation of this property in terms of performance metric. Interestingly, the authors have shown that the property of resilience is a generalization of both notions of resistance, functionality and recoverability. Therefore, the notion allows one to characterize in the simplest way both notions of "shock absorption" (resistance and functionality) and "fast recovery" (recoverability.) Resilience has one parameter k, a positive integer:

Definition 8 (*Resilience*) Given a system cost trajectory $SCT = (cost_1(\omega_1), \ldots, cost_q(\omega_q))$ and a positive integer k, the k-resilience of SCT corresponds to the maximum value among the cost average of each sub-trajectory of SCT of size k. Formally, it corresponds to the following value:

$$max_{1 \leq a \leq q-k+1} \left\{ \sum_{i=a}^{a+k-1} \frac{cost_i(\omega_i)}{k} \right\}.$$

One can observe that 1-resilience coincides with resistance, and when the size of a system cost trajectory is q, then q-resilience coincides with functionality. It has been shown in (Schwind et al. 2016) that p-recoverability can also be represented through an aggregation of several k-resilience values depending on p. Then, by adjusting the parameter k to intermediate values, i.e., between 1 and the size of the trajectory, one gets more insights on the capability for a system to absorb the shocks and to recover to satisfactory states in case of disturbance expression.

We illustrate the property through our example. We have considered two additional scenarios that may have been followed by a similar system, leading to two additional system cost trajectories. Figure 3 depicts the three resulting system cost trajectories: the initial unemployment rate in Finland, and some unemployment rates of two fictive countries *Country* 2 and *Country* 3. One can see that Finland regularly suffers from a "jump" of the unemployment rate, approximately every year starting from winter, and recovers to an initial rate at the beginning of summer. The presence of such "jumps" of the unemployment rate are reflected in the difference of values between the resistance (1-resilience) and functionality (72-resilience) of this cost trajectory; indeed, according to Fig. 4, its 1-resilience is equal to 11.8 (since in May 2015, Finland's unemployment rate reached 11.8 %), whereas its functionality is equal to 8.33 (i.e., from January 2010 to November 2015, Finland's unemployment rate has been equal to 8.33 in average.) Moreover, thanks to the resilience curve depicted in Fig. 4, one can get more information about the *speed* of recovery within these cost "jumps." Indeed, one can see that the k-resilience of this cost trajectory is high for low values of k, but rapidly decreases when the value of k increases until $k = 8$: this reflects the fact that the

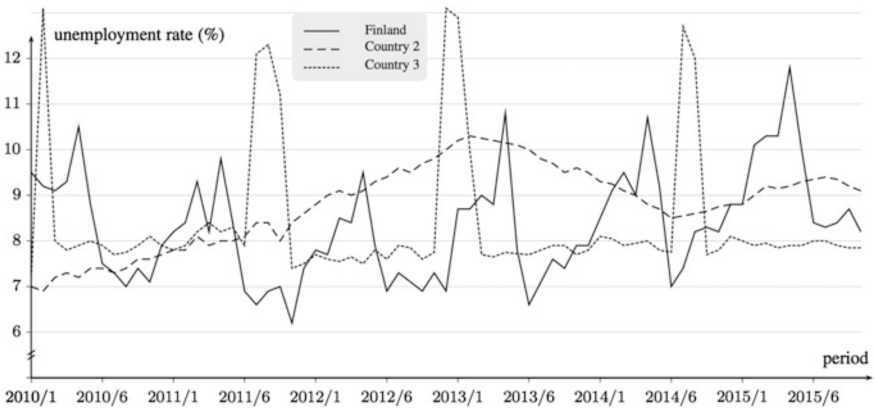

Fig. 3 The unemployment rate from January 2010 to December 2015 in Finland and two fictive countries

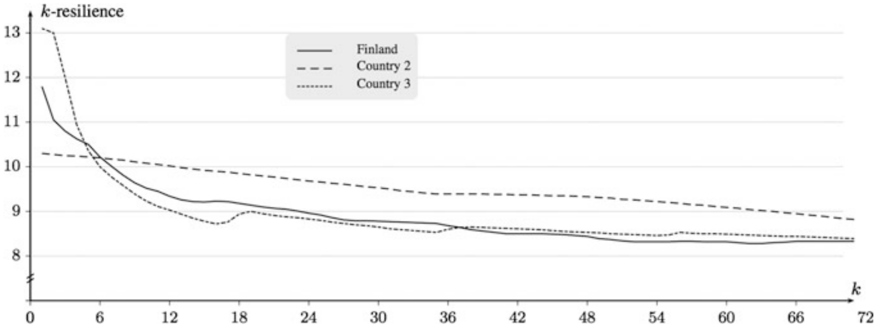

Fig. 4 The k-resilience of each system cost trajectory (corresponding to the unemployment rate in Finland and the two fictive countries), when k varies from 1 to the size of these trajectories, i.e., 72

unemployment rate in Finland reaches relatively high unemployment rates, but as a counterpart exhibits a "resilient" behavior within a time period of approximately 8 months. In comparison, in Country 2 one can see in Fig. 3 that the unemployment rate evolves relatively smoothly, with no drastic rate "jump," which explains why the values of 1-resilience (resistance) and 72-resilience (functionality) for this trajectory are more close to each other (respectively, 10.3 and 8.8) and the k-resilience curve decreases linearly between these two values. Lastly Country 3 exhibits very drastic, high jumps of unemployment rate but always recovers to a satisfactory rate within 4 or 5 months (cf. Fig. 3), which explains why in Fig. 4 one can see a drastic decrease of k-resilience from $k = 1$ to $k = 5$ before a relatively stabilization of k-resilience from $k \geq 6$.

3.2 State-Based Performance Metrics

All performance metrics presented so far, i.e., resistance, functionality, recoverability and resilience, are related to some underlying indicator that is reflected by the cost function, mapping each system state to a cost value. This means that these metrics do not take into account the evolution of the system states themselves but only their cost. Indeed, in some situations the system state may drastically change from a time step to the next one, even if the underlying costs do not reflect that change. In our example of unemployment rate, this would be the case if all positions affected to some citizens at some time step t are assigned to different citizens at time step $t + 1$: even if the cost of these two consecutive system states remain unchanged, there is an underlying drastic, undesirable change between these two states. A way to deal with this issue is to build a performance metric based on the "distance" between each pair of consecutive system states within a trajectory. Measuring the distance between two system states can be done arbitrarily, though the well-known, standard Hamming distance can be used (Hamming 1950). The Hamming distance $d_H((S, \omega), (S', \omega'))$ between two system states (S, ω), (S', ω') is simply the number of differences between the assignments ω and ω'. Then, (Schwind et al. 2013, 2016) have proposed the property of *stabilizability* that evaluates how drastically the transitions between a system state and the next one are performed within a system state trajectory. We give below an adaptation of this property of stabilizability in terms of performance metric.

Definition 9 (*Stabilizability*) Given a system state trajectory $SST = ((S_1, \omega_1), \ldots, (S_q, \omega_q))$, the stabilizability of SST corresponds to the following value:

$$max_{1 \le i \le q-1}\{d_H((S_i, \omega_i), (S_{i+1}, \omega_{i+1}))\}.$$

Therefore, stabilizability evaluates the ability for a system state trajectory to avoid undergoing modifications, even if its associated system cost trajectory exhibits a resilient behavior.

One could go further in the consideration of state-based performance metrics. For instance, in some situations it may be useful to analyze the state of the system after a situation of recovery and compare it the initial state. Referring to (Maruyama 2016), a recovery could be a full restoration of the original system or something new. More precisely, our framework allows us to analyze whether the recovery is structural or functional (two recovery types among the three identified in (Maruyama 2016)), by measuring the distance between the "regime"[2] of states before the shock and those after recovery. This kind of metrics are interesting,

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[2] Used in the sense of system dynamics (Scheffer and Carpenter 2003) a "regime" is the set of states that define a domain of attraction. In a regime the system has the same essential structure, function, feedbacks and, therefore, identity (Walker et al. 2004). A regime shift occurs when a system crosses a threshold into an alternate domain of attraction.

however, they would be out of the scope of this chapter since they would be more arbitrary than the cost-based performance metrics introduced in this section.

4 Performance-Based Competency Metrics: Evaluating the Future

We have provided in the previous section a set of performance metrics that can be used to evaluate a specific scenario (i.e., a system state/cost trajectory) followed by a given urban system, in the past. A performance resilience metric gives an objective and quantitative measure of resilience given a particular sequence of past events. However, this kind of metric has little to indicate about the resilience of a city against *future* shocks. For instance, the city may have demonstrated performance resilience simply because there has been no significant shocks during the observation period. Or, the city has been simply lucky to recover after disturbances without any effort by the city administration. For example, after many former Nokia employees lost their job in Finland, a completely independent company happened to decide to open a large site in the city of Oulu, Finland, which would not be shown by the corresponding system cost trajectory.

Nevertheless, we show in this section that we can exploit these performance metrics to evaluate how resilient the system is expected to be in the future. The adaptation is not trivial, as a scenario (or system state trajectory) is not a prediction of the future. A scenario can be viewed as a possible, plausible future that might arise under certain circumstances (Maruyama 2016). But being provided with a set of scenarios that bracket the range of possible futures starting from a given system state is useful for predicting the behavior of the system, or at least to provide some "bounds" w.r.t. the performance metric of interest (resistance, recoverability, etc.)

One way to quantify resilience for the future events is to assume being given such a set of possible future scenarios with shocks and then simulate how the city will respond to these shocks. Let us start with a motivating example of possible future situations of the unemployment rate in the city of Oulu, Finland. To simulate a given scenario, we used a tool called "Agent-Based Modeling" (ABM) developed in the International Institute for Applied Systems Analysis (IIASA), Vienna, Austria. The ABM model has been applied for analysis of regional economics of several regions in Finland including Oulu. The project studying regional economies' capability of facing potential futures shocks is using the ABM model as a method for stress testing against uncertain futures. In the ABM model there are individuals or agents that are heterogeneous (people, companies, municipality), differing from each other in distinct ways. These agents can be represented as the variables in our abstract framework. Agents can act (thus the corresponding variable would change its value) in response to the current state in which they lie at a given time. Thus, they can modify the next system and system state through their

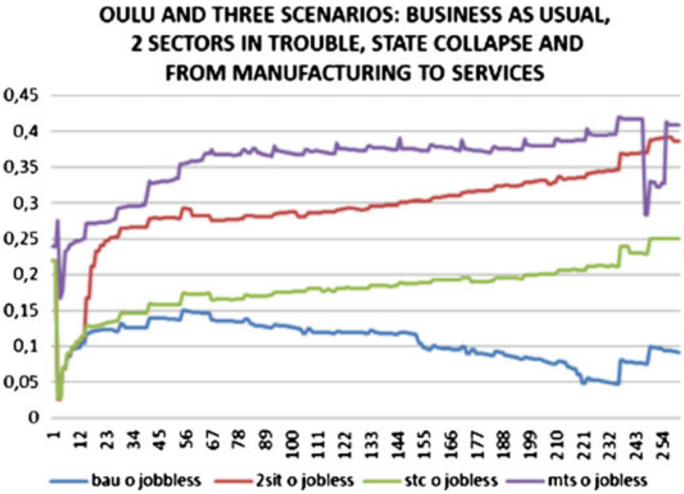

Fig. 5 The system cost trajectories representing the unemployment rate in the city of Oulu, Finland. Four scenarios were simulated independently starting from the same initial state

actions, which refers to the dynamic interactions between the components of an urban system mentioned in Sect. 2.

Figure 5 represents the unemployment rate in the city of Oulu, Finland, in four simulated distinct scenarios, starting from the same initial situation. Four kinds of scenarios were triggered at the initial state: (i) business as usual, (ii) the collapse of the state, (iii) the escape of some industries from the system, and (iv) the transition of the economic structure from manufacturing to service sectors.

It was run with several hundred variables, on a 20-year time horizon, and a time granularity of one week between two time steps.

Then, one way to define a performance-based competency metric, i.e., a metric that evaluate the potential performance of the system in the future, is to apply a given performance metric on each of these four curves, and then to aggregate them. However, it is impossible to enumerate by hand the set of all possible future scenarios that may occur in our system. For instance, in case of the city of Oulu, many other possible scenarios could be considered. For instance:

- In 20xx, Microsoft sees a major revenue decline and decides to shut down their data center in Oulu.
- In 20yy, the city of Pori, Finland, starts an aggressive subsidy and takes many jobs away from Oulu.
- In 20zz, Boarder conflicts in Eastern Europe makes the Finnish currency drop sharply.
- …

Especially, it is not only practically impossible to list all possible scenarios which may occur in the future, but different shocks/scenarios may interact with each

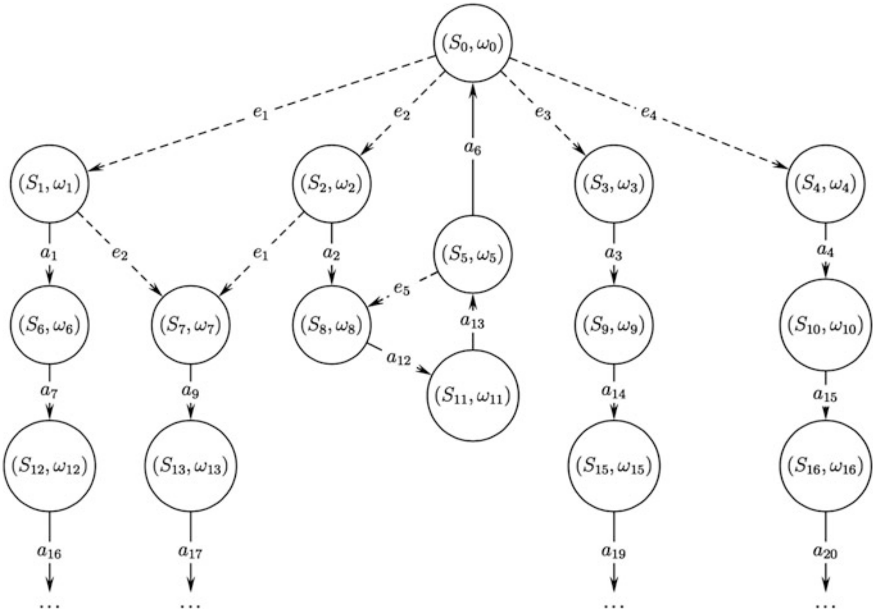

Fig. 6 The graphical representation of a dynamic system *DS*

other and affect a state trajectory and its outcome sequence in an unexpected way, leading to a combinatorial explosion of all possible future system state/cost trajectories with respect to these potential shocks: it can be the case that two given scenarios do not cause significant disturbances, whereas a combination of these same two scenarios will do.

We propose a model, called *dynamic system,* that intends to deal with this issue, assuming that we know which events may occur in some given state, and which are the local, "direct" effects of some (set of) event(s) in any system state. The following definition is a simplified version of the notion of dynamic system introduced in (Schwind et al. 2016).

Definition 9 (*Dynamic system*) A *dynamic system DS* is characterized by a tuple $\langle \mathcal{S}, E, A, f_e, f_a, (S_0, \omega_0) \rangle$, where:

- $\mathcal{S} = \{(S_0, \omega_0), (S_1, \omega_1), \ldots\}$ is a set of system states;
- $E = \{e_1, e_2, \ldots\}$ and $A = \{a_1, a_2, \ldots\}$ are two disjoint sets of symbols; E represents a set of potential events that are exogenous to the system, thus uncontrollable; A represents a set of decisions that can be taken by the actors of the system: the components of the system (i.e., the variables), or a system controller not represented within the variables (e.g., the city administrator); these decisions will have an effect on the next system state;
- f_e and f_a are partial functions associating a system state and an element from $\mathcal{S}$ with another system state from $\mathcal{S}$; f_a specifies how a given system state may be

modified in response to some decision; respectively, f_e specifies how a system state is modified in response to some exogenous event.

- (S_0, ω_0) is a specific system state from $\mathcal{S}$ representing the "initial" or "current" system state.

A dynamic system can be represented through a graph. The vertices of this graph represent the system states (S_i, ω_i) from $\mathcal{S}$. Each edge is labeled with an element from $E \cup A$, thus an edge represents a one-time-step transition between a system state to another system state, where the transition is triggered by either an exogenous event (if it is labeled by an element of E), either a decision from A. Therefore, an edge can be of two types depending on whether it is labeled by an element of E or A. Formally, there is an edge labeled by a symbol e_i (respectively, a_i) between two system states (S, ω) and (S', ω') if and only if there is an event $e_i \in E$ (respectively, a decision $a_i \in A$) such that $f_e((S, \omega), e_i) = (S', \omega')$ (respectively, $f_a((S, \omega), a_i) = (S', \omega')$).

The four scenarios depicted in Fig. 5 can be represented as symbols e_1, e_2, e_3, e_4 in the set E representing four exogenous events, i.e., not under the control of the actors of the system. Figure 6 depicts an example of dynamic system. The edges labeled by an exogenous event from E are represented by dashed lines, whereas the edges labeled by a decision from A are represented by full lines. From the initial system state, four types of events (or shocks) exogenous to the system may possibly occur. Then from the next time step (in one of the system states $(S_1, \omega_1), (S_2, \omega_2), (S_3, \omega_3), (S_4, \omega_4)$), some decision ($a_i$ in (S_i, ω_i)) can be undertaken by the actors of the system in order to

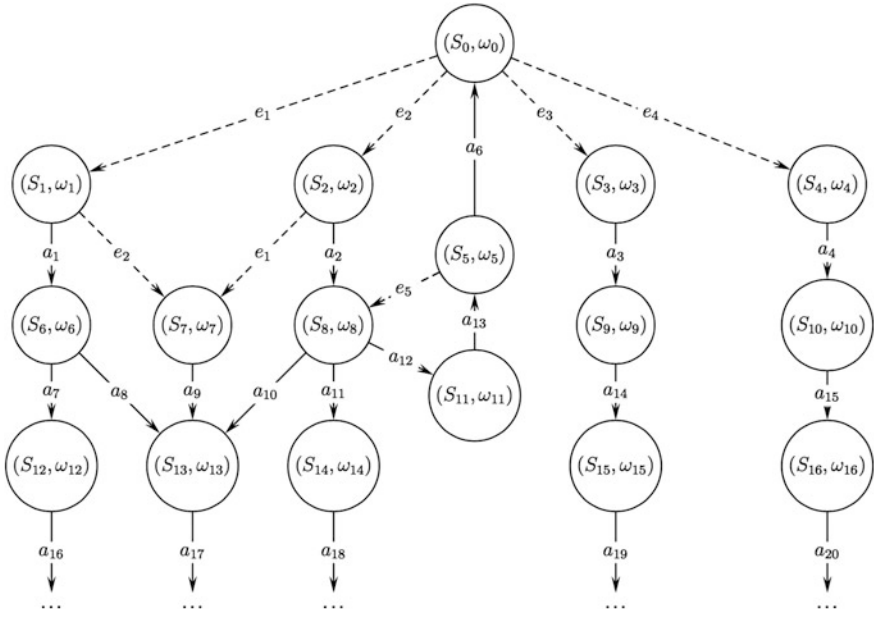

Fig. 7 An example of strategy for *DS*

adapt the system state appropriately depending on the situation. Please note that this model allows one to take into consideration a combination of several shocks: event e_2 is expected to occur in the system state (S_1, ω_1) after event e_1, and conversely, event e_1 is expected to occur after event e_2 in the system state (S_2, ω_2).

This formalization provides us with a compact description of the dynamics of the system. It allows one to represent in a simple way a number of system state trajectories which is exponential in the number of considered system states in $\mathcal{S}$. Our goal is to define a performance-based competency metric that evaluates the system in the state (S_0, ω_0) by considering all possible futures of the system, what we call here *realizable* system state trajectory. A realizable system state trajectory in a dynamic system *DS* is simply the set of all possible paths in the graph starting from (S_0, ω_0), where the path can go through both types of edges.

The role of controllable events (i.e., the decisions from *A*) is that the set of realizable system state trajectories in a dynamic system can be "controlled," i.e., reduced to a smaller set. An example of such control is called here a *strategy*:

Definition 9 (*Strategy*) A *strategy St* for a dynamic system $DS = \langle \mathcal{S}, E, A, f_e, f_a, (S_0, \omega_0) \rangle$ is an assignment of each system state (S_i, ω_i) from $\mathcal{S}$ to a specific decision $a_j \in A$ such that a_j is feasible in (S_i, ω_i), i.e., there exists a system state (S', ω') from $\mathcal{S}$ such that $f_a\big((S_i, \omega_i), a_j\big) = (S', \omega')$).

We denote *Strat*(*DS*) the set of all possible strategies for *DS*. Accordingly, a strategy for a dynamic system *DS* can be viewed as a subgraph of the graph representing *DS*. It simply consists in removing all edges that are labeled by a decision not assigned within the strategy, so that each vertex has only one outgoing edge labeled with a decision from *A*. An example of strategy is depicted in Fig. 7. The notion of realizable system state trajectory in a dynamic system can be easily extended to a realizable system state trajectory with respect to a strategy of this dynamic system: it is simply a path *SST* starting from the system state (S_0, ω_0) in the graph representing the strategy *St* under consideration. Similarly, a realizable system cost trajectory for a strategy is the system cost trajectory associated with a realizable system state trajectory of this strategy. The set of all realizable system cost trajectories given a strategy *St* is denoted by *Real*(*St*).

We are ready to introduce the notion of performance-based competency metric. Given one of the resilience-based performance metrics presented in Sect. 3, one can use it to predict the extent to which a given system will be resilient in the future, by taking advantage of our formalization of a dynamic system:

Definition 9 (*Performance-based competency metric*) Let *pm* be a performance metric associating with any system cost trajectory a number (e.g., resistance, recoverability, etc.) The corresponding performance-based competency metric *cm* associates with any dynamic system *DS* the following number:

$$cm(DS) = \min_{St \in Strat(DS)} \max_{SCT \in Real(St)} pm(SCT).$$

Thus, given a specific strategy for a dynamic system, one computes all realizable trajectories within this strategy and compute the highest number given by the performance metric applied to each one of these realizable trajectories; this corresponds to the worst-case scenario that is considered since exogenous events are not under control. Then, one assumes that a strategy is fully under control, and this is why we consider among all computed numbers the one returned by the best strategy, i.e., the minimal number. Though this definition focuses on those performance metrics applied to system cost trajectories, it can easily be adapted to metrics applied to state trajectories.

This new kind of metric is useful to validate existing competency metrics such as the ones proposed in (Ilmola 2016) for urban systems, by aligning these competency metrics with our performance-based ones.

5 Concluding Remarks

We provided a general computational framework that allows one to predict how resilient a given urban system will be in the future, by considering all of its possible expected scenarios. The model presented in this chapter is a simplified version of the one proposed in (Schwind et al. 2016). Noteworthy, this framework does not address the resilience of urban systems at all layers. For instance, improving the *perception* of an urban system with respect to its environment is an open, challenging issue, not addressed in this chapter. Indeed, in our model we must assume that the transition rules characterizing a dynamic system are "correct" and that the agents playing the role of selecting the best strategy to perform are fully rational, i.e., their intention is only to maximize the resilience of the system in the future. Additionally, partial observability is a more realistic parameter to take into account for further research.

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Urban Resilience Assessment: Multiple Dimensions, Criteria, and Indicators

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Abstract Over the past few years, there has been a proliferation of studies that focus on enhancing resilience of cities against a multitude of man-made and natural disasters. There has also been an increase in the number of frameworks and tools developed for assessing urban resilience. As climate change advances, resilience will become an even more significant topic in the science and policy circles that influence future urban development. Resilience indicators, in particular, will be essential for helping planners and decision makers understand where their communities stand in terms of resilience and develop strategies and action plans for creating more resilient cities. This chapter draws on the extensive literature on urban resilience assessment and provides a set of principles and indicators that can be used for developing an urban resilience assessment tool. Selected indicators cover multiple dimensions of urban resilience. They are divided into five main categories, namely, materials and environmental resources, society and well-being, economy, built environment and infrastructure, and governance and institutions. It is argued that resilience indicators should be used to help planners understand how best to enhance the abilities to plan/prepare for, absorb, recover, and adapt to disruptive events. The chapter concludes with proposing a matrix to relate resilience indicators with the main underlying characteristics of urban resilience that are namely, robustness, stability, flexibility, resourcefulness, redundancy, coordination capacity, diversity, foresight capacity, independence, connectivity, collaboration, agility, adaptability, self-organization, creativity, efficiency, and equity.

Keywords Urban resilience · Indicator · Criteria · Measurement · Assessment tool · Adaptation · Matrix approach

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1 Introduction

Cities as socio-ecological systems are facing the growing challenges posed by a broad array of stressors such as climate change, population growth, urbanization, natural and man-made disasters, and resource depletion. Recognition of the fact that not all these threats can be avoided has led to the diffusion of the concept of resilience (Renschler et al. 2010a). The increasing attention to resilience is reflected in the growing number of assessment tools and frameworks developed to measure resilience of urban communities and various activities and projects undertaken to operationalize assessment strategies. Resilience assessment tools are either focused on single sectors or take a multi-sectoral approach. Those falling under the latter category have a broad approach toward resilience and try to address different environmental, social, economic, and institutional aspects of urban resilience.

As resilience assessment is a relatively new and still growing field, there is a paucity of studies elaborating on different indicators that should be incorporated into urban resilience assessment tools. Indicators should be used to transform resilience into a measureable concept and provide a lens through which complexities of cities as socio-ecological systems can be better understood. These indicators can later be used to develop assessment tools that, among other things, can be used to determine baseline conditions, evaluate effectiveness of interventions, and measure progress in achieving community goals. These functions signify the important role of resilience indicators as building blocks of any assessment system. An appropriate assessment tool should feature characteristics such as multi-dimensionality and comprehensives, context-specificity, simplicity, replicability, updatability, and scalability (Cutter et al. 2010). This chapter tries to elaborate on the multi-dimensionality and comprehensiveness characteristic of urban resilience assessment indicators. For this purpose, the theoretical underpinnings of urban resilience and various resiliency principles are described in the next section. In Sect. 3 various indicators, which are drawn from an extensive review of literature on urban resilience assessment, are grouped under five major themes. Section 4 proposes development of resilience matrices that can better explain to which stages of the disaster risk management process each indicator relates. In addition, these matrices can provide information on resilience characteristics associated with each indicator. If developed, such matrices can help planners and decision makers make more informed decisions when prioritizing resource allocation for enhancing resilience of urban communities.

2 Underlying Characteristics of Urban Resilience

Resilience is a contested and normative concept. This could be explained by the fact that it has been adopted by various disciplines that have interpreted it differently according to their needs and priorities. It was originally developed in physics and psychology. Over the past four decades it has been introduced to other fields such as ecology, engineering, and disaster risk management. Although introduction of resilience notion to urban studies occurred comparatively late, it has been rapidly gaining ground since the turn of the century (Sharifi and Yamagata 2014, 2016). Engineering resilience, ecological resilience, and socio-ecological resilience are three major approaches that can be found in the literature. The first approach conceptualizes resilience of a system as its physical resistance and its capacity to rapidly return to an equilibrium state in case the thresholds are exceeded (Sharifi and Yamagata 2016). The ecological approach to resilience acknowledges that shocks are not always predictable. It advocates enhancing the tolerance of the system and recognizes that the system may need to shift to new equilibrium state(s) in order to be able to retain its pre-disaster functionality (Sharifi and Yamagata 2016). The adaptive approach to resilience is based on the conceptualization of (urban) system as a dynamic socio-ecological entity that continuously undergoes transformation. Accordingly the system may not necessarily return to an equilibrium state after the disruptive event. System integrity, self-organization capacity, and learning are three main components that contribute to adaptive resilience of a system and enable it to not only bounce back from disruptions, but also bounce forward to a more desired state (Sharifi and Yamagata 2016).

The fact that cities are socio-ecological systems, that feature dynamic interactions across time and space, implies that the adaptive approach to resilience can provide a more suitable theoretical basis for conceptualizing urban resilience (Sharifi and Yamagata 2016). This approach is reflected in The National Academies' definition of resilience as "the ability to prepare and plan for, absorb, recover from and more successfully adapt to adverse events" (TNA 2012, P14) which is adopted for the purpose of this chapter. To achieve, maintain, and strengthen these abilities, any urban system should entail the following characteristics: robustness, stability, flexibility, resourcefulness, coordination capacity, redundancy, diversity, foresight capacity, independence, connectivity and interdependence, collaboration capacity, agility, adaptability, self-organization, creativity and innovation, efficiency, and equity (Sharifi and Yamagata 2016). These criteria are distilled from the literature and only briefly explained here. These broad characteristics form the basis for development of a matrix approach that will be discussed later on in this chapter. A more detailed explanation can be found in Sharifi and Yamagata (2014, 2016). Robustness and stability refer to the system's strength against short-term and long-term shocks, respectively. Flexibility indicates the ability to rearrange structure and functions when facing disruptions. Resourcefulness relates to availability of resources needed for enhancing the above-mentioned four abilities of a resilience system. Coordination capacity is needed to make optimal use for resources at disposal of citizens, planners, and decision makers. Redundancy is important to ensure that, in case components of the system are out of function, they can be substituted by spare components that have been included for this purpose. Diversity refers to inclusion of different components in the system that can be used simultaneously and can make up for each other's dysfunction. Foresight capacity is directly related to the uncertainties innate in the urban system and preparatory work that needs to be done to address potential disruptions. Independence gives the system a certain degree of self-reliance that may be needed to survive adversities. Connectivity refers to interactions and relations that need to be established with other systems that exist in a broader scale. This is particularly important for shock absorption and timely recovery. Collaboration highlights the need for an inclusive and bottom-up approach towards urban management. Agility is related to how fast an urban system can restore its functionality following a disruptive event. Adaptability is specifically related to the capacity to learn and to integrate the notion of "living with risk" in planning and everyday life practices. Self-organization includes establishing and strengthening community-based and voluntary activities centered on social institutions and networks. Creativity is required to find innovative solutions for addressing emergent and unprecedented problems. Efficiency entails considering costs and benefits of actions and developing strategies for maximizing benefits given the limited resources available. Last, but not the least, equity is important to ensure fair distribution of benefits and impacts across different groups in the society (Sharifi and Yamagata 2014, 2016).

When thinking about these characteristics it should not be forgotten that synergies and tradeoffs exist between some of them. For instance improving redundancy may have adverse implications for efficiency of the system. Or, a balance point between independence and connectivity may differ from one context to another and, generally, finding balance between these two may turn out to be very challenging (Sharifi and Yamagata 2016). In order to develop a comprehensive and informative assessment system, it is needed to further discuss these synergies and tradeoffs and also clarify how each of the characteristics is related to planning/preparation, absorption, recovery, and adaptation as the four major abilities integrated into resilient urban systems. Addressing the former is beyond the scope of this chapter. The latter will be briefly discussed in Sect. 4 when proposing a matrix approach to facilitate a transparent and informed assessment framework that can identify whether resilience characteristics have been reflected in the urban system.

3 Multiple Dimensions of Urban Resilience

Resilience is a multi-faceted aspect and, ideally, all different dimensions of an urban system should be addressed in a resilience assessment framework. This section provides a list of various criteria that can be used for developing a resilience assessment system. Although context specificity issues should be taken into account when developing assessment frameworks, paying attention to all relevant criteria is needed for enhancing integrity and content validity of the assessment system. A detailed content analysis of 29 resilience assessment frameworks was conducted to distill major dimensions and criteria related to resilience of urban systems.

A complete list of these assessment frameworks can be found in Table 1. The extracted criteria have been divided into five categories (each referring to a specific

Table 1 The analyzed resilience assessment frameworks [adapted from the draft version of Sharifi (2016). Thirty six tools have been analyzed in the published version]

Tool	Year	Primary developer(s)	Ref
CRC	2015	Bushfire and Natural Hazards CRC	Morley and Parsons (2015)
DRI	2015	Earthquakes and Megacities Initiative (EMI)	Khazai et al. (2015)
NIST	2015	National Institute of Standards and Technology	NIST (2015b)
RELi	2015	American National Standards Institute (ANSI)	http://c3livingdesign.org/
TCRI	2015	Australia Netherlands Water Challenge	Perfrement and Lloyd (2015) http://theresilienceindex.weebly.com/
CoBRA	2014	UNDP | Drylands Development Centre	UNDP (2014)
CRF	2014	The Rockefeller Foundation, Arup	TRF (2014)
FCR	2014	International Federation of Red Cross and Red Crescent Societies (IFRC)	IFRC (2014)
Grosvenor	2014	Grosvenor, real estate investor (industry)	Barkham et al. (2014)
ICLEI	2014	ACCCRN, Rockefeller Foundation, ICLEI	Gawler and Tiwari (2014)
UNISDR	2014	IBM and AECOM	UNISDR (2014)
CRS	2013	Community and Regional Resilience Institute (CARRI); Meridian Institute; Oak Ridge National Laboratory	CARRI (2013), White et al. (2014)
CDRST	2012	Torrens Resilience Institute	Arbon et al. (2012)
BCRD	2011	RAND Corporation	Chandra et al. (2011)
CART	2011	TDC/University of Oklahoma	Pfefferbaum et al. (2011)
CERI	2010	AWM (Advantage West Midlands) Strategy Team	Team (2010)
CDRI	2010	Coastal Services Center and the National Oceanic and Atmospheric Administration	Peacock et al. (2010)
CRI	2010	MS-AL Sea Grant/National Oceanic and Atmospheric Administration (NOAA)	Sempier et al. (2010)
PEOPLES	2010	National Institute of Standards and Technology (NIST)	(Renschler et al. 2010b)
CRT	2009	Bay Localize project of the Earth Island Institute	Schwind (2009)
SPUR	2009	San Francisco Planning + Urban Research Association	Poland (2009)
CARRI	2008	Community and Regional Resilience Institute	Cutter et al. (2008)
Hyogo	2008	UN/OCHA and UN/ISDR	UN/ISDR (2008)
USAID	2008	USAID	Frankenberger et al. (2013)

(continued)

Table 1 (continued)

Tool	Year	Primary developer(s)	Ref
DFID	2007	Department for International Development and other Agencies	Twigg (2009)
USIOTWT	2007	U.S. Indian Ocean Tsunami Warning System Program	USIOTWSP (2007)
ResilUS	2006	US, Resilience Institute is part of Western Washington University's Huxley College of the Environment	Miles and Chang (2011)
THRIVE	2002	Prevention Institute	THRIVE (2004)
CRM	2000	Canadian Center for Community Renewal	Rowcliffe et al. (2000)

dimension) according to their similarities. These are materials and environmental resources, society and well-being, economy, built environment and infrastructure, and governance and institution. Each of these dimensions will be further discussed in the following sections.

3.1 Materials and Environmental Resources

Criteria mentioned in Table 2 are mainly related to quality, availability, accessibility, and conservation of resources. Through providing ecosystem services, environmental resources play a significant role in enhancing resilience of communities. Some resources such as wetlands are necessary for absorbing impacts of disasters such as flood and improving recovery process. Availability and accessibility to clean and affordable resources is essential for survival and prosperity of human communities. Therefore, appropriate measures in terms of resource protection and management should be taken for achieving resilient communities.

Table 2 Criteria related to materials and environmental resources [adapted from Sharifi (2016)]

Code	Criterion
M1	Ecosystem monitoring and protection
M2	Using local and native material and species
M3	Erosion protection
M4	Protection of wetlands and watersheds
M5	Availability and accessibility of resources (air, energy, water, food, soil, etc.)
M6	Reduction of environmental impacts (various types of pollution)
M7	Quality of resources
M8	Biodiversity and wildlife conservation
M9	Material and resource management (production, consumption, conservation, recycling, etc.)

3.2 Society and Well-Being

Criteria related to this dimension can be found in Table 3. This dimension has received considerable attention in the urban resilience literature and is believed to have a strong influence on the achievement of community self-sufficiency and resilience. This signifies the recognition of the fact that physical and engineering measures alone will not be sufficient for creating resilient communities.

Table 3 Criteria related to society and well-being [adapted from Sharifi (2016)]

Asset	Code	Criterion
Socio-economic characteristics	S1	Population composition
	S2	Language abilities
	S3	Car ownership, mobility
	S4	Land and home ownership
	S5	Diverse skills (to pool skills at the time of disaster)
Community bonds, social support, and social institutions	S6	Degree of connectedness across community groups
	S7	Volunteerism and civic engagement in social networks
	S8	Collective memories, knowledge, and experience
	S9	Trust, norms of reciprocity
	S10	Shared assets
	S11	Strong international civic organizations
	S12	Place attachment and sense of community and pride
	S13	Existence of conflict resolution mechanisms
	S14	Empowerment and engagement of vulnerable groups, social safety-net mechanisms
Safety and wellbeing	S15	Crime prevention and reduction
	S16	Security services such as police
	S17	Physical and psychological health
	S18	Preventive health measures
	S19	Responsive health measures
Equity and diversity	S20	Gender norms and equality
	S21	Ethnic equality and involvement of minorities
	S22	Diverse workforce in culturally diverse places
	S23	Decency, affordability, and fair access to basic needs, infrastructure and services
Local culture and traditions	S24	Past experience with disaster recovery; learning from the past
	S25	Cultural and historical preservation (identity); awareness of indigenous knowledge and traditions
	S26	Considering and respecting local culture and specificities in the process
	S27	Positive social, cultural, and behavioral norms

Criteria grouped under socio-economic characteristics can be used to measure community's status in terms of capacity and diversity of human resources. The second group of criteria are related to social capital. Both structural criteria such as existence of civic organizations and cognitive ones such as norms of reciprocity and trust should be taken into account (Sherrieb et al. 2010). Both trust between citizens and trust in official information sources are important. Place attachment and strong sense of community are indicators of commitment to the future of the community and enhance chances of building networks and establishing relationships with other community members (Chelleri et al. 2015). As mentioned earlier, however, the issue of tradeoffs should not be undermined. For instance although place attachment enhances recovery process, strong attachment to place may result in lack of willingness to move to safer places. This will exacerbate the suffering from losses and accordingly it can be said that place attachment can in some cases "impair, rather than facilitate" resilience (Norris et al. 2008). Safety and well-being criteria improve stability of communities. Safe and healthy communities are more capable of withstanding and responding to shocks (Chandra et al. 2011). Equity and diversity are important because impacts of disasters are often experienced unevenly in communities, with vulnerable groups suffering the most. Enhancing equity will be an effort to tackle this problem. Finally, respecting local cultures and traditions is an important element of the learning process which, among other things, can improve the adaptation aspects of resilience.

3.3 Economy

The economic dimension of urban resilience includes criteria related to the structure of the economy, its security and stability, and its dynamism (Table 4). Economic resilience of a community depends on the capacity and skillfulness of its working population to support the dependent population. Availability of reasonably-paid jobs can also be associated with resilience (Burton 2014).

Appropriate planning is needed to reduce potential business interruptions. For this purpose, availability of business mitigation plan will be essential. Such a plan should include financial instruments and insurance plans to ensure economic security of the community. Community members should be aware of the importance of community savings for enhancing redundancy and resourcefulness and also recognize the importance of collective resource ownership for maintaining access to resources for which severe competition exists (Schwind 2009).

Inward investment and economic diversity are indicators of community's ability to attract and retain businesses and avoid negative impacts of economic decline (NIST 2015a). Communities reliant on a single industry are expected to be more vulnerable to disruptions. Both large and small businesses are needed to ensure inward investment and business continuity.

There is evidence suggesting that, compared to large chain stores, local small businesses are more effective in keeping the money circulating within the local economy. This also provides other co-benefits such as additional tax revenues and

Table 4 Criteria related to economy [adapted from Sharifi (2016)]

Asset	Code	Criterion
Structure	E1	Employment rate and opportunities
	E2	Income (equality, multiple sources,…), poverty
	E3	Age structure of working population
	E4	Qualifications of working age population
	E5	Individuals with high and multiple skills; literacy (education)
	E6	Job density (housing-work proximity; extent of out commuting)
Security and stability	E7	Individual and community savings (stockpiles of supplies, monetary, etc.)
	E8	Collective ownership of community assets
	E9	Business mitigation, response and redevelopment plan
	E10	Insurance (domestic and non-domestic) and social welfare
	E11	Financial instruments (contingency funds, operating funds, capital funds etc.)
	E12	Stability of prices and incomes, property value
Dynamism	E13	Inward investment
	E14	Investment in green jobs and green economy (self-sufficiency, urban farming, etc.)
	E15	Integration with regional and global economy
	E16	Business cooperative or working relations (inter and intra)
	E17	Diverse economic structure and livelihood strategies
	E18	Openness to micro enterprises and micro-finance services, self-employment and dispersed ownership of assets; entrepreneurialism
	E19	Public-private partnership
	E20	Private investment
	E21	Locally owned businesses and employers
	E22	Balance of local labor market supply and demand

strong networks wherein local businesses collaborate and employ local workers (Schwind 2009). Large businesses should also exist since evidence suggests that they tend to be better capable of coping with change and recovering from disruptions (Sherrieb et al. 2010). Integration with the regional economy and collaboration agreements are also important for better absorption of shocks and for facilitating a timely recovery process. Also, public-private partnership is needed to adequately prepare individual businesses and also encourage them to engage in collective actions (CARRI 2013).

3.4 Built Environment and Infrastructure

Criteria related to the built environment and infrastructure are listed in Table 5.

Infrastructure has often a long lifetime. Therefore, careful attention is needed to avoid the risk of lock-in into vulnerable and inefficient urban infrastructure.

Redundancy facilitates substitutability of infrastructure in case some parts stop functioning. Robustness implies enhancing resistance of infrastructure and fortifying them against shocks. This may, however, result in complacency and a false perception of safety in the community. Multi-functionality of urban spaces and facilities improves diversity and efficiency characteristics which are essential for shock absorption and timely recovery. For instance, while parks and green spaces are mainly used for purposes such as recreation, thermal comfort provision, and air pollution mitigation, they can provide additional benefits in terms of evacuation and flood mitigation. Similarly, sport arenas and educational facilities can be used for temporary sheltering when needed.

In order to enhance infrastructure efficiency, regular monitoring is needed to inform planners and citizens of the need for actions such as retrofit, refurbishment, and technology update.

Of the various types of infrastructure, more emphasis has been put on communication and transportation systems. Good communication and information sharing are regarded as fundamental for enhancing resilience (Norris et al. 2008). The main role of transportation infrastructure systems is in survivor evacuation, and rescue and aid operations (Faturechi and Miller-Hooks 2015).

Criteria related to land use and urban design have major implications for resource security and management in cities. They can also provide resilience against threats such as urban flooding and extreme heat events. It must be kept in mind that the optimum state with respect to some of these criteria may vary depending on the context and type of disruption. For instance while higher levels of density increase energy resilience of cities, there is evidence showing that lower density is better for resilience against floods and hurricanes (Burton 2014).

3.5 Governance and Institutions

Governance is a cross-cutting dimension that has various inter-relationships with the other dimensions explained above. Governance and institutional criteria are shown in Table 6 and can be used to evaluate the efficiency and effectiveness of relationships between and within community organizations and entities.

Governance and institutional rules define how different activities are communicated and what mechanisms exist to make contingency and mitigation plans and ensure that they are implemented. Strong leadership enhances resilience by strengthening linkages between various elements of the system and empowering bonding and bridging social networks (Frankenberger et al. 2013).

Also, bottom up citizen involvement and transparent decision making is needed to enhance legitimacy of actions and make sure that they have a high level of buy in from the local community. Decentralized and bottom-up initiatives reduce hierarchical complexities. This provides a platform for civic collaborations, encourages community mobilization, and facilitates exchange of ideas and experiences leading to better preparation and response to disasters (Renschler et al. 2010b). A shared

Table 5 Criteria related to the built environment and infrastructure [adapted from Sharifi (2016)]

Asset	Code	Criterion
Robustness and redundancy of critical infrastructure	B1	Redundancy of critical infrastructure, facilities, and stocks
	B2	Robustness and fortification (of critical infrastructure, buildings, vital assets, ecosystems, etc.)
	B3	Spatial distribution of critical infrastructure (measure against cascading effects)
	B4	Location of critical infrastructure and facilities
	B5	Consolidation of critical utilities and collaboration between utility providers
	B6	Multi-functionality of spaces and facilities
	B7	Shelter and relief facilities and services
Infrastructure efficiency	B8	Regular monitoring, maintenance, and upgrade of critical infrastructure
	B9	Retrofit, renewal, and refurbishment of the built environment
	B10	Promotion of efficient infrastructure (technology update, metering, etc.)
ICT infrastructure	B11	Diverse and reliable information and communication technology (ICT) networks
	B12	Emergency communication infrastructure (before, during, after disaster)
Transportation infrastructure	B13	Capacity, safety, reliability, integratedness (connectivity), and efficiency of transportation
	B14	Inclusive and multi-modal transport networks and facilities
Land use and urban design	B15	Accessibility of basic needs and services throughout different stages (food, water, shelter, energy, health, education)
	B16	Site selection and avoiding risk areas and habitat areas (floodplain, flood prone; exposed coastal zone, greenfield)
	B17	Urban form (compact, dispersed, etc., SVF, aspect ratio)
	B18	Mixed-use development
	B19	Street type and connectivity
	B20	Density of development
	B21	Public spaces and communal facilities (for recreation, physical activity, etc.)
	B22	Green and blue infrastructure
	B23	Amount (percent) of impervious surfaces
	B24	Aesthetics, visual qualities, walkability
	B25	Landscape-based passive cooling
	B26	Passive lighting
	B27	Passive heating
	B28	Passive cooling

Table 6 Criteria related to governance and institutions [adapted from Sharifi (2016)]

Asset	Code	Criterion
Leadership and participation	G1	Strong leadership
	G2	Stability of leadership and political stability
	G3	Shared, updated, and integrated planning vision (long term)
	G4	Transparency, accountability, corruption etc.
	G5	Multi-stakeholder planning and decision making
	G6	Decentralized responsibilities and resources
Management of resources	G7	Efficient management of resources (funds, staff, etc.)
	G8	Skilled personnel and emergency practitioners
	G9	Population with emergency response and recovery skills (first aid, etc.)
	G10	Redundant capacity in terms of personnel
Contingency, emergency, and recovery planning	G11	Integration of risk reduction and resilience into development plans and policies
	G12	Existence of climate change and environmental policy and plans
	G13	Understanding risk patterns and trends
	G14	Continuous and updated risk assessment; scenario making for different kind of infrastructure and services (costs, losses, etc.)
	G15	Emergency planning and existence of emergency operation center that integrates different agencies and organizations
	G16	Availability and update of contingency plans (e.g. post-storm traffic management)
	G17	Availability of mitigation plan
	G18	Early warning, evacuation plan, and access to evacuation information
	G19	Inclusion of transient population (tourists, etc.) in emergency planning
	G20	Inclusion of disaster resilience and lessons learned in the recovery plan
	G21	Speed of recovery and restoration
	G22	Ongoing process of revising and monitoring plans and assessments
	G23	Standardized, updated, and integrated databases for action planning, monitoring and evaluation purposes

(continued)

Table 6 (continued)

Asset	Code	Criterion
Collaboration	G24	Cross-sector collaboration (alignment of aims) and partnership among organizations
	G25	MOUs and MOAs with neighboring communities and agencies within the broader region
	G26	Knowledge and information transfer and best practice sharing (inter and intra city)
R&D	G27	Innovation and technology update
	G28	Research (funds, facilities) on risks and academy-society collaborations
Regulations/enforcement	G29	Availability and enforcement of legislations (policing, crime, building code, environmental law, business law, etc.)
	G30	Management of informal settlements
Education and training	G31	Behavioral issues and demand management
	G32	Education (from elementary or secondary school), training, and communication
	G33	Drills and exercises
	G34	Education and training for all linguistic groups; and all groups generally
	G35	Capacity building and enhancing awareness; dissemination of data and assessment results
	G36	Incentives for encouraging mitigation and adaptation (including self-mobilization, self-organization, etc.)

vision should be established and guide all the planning activities in the community. This is argued to be essential for enhancing resilience (Norris et al. 2008).

Due to the complexity of various stressors such as climate change, it would be unlikely that communities be capable of addressing various problems independently. Therefore, collaboration, learning, and information exchange should be necessary components of any resilience planning efforts. Organizational connectivity and presence of interconnected networks is argued to be important for enhancing resilience (Norris et al. 2008). Establishing an integrated network of organizations and individuals can also be effective in increasing trust and knowledge exchange among the members and improve their willingness to partake in mitigation and preparation, and recovery plans (Chandra et al. 2011).

4 Proposed Resilience Matrices

In Sect. 2 resilience was defined as “the ability to prepare and plan for, absorb, recover from and more successfully adapt to adverse events” (TNA 2012, P14). It was also discussed that any resilient system should entail different characteristics, namely robustness, stability, flexibility, resourcefulness, coordination capacity, redundancy, diversity, foresight capacity, independence, connectivity and interdependence, collaboration capacity, agility, adaptability, self-organization, creativity and innovation, efficiency, and equity. The main purpose of any resilience assessment framework should be the achievement of better-informed decisions. Following the “Resilience Matrix” approach proposed by Fox-Lent et al. (2015), here, it is argued that creating matrices that specify to which ability each characteristic may relate could further aware planners and decision makers of the importance of each ability and characteristic. The proposed matrix would have a structure as shown in Table 7.

It would also be useful to develop other matrices based on abilities, characteristics, and criteria mentioned in this chapter. First, a set of matrices that identify to which ability each criterion mentioned in Tables 2, 3, 4, 5 and 6 is related. Second, a set of matrices that show which characteristics are influenced as a result of inclusion of the resilience criteria in the planning process. The relationships can be indicated by checking the respective cells in the matrix. However, as some of the relationships (or influences) may be characterized as either positive or negative, it is preferable to also display the direction of the relationships. As demonstrated in Fox-Lent et al. (2015), it can also be possible to use qualitative and/or quantitative indicators to calculate estimated scores for performance of each cell [e.g. score in terms of planning/preparation for “ecosystem monitoring and protection” (M1)]. This matrix approach can be used for prioritization of activities and resource allocation and lends itself to better planning towards urban resilience. The proposed structure for these matrices is shown in Tables 8 and 9. Here only the proposed matrices for criteria related to materials and environmental resources are shown. Similar matrices should be developed for criteria related to the other four dimensions of urban resilience.

Table 7 Proposed matrix to indicate the relationship between resilience abilities and characteristics

	Robustness	Stability	Flexibility	Resourcefulness	Coordination capacity	Redundancy	Diversity	Foresight capacity	Independence	Connectivity	Collaboration	Agility	Adaptability	Self-organization	Creativity	Efficiency	Equity
Plan/prepare for																	
Absorb																	
Recover																	
Adapt																	

Table 8 Proposed matrix structure to explore association between resilience abilities and urban resilience criteria

	M1	M2	M3	M4	M5	M6	M7	M8	M9
Plan/prepare for									
Absorb									
Recover									
Adapt									

Table 9 Proposed matrix structure to explore association between resilience characteristics and urban resilience criteria

	M1	M2	M3	M4	M5	M6	M7	M8	M9
Robustness									
Stability									
Flexibility									
Resourcefulness									
Coordination capacity									
Diversity									
Foresight capacity									
Independence									
Connectivity									
Collaboration									
Agility									
Adaptation									
Self-organization									
Creativity									
Efficiency									
Equity									

5 Conclusions

Resilience thinking is rapidly gaining ground in science and policy circles. Among other benefits, developing resilience assessment frameworks can be regarded as useful for reducing the complexities of urban resilience and clarifying the inter-relationships between various aspects of resilience. To this end, it is necessary to understand different characteristics of resilience systems and also identify various dimensions of resilience. In addition to identifying major resilience characteristics, this study introduced five major dimensions of urban resilience and an extensive list of criteria related to them. Subsequently a matrix approach was proposed that can be used to further explore the relationship between these criteria and characteristics. Also, it was suggested that additional work is needed to investigate how the four defining abilities of resilience are related to resilience characteristics and criteria. What discussed in this chapter provides a conceptual framework for developing resilience assessment tools. This should be regarded as a preliminary work that needs to be further developed in the future. The next step should be focused on methodologies to complete the matrices proposed in Sect. 4. The matrices could be completed by either using stakeholder/expert opinions, or by taking evidence-based approaches such as literature review and/or analysis of actual behavior of urban systems in response to disasters. Although some components of the matrices could be regarded as generic, some others may be context specific and the final output is likely to vary from one context to another. Resilience assessment will also require identifying specific indicators related to each criterion. This will also be a highly context-specific task. Due to context-specificity issues, it is likely that not all criteria mentioned in this chapter will be useful for application in all contexts.

Another essential task required for building comprehensive and informative resilience assessment tools would be explaining synergies and tradeoffs that may exist between the different components of the system. This would be necessary for achieving better-informed decision making.

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Part V
Future Challenges

Bringing People Back In: Crisis Planning and Response Embedded in Social Contexts

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Abstract Urban resilience requires sophisticated technical expertise to anticipate problems and develop transformative solutions, yet these efforts alone are often insufficient. We argue that resilience work needs to acknowledge the social contexts in which these plans are situated to better identify potential pitfalls and negotiate challenges "on the ground." Drawing on Zukin and DiMaggio's (Structures of capital: the social organization of the economy. Cambridge University, Cambridge, pp 1–36, 1990) embeddedness framework, we explain how cognitive, cultural, structural, and political contexts can complicate resilience work. First, we describe the framework and draw on extant literature to show how the four dimensions relate to urban resilience. Then, we use case studies from two environmental disasters to illustrate how emergency response efforts fell short because they did not adequately account for social context. Our aim is to orient urban resilience experts and practitioners to embeddedness thinking and offer suggestions for ways to better negotiate obstacles to success and opportunities for improvement inherent in the social environment.

1 Introduction

There is little chance that planners, experts, and engineers can create new and more resilient communities until we transform the way we plan for, prevent, and respond to disasters. Too often our efforts fall short (Kapucu et al. 2010). For example, there is near consensus in the literature that the devastation following Hurricanes Katrina and Rita in 2005 was amplified by the failure of agents and organizations to work effectively together and with the communities affected before, during, and after the hurricanes. A successful approach to urban disaster planning and response is one

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where networks between various actors channel information, resources, and skills so that needs are identified and met quickly and efficiently. But it is difficult, because these networks are often embedded in communities that are embedded in larger social systems, and different actors have different pieces of information with different solutions to different problems (Nowell and Steelman 2014). Putting this together for an effective preventive strategy or response is a formidable challenge for those who manage these efforts.

Our intuition is that most experts know that their efforts are embedded in social contexts, but tend to ignore this and neutralize 'human irrationality.' In this volume, Marumaya (Chapter "Taxonomy and General Strategies for Resilience") notes that there are multiple stakeholders involved in these processes and they play a key role; Legaspi (Chapter "Perception-Based Resilience: Accounting for Human Perception in Resilience Thinking With Its Theoretic and Model Bases") shows that people's perceptions are very important. But the social context is more than an array of utility maximizing atomistic stakeholders with different preferences. Serious consideration of the social context is warranted because people have values, beliefs, norms; have ties to one another and are members of groups; are subject to political authorities; and are far from omniscient. For urban planners, the shift toward inclusive governance models involving citizens, non-governmental partners, and local governing bodies makes the cultural values and priorities of stakeholders especially pertinent to planning efforts (Blomgren Bingham et al. 2005). Similarly, measures of urban resilience, as Ilmola (Chapter "Measurement of Urban Resilience") and Sharifi (Chapter "Urban Resilience Assessment: Multiple Dimensions, Criteria, and Indicators") acknowledge, should consider the social and cultural dimensions of coordination with and between government agencies and institutions. As Holden and colleagues (Chapter "From Resilience to Transformation Via a Regenerative Sustainability Development Path") suggest, resilience thinking should not only be framed in terms of ecological risk, but understood as part of an inherently political process. Likewise, we suggest that orienting planners, scientists, decision-makers, first responders, and community members to social realities offers a way to better anticipate problems and develop truly transformative plans and strategies.

Social science critiques of urban planning are not new. Jacobs (1961) offered an early, poignant critique of planning practices, such as zoning laws and suburban development. Writing in an era of urban decentralization, she argued urban decline was the unintended consequence of misguided planning strategies. She called for planning based on how cities and their dwellers actually operated, rather than on assumptions about human behavior. This chapter offers a similar critique and suggests that to formulate transformative responses to urban disasters resilience initiatives need to consider how people actually understand and navigate their urban environments.

More specifically, the paper sensitizes urban resiliency experts and professionals to the various cognitive, cultural, social structural, and political contexts in which they operate using an embeddedness framework. We outline the embeddedness framework and present examples of how planning efforts were stymied or emergency responses failed because those in charge did not adequately account for elements of social context. Our aim is not to articulate a grand theory, but rather to present examples of how dimensions of the social context relate to and complicate disaster planning and response. We conclude by offering suggestions for how planners, technocrats, relief workers, and first responders might better negotiate these contexts in which they operate.

2 The Embeddedness Approach

The idea of embeddedness was first articulated by Polyani (1944) as a critique of neoclassical economics, and later extended by Granovetter (1985) and Zukin and DiMaggio (1990). The original formulation argued that economic action cannot be understood without recognizing that behavior is contingent on cognitive, cultural, structural, and political contexts. The idea of embeddedness has now been applied to organizations (Dacin et al. 1999) and disaster planning (Iversen and Armstrong 2008). This chapter builds off these efforts.

The embeddedness framework is useful for situating urban resilience strategies because it goes beyond saying that ‘context matters’ and identifies four dimensions that shape action: cognitive, cultural, structural, and political embeddedness. We use Zukin and DiMaggio’s (1990) conceptualization proceeding from the micro to macro, but emphasize that they are intertwined. Cognitive embeddedness refers to the limited abilities of individuals (i.e., policy makers, city residents, first responders) to make fully rational decisions. Cultural embeddedness refers to the meanings, values, and norms which are operative in a particular domain. This applies not only to cultures within communities but within administrative structures as well. It has implications for policy implementation, civic engagement, and residents’ political mobilization for or against resiliency efforts. Structural embeddedness highlights the configuration of relations between individuals, among neighborhood organizations, and between neighborhood residents and organizations and actors outside the immediate community. It also refers to network ties within administrative structures such as between relief organizations or first responders. Finally, political embeddedness refers to the institutional context (e.g., laws, regulations) in which planning takes place as well as the realpolitik that surrounds planning decisions. It includes the logistical challenges of coordinating within and across agencies or groups with different institutional directives or political agendas. Political embeddedness also shines a light on power dynamics that can lead to unequal outcomes for urban residents.

It would be wrong to think of each dimension as independent of one another. Human cognition is embedded in local cultures which give cues to actors and provide heuristics, and perceptions, such as those of self-reliance described by Legaspi (Chapter “Perception-Based Resilience: Accounting for Human Perception in Resilience Thinking With Its Theoretic and Model Bases”), are the product of actors’ lived experiences. In turn, social structures often are necessary to formulate and enforce cultural norms (Coleman 1988), and all of social life is embedded in a political environment which sets limits, defines opportunities for action, and stipulates what is legitimate, while political enactment depends upon the consent of the governed and the receptivity of local cultures.

2.1 Cognitive Embeddedness

Cognitive embeddedness refers to the ways in which, "structured regularities of mental processes" limit rational decision-making for individuals and organizations (Zukin and DiMaggio 1990, p. 15). In other words, people use heuristics to perceive, interpret, and act upon information (Gigerenzer and Gaissmaier 2011). This means that people often ignore available information, consciously or unconsciously, to make expedient decisions, especially when faced with uncertainty. "Bounded rationality" also occurs in organizational decision-making such that organizational leaders tend to "satisfice" rather than optimize (March and Simon 1958).

Cognitive shortcuts can lead to deleterious outcomes when planners, technocrats, organization leaders, and first responders fail to recognize pertinent information or they rely on existing heuristics that are insufficient in new scenarios. Weick (1993, 2010) blames a breakdown in cognitive "sensemaking" as part of the reason crises escalated at the Mann Gulch wildfire, where 13 firefighters died, and the Bhopal tragedy where hundreds of thousands of people were exposed to toxic gas. In both cases individuals ignored pertinent information that should have led them to recognize the threats in advance. During Hurricane Katrina, leaders made quick decisions using an existing repertoire of crisis management which was insufficient for addressing the large-scale threat (Comfort 2007). The catastrophic failures of the disaster response were due to the fact that there was no shared "common operating picture" for a coordinated, community response between heterogeneous agencies and organizations even though the threat was recognized in a timely manner (Comfort 2007, p. 193). Medonça et al. (2014) studied reports made by first responders to the Oklahoma City bombing and 9/11 attacks. When aspects of the scenario mirrored familiar aspects of their role (e.g., setting up a perimeter) responders used heuristics to make fast decisions. However, they had to improvise their response with more intentional cognitive processing when the situation called for non-routine tasks. Part of the challenge of transformative urban resilience planning is to develop workable collective, cognitive frameworks a priori that decision makers and first responders can draw upon when recognizing and responding to crisis.

The implication of cognitive embeddedness for urban resiliency planners is that agent-based models are limited to the extent that assumptions about the ways individuals and/or organizations act map on to reality. For example, research on the cognition of space shows that when faced with uncertainty, drivers use heuristic shortcuts to take routes that are "good enough," even though the paths they choose are not the most efficient (Manley et al. 2015). Recognizing this would mean better planning for emergency evacuation insofar as it captures the ways people actually make sense of and move through unexpected traffic situations. Cognitive embeddedness situates decision making within the limits of human rationality.

2.2 Cultural Embeddedness

Cultural embeddedness refers to shared collective understandings, such as beliefs, norms, ideologies, taken for granted assumptions, and formal rule systems that shape goals and action (Zukin and DiMaggio 1990, p. 17). A considerable amount of research has focused on cultural conflict when the meanings, values, and norms embedded in planning documents, rules, and operational procedures run contrary to neighborhood or occupational cultures (e.g., epistemic communities made up of knowledge based experts or professionals). A famous example is Acheson's (1988) study of lobster fishermen in the U.S. Northeast. Faced with government mandates to conserve, local fishermen resisted, believing (correctly) that the informal arrangements they had worked out to prevent over-fishing were more effective. Well-intended disaster relief efforts often fall short because they are not aligned with the local understandings of what is needed. For instance, in the wake of the tornado in Joplin, Missouri, local private and voluntary organizations managed the influx of volunteers and relief aid to address immediate needs first (Smith and Sutter 2013). "Spontaneous volunteers" have been known to travel great distances, often without sufficient knowledge of local conditions and customs that can become a challenge for onsite organizations and agencies to manage (Merchant et al. 2010; Sauer et al. 2014). The importance of local cultures has also been well-documented as they impact local residents after crisis (Erikson 1976). For example, studies of post-disaster resettlement find that residents experience enhanced trauma due to place-attachment (Oliver-Smith 1996) and mental health risks following disaster (Norris et al. 2002).

There has been considerable progress in trying to understand more deeply the nature of local cultures. In terms of resilience planning, Colten et al. (2008) emphasize the importance of the role of inherent resilience which they define as, "practices that natural resource-dependent residents deploy to cope with disruptions and that are retained in the collective memory" (p. 4). This idea of an informal resilience that is developed and retained within social spaces can be expanded to include a broader set of cultural practices more closely resembling Zukin and DiMaggio's (1990) concept of cultural embeddedness. However, these informal cultural resources often are at odds with formal disaster preparedness planning, especially when a top-down approach is utilized. In these cases, conflict is likely to occur between resident behaviors and state expectations, as was seen in the aftermath of Hurricane Katrina (Elliott and Pais 2006).

The framing of issues can also lead to or avert conflict (Snow et al. 1986; Benford and Snow 2000). Building on our discussion of cognition, a frame is a cultural artifact that people use to make sense of their situation. The focus is on "stories," "facts," and "accounts" that define the problem as something which citizen participation can or cannot solve and articulate justifications for collective action or inaction. In a study of 20 communities that faced large energy infrastructure projects, Wright and Boudet (2012) found that communities suffering economic hardship or with past energy project experience were more likely to interpret the projects favorably and less likely to mobilize even though they faced the same risks as the communities that mobilized. This phenomenon was also evident in the aftermath of the Deepwater Horizon oil spill, where a massive compensation program was put into place without much consideration of local cultural norms, leading to misperceptions of appropriate claims and behaviors as well as community corrosion and infighting among neighbors (Mayer et al. 2015).

Research has shown that these frames do not emerge spontaneously. Vasi et al. (2015) suggest there need to be "discursive opportunities" that focus people's attention on a particular problem. In their study of citizen mobilization and local legislation limiting hydraulic fracturing (or fracking) in the Marcellus Shale states, they cite the importance of broadcast technologies to disseminate information about a threat or crisis. For instance, local screening of the documentary Gasland on the environmental effects of fracking was an important factor in prompting citizen response. Social networking (Twitter, Facebook, etc.) also allowed people to share experiences and coordinate responses. These discursive opportunities stimulated conversations where people identified common frames which mobilized the citizens to pass municipal bans on fracking. Thus, in order for planners to capitalize on citizen mobilization rather than incite it against their proposed project or initiative, it would be prudent to be aware of different ways their actions can be interpreted by community stakeholders.

Some communities have a more developed sense of collective empowerment than others. Collective efficacy, coined by Sampson (2012, p. 152), refers to "social cohesion and shared expectations for control" and reflects a sense of collective empowerment at the community-level. It has been linked to improved community outcomes such as crime control, health, civic participation, and children's well-being (Browning and Cagney 2003; Sampson 2012; Sampson et al. 1997, 1999). Thus, from a planning perspective, identifying a community's culture of collective efficacy could be an important strategy for improving urban resilience. It can also tell planners where they may encounter greater resistance.

The natural resource management literature gives us examples where local cultural practices or understandings allowed people to organize and solve problems cooperatively, rather than using a one-size-fits-all approach. For example, agricultural management in central Mali was stymied when on-the-ground definitions of environmental risks differed with government policies, leading to delay and inaction (Crane 2010). Integrating local cultural understandings into resource management planning has facilitated greater agreement and hence more successful management. Studying resource scarcity in the Canadian forest industry, Lyon and Parkins (2013) argue the local cultural system of values is a potential vehicle for collective action to protect the environment. Moving beyond top-down approaches and incorporating participatory-based models offers potential to incorporate cultural values and norms into planning strategies that simultaneously empower local actors and accomplish the larger goals of urban resilience (see also Adger 2000; Berkes and Ross 2013).

2.3 Structural Embeddedness

Structural (or relational) embeddedness refers to patterns of ongoing interpersonal and inter-organizational relations (Zukin and DiMaggio 1990, p. 18) and builds on work by Granovetter (1985) and Coleman (1988). These ties can be cooperative, or competitive, strong (bonding) or weak (bridging). In fact, the latter are often seen as essential for community action (Granovetter 1973; Hays 2014; Putnam 1993). Trust, loyalty, solidarity, and a sense of shared identity are all constructed from networks of social relations. These ties bind a community together and, at the same time, are sources of friction at a more societal level, e.g., ethno-religious conflicts. Sampson (2012) sees these networks, along with collective efficacy, as crucial in explaining civic participation and political mobilization. Social networks also exist within occupational communities and impact how well planners, technocrats, first responders, and relief workers are able to do their jobs.

The disaster research literature has long recognized that communities come together after catastrophic events (Quarantelli and Dynes 1977) and that local networks are important in recovery (Aldrich 2012). For example, the majority of individuals rescued from collapsed buildings in the 1995 Kobe earthquake were helped by neighbors—not first responders (Aldrich 2012). Likewise, in the aftermath of the 2011 earthquake and tsunami, affected residents regularly claimed to be aided more by neighbors and friends than official programs (Aldrich and Meyer 2014). In the 1995 Chicago heat wave, Klinenberg (2002) found two distinct mortality rates in comparing neighborhoods with high levels of bridging capital, where neighbors helped neighbors and lives were saved, and those with low levels of bridging capital, where many elderly residents died alone in their apartments.

Relational embeddedness also affects how planners, technocrats, first responders, and relief workers do their jobs. Pre-existing interpersonal and inter-organizational networks are especially important, because an effective response is the result of voluntary coordination between different organizations to create a network, rather than the result of bureaucratic controls and planning. Nowell and Steelman (2014) studied the leaders of various organizational units that responded to three different wildfires. They found that communication was more frequent and effective when fire personnel worked with colleagues with whom they had prior familiarity than when they worked with colleagues they did not know. In contexts which are fast-moving, complicated, and critical, stronger ties may be superior to weaker ties and relational embeddedness is superior to institutional embeddedness (e.g., two people occupy the same functional role or work for the same type of agency). In other words, it is not the time or circumstance to be interacting with strangers.

Neighborhoods also include community based organizations (CBOs) as well as individuals and households. Janowitz's (1967, 1969) work on the community press and elementary schools and Alinsky's (1971) accounts of community organization activity in Chicago highlighted the importance of these kinds of organizations for community building. CBOs (e.g., choral groups, bowling leagues, service clubs) can build bridges across various factions or groups within the community by 'mixing up' people with different backgrounds and values (Putnam 2000; Hays 2014). This 'mixing up' will supposedly foster the trust, norms of reciprocity, and sense of collective purpose needed to bring together diverse communities to work on common problems. CBOs can also link residents with economic and political actors outside the community to create a channel through which resources and information can flow (Marwell 2007; Small 2009). Finally, CBOs themselves can work together to solve community problems thus increasing the potential to collaborate when a crisis arises.

Organizations are clearly important in local political mobilization. Vasi et al. (2015) found a positive effect of nonprofit organizational densities on anti-fracking municipal bans in the Marcellus Shale states. Nonprofits can aggregate local demand and give voice to different constituents. Creating norms of reciprocity and trust between organizations can also lead to greater mobilization of resources for populations that can be traditionally difficult to reach, as was the case in the aftermath of the 2014 Indian tsunami, where a coalition of international aid organizations worked together to facilitate the delivery of resources to hundreds of small villages and islands which were otherwise politically isolated (Aldrich 2012).

Clearly both interpersonal networks and the presence of CBOs are important in explaining a community's resilience. Aldrich's (2012) study of the 1995 Kobe earthquake linked qualitative accounts with a panel analysis of recovery over time. Aldrich concluded that social capital was a much more significant predictor of recovery than economic capital. Affected residents overcame common collective action problems by working together, forming their own CBOs (ward associations) to clean up debris, prevent looting, and find and distribute aid. Though these CBOs linked with formal authorities on occasion, the local community mobilization efforts led to swift recovery in neighborhoods where trust and social capital was high.

2.4 Political Embeddedness

Political embeddedness refers to the context of the state, its laws, and the struggles for power between stakeholders (Zukin and DiMaggio 1990, p. 20). Resilience strategies are often commissioned (or at least supervised and directed) by government entities, and increasingly solicit involvement from non-governmental and community-based actors. These activities are shaped, explicitly and implicitly, by the political milieu of a given jurisdiction as the public increasingly expects the government to lead planning and response efforts (Kapucu and Van Wart 2006).

One complication is the intentional use of what Clarke (1999) termed "fantasy documents." These documents are created to fulfill government regulations, but are largely symbolic and have little utility to address large scale crises like oil spills or nuclear disaster. Clarke suggests fantasy documents can sometimes create more problems on the ground because they fail to understand the cultural and structural embeddedness of crisis response.

Collaborative resilience planning models have become increasingly popular to reduce complications. Proponents argue engaging government, non-governmental agencies, and the local community can expedite response time to disasters, tailor planning efforts to local needs, and get buy-in from the community (Blomgren Bingham et al. 2005; Lebel et al. 2006). One U.S. strategy is the creation of interstate partnerships, such as the Emergency Management Assistance Compact, that allow states to assist one another before federal aid can be disbursed (Kapucu et al. 2009). Community participatory governance models, particularly for climate change planning have become increasingly commonplace (Booher and Innes 2010; van Kerkhoff and Lebel 2006; Moser and Ekstrom 2011). For example, Gidley et al. (2009) described how community members brainstormed potential planning solutions successfully in climate-vulnerable areas of Australia. Lebel et al. (2006) studied how coastal communities of Trinidad and Tobago engaged local stakeholders in disaster planning and worked collaboratively with the government regulators to protect marine areas vital to the fishing economy.

For urban resilience planners and responders, one implication of the shift toward collaborative approaches means there are more parties involved. Coordinating planning and response between multiple governmental and non-governmental agencies at different levels of jurisdiction, even across national borders, can be exceedingly complex (Kapucu and Van Wart 2006; Kapucu et al. 2009, 2010). This is evidenced by a large body of research in public administration that focuses on corralling different bureaucratic institutions to respond swiftly and efficiently to man-made or natural disasters (Comfort and Kapucu 2006; Kapucu 2012).

Moreover, planning and participation dynamics are not power neutral. "We not only need to ask: The resilience of what, to what? We must also ask: For whom?" (Lebel et al. 2006, p. 18). Critics point to the "illusion of inclusion" when community stakeholders are impotent; contributing in name only (Few et al. 2007). Even when empowered citizen action groups demand participation in planning and implementation, this does not mean that this applies to or will benefit all citizens equally. Scholars of the political economy of place have long noted the unequal distribution of resources across cities and the role of governments in perpetuating and reproducing those inequalities (Harvey 1973; Logan and Molotch 1987). This line of thinking can be readily extended to our discussion of urban resilience. Resilience planning and crisis relief is subject to a multitude of considerations at numerous levels of government (Cohen and Werker 2008). These various actors may not be well-coordinated or may be acting out of self-interest rather than in the best interests of the public. Indeed, such scholars note that, "disasters tend to be more severe in poorer countries that are poorly run" (Cohen and Werker 2008, p. 796). Furthermore, studies demonstrate that presidential disaster declarations in the United States (which disburse federal relief aid) increase in election years and in locations which are more politically expedient (Sylves and Búzás 2007). From planning and prevention to disaster relief efforts, government at its various levels can shape outcomes and the unequal distribution of key resources.

Finally, a prime example of the politicization of urban resiliency is the catastrophic failure of government relief efforts after Hurricane Katrina. Prevention strategies leading up to the event left poor and minority communities more vulnerable to Katrina and its effects, while the relief that followed the hurricane favored the wealthy and well-connected (Kestin et al. 2005; Cohen and Werker 2008). Studies fault various aspects of government for this failure, such as the layered bureaucracy, the over cautiousness in planning and implementation of relief, and political manipulation. Most experts agree that the private sector was more efficient and coordinated in their relief efforts and that government efforts resulted in various negative externalities and inequalities due to political considerations (Depoorter 2006; Shughart 2006; Sobel and Leeson 2006). In reviewing the lessons from Katrina, urban planners have called for greater citizen participation, an understanding of urban planning as a guide rather than a rulebook, increased collaboration across a wider range of stakeholders, and for better attention to policies which may disadvantage some for the alleged betterment of the city as a whole (Nelson et al. 2007).

3 Case Studies

With the embeddedness framework established, we now describe two case studies to illustrate how the various dimensions of embeddedness interact with each other in complicated and often unpredictable ways. In 1972, an area in the coalfields of West Virginia known as Buffalo Creek experienced a deadly disaster when a dam built in the 1940s by the coal mining company to store sludge and other mine waste collapsed after a period of heavy rain. The dam's collapse led to a flood of water and debris that killed 123 people and left 4,000 homeless. Following the flood, sixteen small towns were completely relocated. Former neighbors found themselves moved far apart, resettled into new 'communities' and expected to return to their normal lives. However, later sociological investigation found that the trauma of destroying victims' sense of community was much more psychologically devastating than the experience of the flood itself (Erikson 1976). The relocation effort operated according to efficiency, not community sensitivity, which led to greater collective trauma and community destabilization than the event itself.

A similar pattern follows a more contemporary disaster; the Deepwater Horizon oil spill, the result of mismanagement and risky oil exploration at some of the most extreme depths human engineering has attempted. The escaping oil spread to over 10,000 km of ocean and hundreds of kilometers of shore. The recovery and cleanup efforts were among the largest conducted and the subsequent economic claims program, at over $10 billion, the largest in history. Despite the relatively quick disbursement of billions of dollars of claims, dissatisfaction and frustration with the claims program ran rampant across the Gulf of Mexico. How could swift compensation for lost wages and property be perceived as a failure on the part of the government and responsible corporate party, BP? Within the Gulf of Mexico commercial fishing industry, a hierarchical economic system ranging from wealthy dealers to working class fishers had existed for decades—informally in some places with cash being paid in place of taxable income. Likewise, the other major economic driver, tourism, was divided along class lines separating service workers from hotel and restaurant owners. The implementation of the compensation program was hastily crafted, with unclear rules and procedures. Residents would regularly report receiving less than their neighbors for identical claims (Mayer et al. 2015). Fisherfolk used to receiving small paychecks were suddenly overwhelmed with significantly larger claims checks, leading to misspending and a lack of investment back into damaged communities. Business owners complained about delayed payments while their staff received smaller, but more regular claims checks leading to high turnover and unfilled jobs. With competition, misunderstandings, and frustration being produced not by the spill, but by the recovery process, many Gulf of Mexico residents blamed the government for the suffering instead of the corporation responsible for the spill in the first place. Lacking a familiarity with local community embeddedness, the most well-intended relief efforts such as the oil spill compensation program can lead to secondary traumas (Mayer et al. 2015).

4 Conclusion

Together, the embeddedness framework and illustrations from disaster relief efforts gone awry provide a useful toolkit that can be incorporated into urban resilience planning and implementation. The problems are complex and require sophisticated responses that tap into cutting-edge advances in technology and engineering. At the same time, the social sciences bring people, groups, and their institutions back into the discussion. What can the professionals responsible for planning for disasters and calamities and response do to better cope with the various contexts in which their activities are embedded and construct truly transformative strategies?

First, planning teams need to identify the key stakeholders in their activities. This will vary by project and community, but knowing who is being asked to contribute resources, who is being asked to change their behavior or absorb costs, and who will be affected indirectly is an important first step. They are the actors one needs to know something about, because they are potentially important sources of new ideas as well as resistance.

Second, planning and response teams need to think more sociologically about the various stakeholders and it is here where the embeddedness framework is especially useful. Instead of just knowing which residents are affected, it is necessary to be aware of their culture, the extent to which they are united, divided, or just indifferent towards one another, their local organizations, and their history, interests, and political connections. Instead of just knowing which agencies or foundations are funding the project, it is necessary to know their priorities and missions, their current inter-organizational ties to other funders/foundations, planning efforts in other cities, and the rules and regulations that they expect your team to abide by. However, planning teams need to remember that cognition, culture, social structure, and political context are themselves intertwined and feedback upon each other. Thus, putting the puzzle together is not easy given that there are multiple stakeholders and multiple dimensions to each stakeholder's condition.

Finally, planning teams need to anticipate both the benefits (good will, trust, respect) and costs (demonstrations, harassment, lawsuits) which they will realize if they respect or transgress stakeholders' norms or values. This kind of risk analysis is very difficult because it is often hard to know such things as funders' culture, residents' social structure, and the political context in advance let alone calculate outcomes. Yet, we believe that it is better that planning teams struggle with these unknowns than to plow forward indifferent to context. Thus plans need to be flexible and adaptive, and the most cost effective or technically innovative plan is not necessarily the best plan in the long run.

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From Resilience to Transformation Via a Regenerative Sustainability Development Path

Meg Holden, John Robinson and Stephen Sheppard

Abstract Urban resilience frameworks and strategies currently taken up in cities around the globe fall short of adequately preparing urban communities for the scale of change that many will face in coming decades. For cities aiming to address the impacts of climate change in a proactive sense as well as post-disaster, urban resilience presents itself as a useful frame, grounded in both ecological systems theory and psychological theory. This chapter tackles the question of where the notion of resilience helps, and where it holds cities back, in terms of urban planning and policy. Resilience in the urban planning and policy context may hold cities back because it lacks normative value in social and political spheres. That is, while concepts such as social justice and sustainable development suggest a normative direction for planning toward the improvement of our communities, resilience thinking does not imply any value-based criteria by which communities might determine how best to "bounce back" or "bounce forward." Additional tools for urban resilience planning are needed, and we suggest and elaborate here upon two: the development path and regenerative sustainability. The notion of the development path originated within the IPCC process and draws upon futures studies, scenario planning and backcasting, in order to understand the social and political change and decision making implications of responding to climate change. The second concept we offer, regenerative sustainability, can be considered as the work of increasing the capacity of the current generation to give back more than we receive. The contribution of these two concepts to the value of urban resilience

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thinking in political contexts is explained through a discussion of five possible scenarios of urban transformation, which vary in terms of the social and political intentions at work in the strategies needed to build resilience.

1 Resilience and Its Skeptics

It has become commonplace in recent years to tackle the question of urban climate policy, disaster response and emergency management in terms of a framework of resilience (Bonanno 2004; Godschalk 2003; Hill et al. 2012). This volume is full of such frameworks and attempts to improve their definition and use value. Amidst growing interest in resilience as a theme for urban planning and development that responds to the threats of climate change, some standard urban policy protocols and responses have emerged. In the context of British Columbian communities that we are studying as part of the Meeting the Climate Change Challenge project, some typical answers to the question "what is your municipality doing to address climate change resiliency?" include: signing the BC Climate Action Charter, conducting an energy and emissions inventory, mapping sea level rise scenarios and designing sea dikes, and devising flood management strategies (Dale et al. 2013). In terms of the perspective presented in this volume, it is not difficult to see this as a limited set of municipal climate change strategies. This is not to dismiss the utility of efforts to understand the sources of a community's GHG emissions, reinforce seawalls and dikes, and improve natural as well as engineered flood and stormwater management systems. These efforts will surely save lives into the future, and prevent damage to property and shared values in storms to come. In terms of Sharifi's proposed matrix in this volume and the frameworks compared by Ilmola, such efforts will contribute to certain resilience abilities of communities.

However, what most communities are doing now in order to accommodate increased resilience in local policy structures stops short of what communities need in order to prepare for an uncertain future, including being prepared to initiate change intentionally and purposefully, as well as being prepared to change urban development models and assumptions to respond effectively to changing social and political circumstances. Legaspi's contribution related to the variety of perspectives of what constitutes risk and effective response, as well as Brudermann's work on the range of behaviours apparent in community energy sharing, and Murayama's case of collaborative planning initiatives in Nagoya City all point to the broader field of practice in urban resilience, and the need for broader-based research and action. Whereas Thompson-Dyck et al. reflect upon the sociological determinants of how social context matters to resilience in diverse ways, in this concluding chapter, we revisit the meaning of urban resilience from a political and planning studies perspective. From this perspective, the pursuit of even multidimensional urban resilience leaves a considerable amount to be desired and has given rise to a critical backlash from some theorists and urban activists. In pursuing this line of critique, we offer a response to this backlash that has been articulated against resilience by adding two new concepts to urban resilience planning and action, essential for socially-valuable outcomes of our efforts: development path thinking and the pursuit of regenerative sustainability.

Planning for community resilience is typically treated as an exercise in articulating the desired outcome of community planning with an emphasis on aversion of particular specified disasters. In his contribution to this volume, Maruyama offers a helpful classification scheme of different kinds of disasters, which depending on frequency and severity may or may not be worth planning for. In this way, the concept of resilience offers "a framing device for thinking about socioecological and urban systems … a new vocabulary for thinking about place-making based on evolutionary change rather than a linear pathway towards a single end-state" (Scott 2013: 430). Resilience thinking, applied to cities, permits and gives structure to planning for a diverse range of possible futures, such that these options can be considered more clearly by the community in order to determine the kinds of future social, economic, and built configurations that are most desirable, and perhaps also the best means to move toward a more desirable future in spite of shocks and surprises. Thus, the work of community resilience planning may begin with an assessment of the risk of certain historical disasters or disturbances, followed by planning for the best techniques and resources needed to respond effectively to each of these. The typical social component of such community resilience planning, when considered at all, is to assign roles and methods for building capacity within the community or social group to rise to the challenge of responding to disaster and instituting social changes to prevent disaster (Norris et al. 2008). Essentially, this is a social response driven by defensiveness and imposing limits on human activity. This very mix of ecological demands, on the one hand, and necessary social responses, on the other, as a basis for effective community resilience planning, has driven a backlash amongst social justice-oriented planners against resilience as a framing concept and structure for community planning. Such planners call for either revising the concept to be more socially-engaged, or pairing the concept with one that better represents the different demands of social justice.

A 2012 "interface" debate about this tension within the topic of community resilience planning in the journal *Planning Theory and Practice* (Davoudi et al. 2012) became the journal's most downloaded paper, with a blockbusting 15,428 downloads by the end of August 2015. This debate introduced an essential addition to the socioecological concept of resilience to gauge the concept's adequacy in the context of planning for social ends. Namely, the conclusion of the debate was that the resilience dynamic should not be limited to rising to a challenge to "bounce back" from a disaster event to a pre-disaster state, an approach to resilience determined by conformity with a previously known outcome of stasis, but to actually "bounce forward" toward a state, perhaps unachieved historically, which may only become perceptible or feasible following the disruption of a disaster. The typical analogy to help understand this possibility is ecological: before disaster strikes a mature ecosystem, change to the structure and components of this ecosystem may seem impossible, because it has existed for a long time, because the most prominent organisms are old and large, and because the relationships between key pieces of the system are so ingrained. However, once disaster strikes, and many or all of these large organisms, long-term relationships and intricate structures are broken, opening up space for new pioneers and structures and opportunistic relationships, the likes of which could scarcely have been imagined previously. Whereas in ecology, this process may tend toward re-establishment of a similar structure as existed before, this is not necessarily the case, particularly if soil, energy, water, or climate conditions have changed along with the disaster.

Likewise, within a social justice context, the hypothesis is that a correlate possibility may exist for social communities, and indeed that if resilience is to be a socially-useful concept, community resilience planners need to seek out opportunities for social “bounce forward” when crafting resilience plans. A socially useful plan for community resilience would help us to articulate the injustices that often seem as unmovable as mountains or mature forests, and to recognize in advance where certain kinds of system shocks or drastic changes might propel opportunities to improve the standing or life opportunities of disadvantaged people in a community, or close the social gap between the haves and the have nots. This pursuit of a social justice frame of resilience would work toward a more advanced state of social justice and community well-being than that which existed previous to a shock. It is an approach to resilience that can only be understood as a process, as it tends toward an outcome that is unknown since it has only been imagined, never achieved. As discussed in more detail below, such an approach has connections (mostly unexplored) to the literature on backcasting approaches to futures studies (Robinson 1988; Dreborg 1996; Holmberg and Robèrt 2000; Quist and Vergracht 2006; Vergracht and Quist 2011), and also to arguments about procedural approaches to sustainability (Robinson 2004, 2008; Miller 2013).

This process-based as opposed to outcome-based approach to resilience, so framed, may constitute a significant difference when approaching social compared to ecological system resilience; and the merits of the different approaches have been contested (Cox and Perry 2011). There may be a paradox, from the perspective of community, in preparing carefully and effectively for a crisis event or disaster, taking an outcome-based approach to resilience, while conducting community planning that takes a process perspective to recognize and build on all of a community’s social strengths (Gibbs et al. 2015). In fact, the very notion of a social justice approach to resilience may be incompatible with the dominant thrust and usage of the concept of resilience, when applied to cities.

To shed some light on the possibilities and limitations of the concept of resilience to tackle social justice in urban communities, we can look to the established debate between the nature of “sustainability” framing of planning goals compared to “resilience” framing. Elmqvist and colleagues at the Stockholm Resilience Centre differentiate the concept of sustainability from that of resilience in terms of the normative dimension of the former, as opposed to the latter. That is, the concept of sustainable development articulates a goal toward which urban planning and development efforts should be oriented, namely: providing for the needs of present generations such that future generations will have the ability to meet their own needs (UNCED 1992). Sustainable development, publicized internationally within the United Nations' 1987 Brundtland Report, has been described politically as "a discourse of and for global civil society" (i.e. 'think global, act local') (Dryzek 1997: 131). An underlying assumption of sustainable development is the 'triple bottom line' where economic, social, and environmental sustainability all positively correlate. And, even beyond a correlation, that seeking to address challenges in these three domains at the same time can lead to "synergistic" solutions that go beyond the outcomes which could be attained by addressing any one domain by itself. By contrast, other than embracing broad goals such as preserving life and property, resilience thinking remains on the sidelines of such value-based goal making, or criteria by which a good decision could be differentiated from a bad one. Fainstein (2015) worries that, with this lack of a normative thrust, employing resilience "leaves the analyst with enormous mapping jobs and model-building challenges but provides little in the way of decision rules." Scott's (2013: 430) related concern about "the dangers of elastic use and abuse of resilience," is that "we are in danger of merely inventing new words to describe long-established problems—and developing urban resilience as fashion or an empty concept without any real substance or potential to contribute to planning theory and practice" (Scott 2013: 431).

In order to conclude this volume on urban resilience on a constructive and forward-looking note, and in order to shed some new light on this critique of resilience from within the ranks of urban planning and political thought, our argument in this chapter begins with a validation of the notion that a meaningful difference exists between sustainability planning and urban resilience planning. What we have to offer here will be based on: (1) our own experience as action and policy-engaged researchers who have been assisting local governments in the conceptualization and implementation of plans for both sustainability and resilience over the past decades; and (2) our read of the landscape of appetite and opportunity for both concepts in terms of organizing the kind of change that we consider in this volume to be necessary to a better urban future. This chapter will, first, detail the specific failures of resilience as a framing concept for urban planning, from both social and political perspectives. As a concept for organizing planning, resilience is handicapped not only by an absence of normative meaning, as per Fainstein, but by an orientation toward a politics of restraint or limits, which, although it may have some value from a perspective of psychology or ecology, is socially and politically unappealing. Because political and social resilience tends to imply limiting our actions and efforts, and because a socially valuable outcome of "bounce forward" resilience demands positive action on the part of politicians and communities, we need to bring additional concepts and tools to the task of urban resilience planning in order for the effort to have social and political value.

The first incremental concept we offer here is that of the development path. The notion of the development path originated within the IPCC process and draws upon futures studies, scenario planning and backcasting, in order to reach beyond the scientific study of climate change impacts and responses toward the social and political change implications and prescriptions for changing the direction of decision-making. Borrowing from the development path approach, we present five different scenarios of urban transformation, each with a distinct view of exactly what is on its way to transformation, and how, in the context of predictions of impending large-scale urban change. While all five scenarios imply massive change to current patterns of social and political relationships and behaviours, we will suggest that the key dimension on which these predictions differ is that of the intentionality of the change on the part of local leaders and society at large. This conclusion brings us to the second concept we offer as adding incremental value to the notion of planning for urban resilience: regenerative sustainability, or the work of increasing the capacity of the current generation to give back more than we receive. We close the chapter with a discussion of why intentionality matters so much to achieving a development path that can be sustainable and resilient for the long-term prospects of our cities and communities.

2 Resilience Thinking and the Nature of Restraint in Ecological Versus Political Perspective

Resilience thinking, then, as currently articulated and practiced in urban planning, formulates ecological systems risks and mandates and imposes limits on human activity. This makes resilience insufficient as an organizing concept for urban planning because of both its lack of a clear normative thrust, as has been noted already, and because of its insinuation of limits. Whatever the scientific validity of the thinking behind the need to impose limits in essentially closed systems, as an idea expressed as a cultural narrative, the message of reducing harm through voluntarily limiting activities is problematic. There are numerous reasons for this. First, at a personal level, in most contemporary cultures, being told to limit one's consumptive activities runs counter to the dominant grain of cultural messages that are deeply seated within our nations, communities, and households. Instead, in almost all instances, we are urged and incentivized to grow, increase activities, and put self-interest first. Based on what we know about human sociology, this makes it extremely unlikely for any notion of resilience via harm reduction and imposed limits to appeal to more than a small, counter-cultural segment within society. Thus, the narrative misses the opportunity to be backed by a political, cultural majority.

In addition, the limits approach embedded within resilience thinking holds insufficiently grand ambitions to motivate path-breaking or transformative change: "The logical goal of a harm-reduction agenda is zero harm, which does not prompt a search for more positive possible outcomes" (Robinson and Cole 2015: 133). The notion of "bounce forward" as opposed to "bounce back" resilience addresses this challenge of the insufficient ambitions of a restorative approach. However, the nature of the restoration and new imposed limits within practices of resilience planning are nearly always framed in terms of privileging a better understanding of non-human environmental systems, a context into which social and economic systems must be made to fit. As undeniable as this logic may be from an ecological perspective, actual realization of "bounce forward" resilience outcomes in human cities and communities requires more social and economic than environmental strategies, strictly speaking. Consequently, achieving these outcomes demands a meaningful social, economic, and cultural narrative of progress, which recognizes the more attractive concept of opportunity rather than risk. There are links here too to the concept of building adaptive capacity in society (Adger 2003), rather than just seeking to pre-empt specific environmental threats.

Some psychology-based understandings of resilience have made inroads here, in recent years, and enriched the social understanding of a resilient lifestyle at the scale of individual human psychology (Eraydin and Tasan-Kok 2013). The concept of 'bounce forward' ties the conservative ecosystems orientation of resilience to an individual's positive psychological resilience. In the *New York Times* Opinion pages, Zolli (2012) advocates for the transition that he perceives to be necessary from "sustainability" oriented urban planning to a framework around resilience on this basis. Resilience is key, to Zolli, for three human-centred reasons. One reason is because of the way resilience thinking centres planners' focus upon the need to respond to environmental threats, rather than reduce environmental impacts, resilience offers a psychological stretching of the time and alternative possibilities horizon of planning further than is typical. Secondly, resilience planning opens up a connection within the practice of urban planning to human psychological resilience and needs in the face of change, which stretches the scope of technical expertise of planning into new adding new domains of better understanding human individuals. Finally, Zolli sees potential within resilience framing for emphasizing the value of more and better data, including social and psychological data, to planning and managing for resilience.

However, there is more at stake socially in the concept of urban resilience than the individual psychology of resistance. According to social scientist Ross (2011: 16), creating policy and plans to combat climate change represents a "vast social experiment in decision-making and democratic action" more than anything specific about scientific or ecological truths, technologies or targets. In further explaining the predominantly social, rather than biophysical, nature of the climate crisis, Ross (2011: 16) goes on to explain that the key areas in need of resilience in this context are "our social relationships, cultural beliefs, and political customs," all of which need significant change in order to demonstrate social resilience in the face of change.

If we are to grapple with a socially-relevant concept of resilience, we will need a better understanding of social motivations and organizing principles. In particular, we need this understanding in order to advocate, in the name of resilience, for those social principles that are less visible and overt than the dominant motivations of growth, self-advancement, and accumulation; such as justice, fairness and compassion. This is crucial work for the transformation of society toward a more resilient development path that is sustainable in the social domain; and it is work that will never be approached by an exclusively environmental science model of resilience- seeking. It demands, instead, the work of social scientists and humanists.

And a wide gap exists between the natural scientists, on the one hand, and the social scientists and humanities, on the other, in understanding the nature of resilience.

Howlett (2014) offers an understanding of what constitutes political resilience, which sits in stark contrast with the understanding of resilience offered within natural science-dominant climate change scholarship. Political resilience, Howlett (2014) notes, demands conservative and restrained response to any but the most immediate, opportune, and direct policy shifts. Because the lines of correlation and causation between any specific policy intervention and climate improvement are so convoluted and uncertain, the normal political reaction to the threat of long-term catastrophic climate change is to do nothing, or very little. Decisive or bold action, such as adopting a medium to long-term emissions reduction target, and reporting on progress to meeting this target, is politically risky for a number of reasons: the bold politician could be blamed, by powerful local actors, voters, or both, for negative side-effects of such actions, or blamed for a lack of effectiveness. This is not the whole story of climate policy, from a political science perspective, of course. Ambitious and effective urban climate policies do exist, and stories of their success have been catalogued in various ways (Auld et al. 2014; Burch 2010). Still, recognizing the basic dynamic as expressed by Howlett (2014), Jordan et al. (2015) turn around and ask: “if this blame-avoidance motivation is really as common as Howlett suggests, what is driving the new policy activity”? They suggest a few possibilities, both related to the trend toward “green cosmopolitanization” (Blok 2012: 2335) of cities, which shape local climate policy around external pressures and opportunities, filtered through context-specific placemaking and capital-attraction goals. First, the internal political dynamic is not the only one at play for today’s cities, and political leaders may feel pressured by peer cities elsewhere to either emulate or innovate in order to manage their political status and standing, a more complex form of political risk management. Second, a more cynical view is that cities are responding to external pressure from peers and international events and organizations, and are innovating in policy terms not with the intent to learn or lead so much as the intent to capture funding from international competitive sources. Much additional work is needed in order to fully understand the political nature of engaging with urban resilience.

3 Understanding the Difference that a Development Path Approach Makes

A different approach to the challenge of constructing urban resilience policy that has the potential to create change at social and political levels engages the concept of the development path. The origin of the development path concept is the work of the IPCC Special Report on Emissions Scenarios (SRES) on narrative storylines (Nakicenovic et al. 2000). This effort constructed prototype socioeconomic and political world models, adapted into four narrative storylines, and modelled these quantitatively into 40 scenarios with different implications for development and emissions, at present and over the course of time. Climate policies per se are ignored in the analysis, such that only policies driven by other development dynamics are factored in, based on the understanding that "government policies can, to varying degrees, influence the GHG emission drivers such as demographic change, social and economic development, technological change, resource use, and pollution management" (Nakicenovic et al. 2000). The result clearly showed that the underlying dynamics of the particular development pathway being followed have more significant impact on progress toward climate goals than do climate policies themselves. That is, in a world consistent with the "A1" storyline of a high level of equitable economic growth, high investments in education, technology, and institutions, and high mobility of people and ideas, the amount of climate policy required to reach stabilization would be ruinously expensive and disruptive. In the "B2" storyline, by comparison, where policy emphasizes local solutions to economic, social and environmental sustainability, with a slower overall pace of growth than A1, the amount of climate policy required to reach stabilization would be modest and affordable. To be effective in the realm of climate policy, policy attention needs to turn not to climate dynamics per se but to the storyline of development and the socio-economic, political, and cultural dimensions of moving toward a more sustainable development pathway (Robinson and Herbert 2001; Robinson et al. 2001; Swart et al. 2003).

The 2007 IPCC Fourth Assessment Report from Working Group III formalized the concept of a development path, defined as follows:

> Development paths are defined here as a complex array of technological, economic, social, institutional, cultural, and biophysical characteristics that determine the interactions between human and natural systems, including consumption and production patterns in all countries, over time at a particular scale. (Sathaye et al. 2007: 696)

Significantly, development path choice results from an uncoordinated assemblage of choices made at a range of formal and informal levels of decision making, and a range of scales from the global to the ultra-local. As Working Group III further specifies:

> Development paths do not result from integrated policy programmes. They emerge from fragmented decisions made by numerous private actors and public agencies within varied institutional frameworks of state, markets, and civil society. Decisions about the development of the most significant sectors that shape emission profiles - energy, industry, transportation and land use - are made by ministries and companies that do not regularly attend to climate risks. The same is true for even more indirect influences on these sectoral pathways, including financial, macro-economic, and trade practices and policies. The focus on development paths places new emphasis on development's impact on climate and on indirect rather than direct actions that affect climate mitigation. (Sathaye et al. 2007: 699–700)

Using this concept, if we do not change the underlying development pathway of any jurisdiction to make it more sustainable, we will find it very hard to achieve our climate goals. Changes in climate and energy policy alone are not sufficient, if the underlying development path moves in an unsustainable direction. Tim Jackson's (2009) *Prosperity Without Growth* has become a key text for visualizing a middle ground development path transition away from growth without falling into "unstable degrowth." He argues that changing social structures is necessary, and that nothing that he has seen within what we refer to below as the green city transition model is sufficient to this task. Different development path narratives are needed.

So the development pathway argument inescapably takes us away from resilience policy, defined in the limited and limiting way above, to the question of how to achieve a sustainable future via political, social, cultural, and personal at least as much as scientific means. This understanding leads directly into current social science work in the dynamics of sociotechnical systems, and multilevel systems of governance, which helps Burch et al. (2014: 471) observe the following further characteristics of a development path:

- It operates at the scale of socio-technical systems and systems of governance, which consist of social systems (formal and informal rules, habits, and norms), networks amongst actors, diverse technologies, and ecological systems
- It is an emergent property of a system, imbued with values, norms, rules, and habits rather than a measurable set of conditions/characteristics
- It exhibits a particular set of interlinking regime rules and behaviours, including inertia and cascading effects over time
- It is reinforced at multiple levels, with varied capacities and constraints on local agency occurring at each level.

These characteristics lead to more detailed studies of energy and material use and flows in order to expose the roots of consumption and impact within particular development path choices and conditions. An example of such detailed decomposition analysis, examining energy use specifically, is the Trottier Energy Futures Project, which modelled the current and potential energy output of different sources of non-fossil fuel energy for Canada. The report illustrates the importance of the nature of the demand that we are serving when we plan for urban resilience, in terms of the distinction between providing mobility and providing access. Imagine a worker whose home is 60 km distant from her place of work. To meet this demand for "60 person km of mobility," we have to plan for the infrastructure and access that this person will need in order to drive, take transit, or carpool (or, for the extreme, cycle). A planner could influence the resilience of this mobility pattern by moving from providing road and parking spaces for private vehicles to facilitating car pooling and car sharing, to providing efficient public transit options, and even facilitating cycling, or cycle-and-ride. While considerable energy efficiencies can be gained by moving down this list in planning approach, the demand for "60 person km of mobility" remains the same, and remains a limit on the reach of the resilience strategy, when considered in this way.

If, alternatively, the situation is seen as one demanding "access" and not "mobility," the suite of planning options, and the possible extent of resilience results, expands greatly. Seeking to provide access to employment as an amenity, with a low energy demand, breaks with the need for the "60 person kilometres" entirely and enters the terrain of urban design, mixed use communities, job-housing balance, and work-life balance. In this way, we can generalize from this simple example that "innovations that are outside the energy sector itself, for example in urban planning and information technology, can reduce the demand for energy services like mobility, which in turn reduces the demand for fuels and electricity" (Torrie et al. 2013: 2).

This is, in essence, what was meant in the IPCC Fourth Assessment Report, Working Group III, by the assertion of a: "close connection between mitigative and adaptive capacities and the underlying socio-economic and technological development paths that give rise to those capacities." With attention to development paths, and the uncertain but path dependent (and sometimes obdurate) nature of societal organization, we can steer the framework of resilience away from the political trap of prescribing restraint.

4 Transition and Transformation of Development Paths

The recent experience of the Paris COP21 climate summit provides evidence that a development path approach to climate policy is taking root, a new course set by the realization that a monolithic approach to an international climate agreement, operating since the striking of the Kyoto Protocol in 1990, has borne no fruit. Christiana Figueres, chief climate negotiator with the United Nations, has referred to this as a turning point. By this she means to signify a turning point in political will to address climate change, but this is also commensurate with a turning point in the framing of the nature of the climate change challenge. Figueres calls the challenge: "to intentionally transform the economic development model." That is, current international climate action meetings are framed as a historically unprecedented set of negotiations to define and regulate a new economic development model, not a new climate regulation model. As such, she sees the work as "a process, because of the depth of the transformation" (UN Regional Information Centre for Western Europe 2015). This is entirely consistent with the argument presented by Jordan et al. (2015), who draw attention to the need for, not a "comprehensive global climate regime" but instead "interlocking 'regime complexes'" on key sectors of climate change policy, such as trade, energy and climate. At the same time, they note that efforts to date in this direction essentially emulate the international, top-down, state-centric form that the comprehensive approach has taken, to little avail. Jordan et al. (2015) find hope in their sense that "the overall landscape of climate governance has started to exhibit some of the characteristics of polycentricity foreseen by Elinor Ostrom, that is, more diverse, multileveled, and with a much greater emphasis on bottom-up initiatives." In particular, they review a range of well-distributed polycentric forms of transnational and within-nation climate governance emerging ("from setting rules to sharing information"), in a range of specific sectors, involving a diversity of countries and cities and regions in between. They cite Globe International's database of 487 climate-related laws and policies in 66 countries in 2013, up from 40 in 1997, with rapid growth of policies evident across the board, especially related to adaptation. However, new directions and actions in moving towards lower carbon emissions and more resilient communities are not limited to government policies and initiatives. In a review of studies evaluating various attempts to engage Canadian communities in clean energy and other transitions, Sheppard et al. (2015) point out that third party NGOS and ‘grassroots’ citizen groups have sometimes been highly effective in reducing emissions and increasing energy security on their own initiative.

The significant task remains to ensure that all of this disparate work is complementary and reinforcing, rather than competitive, as per Green’s (2013) suggestion that adequate “global climate governance is a positive-sum game where governance efforts by state and non-state actors grow simultaneously and in a mutually reinforcing manner” (quoted in Jordan et al. 2015). Supporting the continued pursuit of global climate governance in this manner is the fact that it is commensurate with many “non-climate” co-benefits with meaning to the dominant development path of cities, such as “[addressing] moral concerns, fear of new regulation (or the opportunity to secure first-mover advantages by shaping it), the pursuit of direct financial rewards, indirect … benefits (for example, reputational enhancement), and the satisfaction of consumer expectations” (Jordan et al. 2015). A further example is the need to identify explicit goals and metrics in planning not just for mitigation and adaptation, but also for things that appeal to citizens’ values such as community aesthetics, as in ‘low-carbon attractive resilient communities’, as argued by Sheppard et al. (2008).

Keeping this notion of synergy in mind, in terms of a sustainable development path approach to urban climate policy, the concept of resilience does not lose its value, but at the same time cannot be treated as sitting above other crucial aims. Dissatisfaction with the concept of resilience as an overarching driver of climate policy exists within some of the most thoughtful work on articulating the principles needed to generate sustainable systems. Torrie et al. (2013) recognize “resilience” as one essential component of a sustainable energy system, namely a distributed energy system that can more readily recover from shocks and continue providing energy services in the face of social, economic and environmental disruptions, but it is only one of seven such components that distinguish a sustainable system from a resilient one: no waste, renewable supply sources, environmentally benign, diverse and distributed sources of system input, equitable in distribution of costs and benefits, and with embedded social values of human welfare, social justice and self-determination. The eight criteria for sustainability conceptualized by Gibson et al. (2005) similarly include ‘system integrity’ which can be considered a proxy for resilience, as well as: livelihood sufficiency, intra- and intergenerational equity, sustainable use of resources, democratic government, precaution and adaptation, and long-term integration. These examples, along with other conceptual and modelling work in this domain, support a systems, process-based and politically-embedded view of sustainability as the “emergent property of a discussion about desired futures—a discussion informed by some understanding of the ecological, social and economic consequences of different courses of action (Miller 2013; Robinson 2004, 2008).

Arriving at an understanding of the development path as crucial for effective interventions against climate change is one thing; arriving at an approach that actually pushes from within to change this path toward greater sustainability and resilience, is quite another. The theory and practice of transition management aims to provide path-changing capacity, beginning from a socio-technical understanding of past societal transitions. Transition management seeks to translate sustainable practices into the active management of a large scale transition toward sustainability (Smith and Kern 2009). Smith et al. (2005) articulate the preconditions for such a transition in terms of societal pressure for change and adaptive capacity. Transitions can be generated from within or from external structures and resources, although they will happen in a different way and at a different rate depending upon their motivation. Though full-blown societal transitions can seem extremely unlikely, evidence exists in cities today of considerable appetite for just this scale of change. Hodson and Marvin (2009: 477) in their research in some of the world's most powerful cities, found "strong evidence of expectations, aspirations and plans to undertake purposive socio-technical transitions," in line with sustainability and climate change adaptation and mitigation goals. Transition theorists identify a number of factors that increase the potential for a system of governance to undergo an effective transition, in line with its adaptive capacity (Smith et al. 2005). Hodson and Marvin (2010: 484) qualify success in transitions as a fully coordinated constituency, where "those who intermediaries need to engage to realize the vision would have been successfully enrolled. Any issues, controversies or problems that arose would subsequently have been addressed through involvement of the 'necessary' social interests and the 'relevant' resources and be coordinated—through various methods—with the initial objectives of the vision."

Cloaked within the project of managing a development path transition is the question of directionality, or how the transition ought to tend. Within the growing appetite for transition that is evident in many cities today, and evidenced most strikingly by the agreement of just under 200 countries to the Paris climate accord, we identify at least five distinct visions or development path storylines operative in urban climate change discourse today. The direction and purpose of transition we have in mind dictate the kind of transition that cities may be steered down in pursuit of a resilient, sustainable development path, and this in turn has a bearing on the kinds of actions we take and the kind of outcomes we can expect. We outline each of these next, in rough order of increasingly transformative ambition.

4.1 The Urban Future

In the urban future narrative, the transition at hand is already underway, indefatigably, constituting a geographical, demographic shift of humanity from a primarily rural to a primarily urban base and lifestyle. Fully coming to terms with the implications of a global transition from agrarian and land-based lifestyles to urban-based lifestyles, and the shifts in values that are entailed by this, is a distant goal. Swyngedouw and Heynen (2003: 899) remark that "little attention has been paid so far to the urban as a process of socioecological change." Significant socioecological changes are, nonetheless, underway within ongoing urbanization; we have reached a global condition of urbanity. Harvey (2012: 14) writes that urbanization has "brought with it incredible transformations in lifestyles. Quality of urban life has become a commodity for those with money, as has the city itself in a world where consumerism, tourism, cultural and knowledge-based industries, as well as perpetual resort to the economy of the spectacle, have become major aspects of urban political economy."

There may well be potential within this global urban transition for a sustainable development pathway, but without better understanding of the socioecological and political dynamics at play, we really have no idea. The changes that inhere to rampant urbanization do not suggest anything about the relation of these changes to material consumption, social justice, or ecological awareness, per se. Swyngedouw and Heynen (2003: 899) describe cities as "dense networks of interwoven socio-spatial processes that are simultaneously local and global, human and physical, cultural and organic." One way an ecologist might interpret such a statement is that this means cities represent ecological footprint zones that draw upon vast ecological hinterlands. Can this be changed? Harvey (2012: 127) reflects that "there is no technological fix to this question. There have to be significant lifestyle changes… as well as major shifts in consumerism." It would be cynical not to see the large migration into many cities from elsewhere as an opportunity to effect wholesale lifestyle shifts. But achieving such a lifestyle shift with the consent and ready participation of large swathes of the urban population toward recognizing the sustainability implications of their personal, social, and economic choices, is neither obvious nor easy. Work on transition in this vision proceeds on two separate tracks: creating space and home for vast numbers of new and continuing urbanites, a "way in" to being welcomed into urbanity as a meaningful way of life; and creating opportunities to change the understanding of the affordances of urbanity amongst urbanites in a sustainable direction.

4.2 *The Global Leadership City*

A variant of the urban future transition is the political shift in favour of a subset of certain globally hegemonic or leadership cities that act as particular kinds of poles of power and growth, and away from cities that do not. This transition theory rests upon the nature of multilevel governance discussed above, in which cities' climate actions may be influenced more by commitments and changes made in cities they consider to be peers or competitors than by internal political dynamics, and their ability to act also depends upon their mobilization of networks of actors within and beyond formal government. Tied to urban economic development theory which has observed a shift from a managerial to an entrepreneurial approach to urban governance, successful cities capture an image of creativity, liveability, and global mobility rather than recruiting or retaining any industry or employer in particular. Successful cities in this competition for liveability and the creative class take a polar position within the global network of cities, and so gain attention from other cities that are within this privileged set, and attention from those that aspire to join their ranks as new leaders. More so than cities in general, then, this subset of global leadership cities attracts attention and power which, some believe, gives them particular potential to mobilize change for a wider set of cities, via leadership by example. Shifts which are believed to have helped a city receive status in the global leadership network of cities, will be sought out for replication elsewhere. The C40 initiative of the Clinton Foundation draws upon the logic of a global cities transition in convening a network of the world's largest cities in order to set an example for others, and demonstrate their political economic might as a set.

4.3 The Green City

The green city transition is evident in shifts from calls to make cities more urban and global in order to guarantee future success, toward a more overtly green urban politics. This is more of an additive layer of overall urban and global leadership city transitions, rather than a departure from either model. Those in favour of a green city transition urge action to green the city, where "green cities" privilege environmental, architectural, urban design and technological expertise in creating a green image, brand, and aesthetic. The Rockefeller Foundation 100 Resilient Cities Program subscribes to a green city transition model, in seeking submissions from cities interested in entering into a competition to demonstrate the seriousness of their greening endeavours, and their interest in receiving financial and expertise supports toward increasing these efforts.

In practice, green city transition models are driven to a very large extent by expertise and top-down management, although they often incorporate network-based and multilevel governance approaches in order to leverage formal efforts. They also tend to be based on a logic of interurban competition, much like the global city transition model, although sometimes based on a different logic of determining winners and losers. Jonas et al. (2011) point out the way in which competition for carbon control becomes the new language around which a certain set of cities attempt to establish their competitive position over others. At the extreme, controlling carbon flows, to the extent that these are understood to be within the city's jurisdiction, becomes the singular focus within arguments about both economic and environmental policy change. This situation dictates the "centrality of carbon control in discourses, strategies and struggles around urban development and place promotion" (Jonas et al. 2011: 2539). This can have an unintended consequence of sacrificing some measure of open minded consideration of possible futures to stay within the constraints of lowering carbon emissions each step of the way, in order not to lose a competitive edge. It is worth noting, also, that green city transition politics are most prominent in cities that have already transitioned away from an industrial economic model to a post-industrial model, in which image and branding become key assets for urban economic development.

4.4 The Anarchist City

While the urban future, the global leadership city, and the green city transition are the predominant development path narratives being advanced in contemporary cities that have entered into policy debate around resilience and sustainability, two other narratives are advanced, although by few advocates and in less concerted ways. While the previous three models of urban transition do not fundamentally question such basics of the global political economic system as the necessity of economic growth, the motivating potential of competition, or the nature of distinguishing winners from losers, the final two models that we will discuss do question these basic assumptions. For this reason, we classify these models as "transformations," distinguishing them as a radical subset of "transitions."

First, the anarchist city transformation takes aim at ridding the city of centralized power held by formal government and capitalist leaders under neoliberalism. The anarchist strategy is multiform and driven by a host of different strategies, contestations, and other change initiatives, from managed to radical. The overarching aim of an anarchist city transformation is to decentralize power and commitment to a neoliberal model of private profit and consumption to a production, consumption, and social organization model of common value, sufficiency rather than efficiency, optimizing contributions from different individuals and sectors, and socially-oriented reward systems. Leitner et al. (2007: 5) describe the practice of such an anarchist transformation, and the entire notion of neoliberal contestations, as a "vast variety of imaginaries and practices of all political hues that not only practice resistance but also are resilient to and rework neoliberalism." Other support for this kind of urban transformation, and piecemeal evidence of its existence on the ground in certain cities, for certain times, comes from radical leftist scholar-activists (e.g. Autonomous Geographies Collective 2010).

4.5 The Urban Commons

Not entirely dissociated from the anarchist transformation, but different in emphasis, the practice of urban commoning has evolved from Elinor Ostrom's theory of common property resources, adapted to the physical and social setting of the city. An urban transition toward valuing the commons, then, offers a vision (imaginary, but not necessarily anarchist or socialist) of the future with stories and images of success, to replace the dominant narratives of private wealth, accumulation and growth, and personal security. These alternative images, instead, imagine a joyful public life in the commons, and a right to the city for all. In the domain of practice, the task is “reappropriating urban space for collective social uses rather than for private profit” (Brenner 2000: 374). Much like the anarchist transformation model, but perhaps more so because of the need for very localized agenda-setting around rights and responsibilities to common property, the specific goals and methods of an urban commoning transformation model must be left open to any given local circumstance. Brenner (2000: 367) argues that this is a matter of both local self-sufficiency and the right to reject the kind of hierarchy of cities imposed by the global city model: “thus conceived, the urban scale is not a pre-given or fixed platform for social relations, but a socially constituted, politically contested and historically variable dimension of those relations.” This urban transition model is thus the only one to represent the possibility of a largely ‘bottom-up’ transformation, not dependent on shifts in government policies or strategies.

We can identify some techniques that have been documented within this model of urban transformation, including the purposeful construction of new stories of human and development progress, such as voluntary simplicity, downshifting, simple living, and others. Small groups and individual households also are implementing these ideals, generally defined as “patterns of action and consumption, used by people to affiliate and differentiate themselves from others, which: meet basic needs, provide a better quality of life, minimize the use of natural resources and emissions of waste and pollutants over the lifecycle, and do not jeopardize the needs of future generations” (Scott 2009: 1). Households may, specifically: limit automobile and fossil fuel use (as documented in Sheppard et al. 2015), live in smaller spaces, eco-villages or cooperative housing, limit their non-essential consumption and waste production, and grow their own food (Hopkins 2008). Relative to contemporary Western standards of urban life, this amounts to *drastic* reduction of individual and household consumption to decrease ecological footprint; importantly, it is also argued and adopted as a means, by the very same token, of improving resilience and well-being (Jackson 2009). While these efforts remain predominantly matters of personal conscience for those who get involved, research in the UK with those who made such sustainable lifestyle choices found that these early actors also sought complementary efforts from government in order to facilitate their individual transitions (Evans and Abrahamse 2009).

In summary, the five urban development pathways offer a range of divergent options for confronting the need for wide-scale urban change in order to achieve resilience:

- The scale and pace of urbanization today demands that we create a “way in” to urban life for more urban migrants than ever before. This is a continuing development path. The change to the development path advocated in this narrative is the challenge to create new lifestyle opportunities in cities that allow people to envision “ways out” of current destructive trends in urban life and create a new urban life that is much less consumptive and exploitative.
- An upper echelon of cities is aiming to follow a development path in which their economic prosperity is advanced on the global stage, often at the expense of more traditional national hierarchies of cities. This development path narrative

engages an urban politics of cities self-segregating into peer groups of sometimes unlikely partners.
- Another subset of cities, following the green city development path, is attempting to gain competitive advantage specifically through green technological advances, often advanced through the embrace of scientism and technological expertise.
- The anarchist city development path aims to achieve urban change by breaking down the centralized power structures of current cities and encouraging a multiform and bottom-up exercise of initiatives and powers.
- The urban commons development path narrative aims to replace the pre-eminent importance of private property to contemporary urban success with collective work, stewardship, and engagement in shared and public life.

While these narratives differ considerably in terms of the degree to which they might require departures from currently trending policies and actions, all represent massive change scenarios. Indeed, from our vantage point at least, there is no plausible future that does not imply some such drastic change. One important question about all of these urban development pathways is what assumptions about human or environmental wellbeing underlie the particular proposed programs of change. Ironically, it may be precisely those futures that seem at first to continue existing trends without significant intervention, such as the urban future or global city leadership scenarios, that may give rise to the greatest unanticipated changes and most severe consequences for society. Will increasing urbanization and continued technological change more or less automatically produce environmentally and socially benign outcomes, as is often implied in stories about urban futures and global city leadership? Conversely, does enduring resilience and sustainability require the kind of major reductions in individual consumption and changes in political organization called for in the anarchist city or urban commons? These are contested issues, which cut across the sometimes unquestioned assumptions of particular urban narratives.

Within the camps of these five visions of transformative change are housed various levels of commitment to scientism, by which knowledge which does not fit the rational, natural science model is discounted or disregarded. They express different levels of commitment to a capitalist growth model, within which the wisdom of continuous growth cannot be questioned. Across these and other differences among these five models of transformative change, the single key dimension of difference for the ultimate resilience of the development path, we claim, is the intentionality of the transformation at hand. The recognition of the substantial change implied in any of these futures suggests that the meaning of transformative change may lie less in the amount of change involved and more in the degree to which that change is intentionally chosen. Transformation, in this way, implies some attempt to shape the future in accordance with explicit goals and discussion about desirable futures. This in turn brings to the forefront the question of whose intentions are considered in such processes.

For, while understanding the resilience properties and shortcomings of an urban system can help planners plan with a better perspective on what non-human system shocks might have in store, socially-desirable and progressive resilience planning must provide opportunity space for proactive human system interventions in order to shape the change that is coming at any rate. Support for this work, also essential to achieving the outcomes of urban resilience, can come from a regenerative sustainability model.

Regenerative sustainability is described by Robinson and Cole (2015: 134) as "a net-positive approach to sustainability that departs from dominant sustainability narratives." It borrows ideas from theories of regenerative design of the built environment, but diverges from strict ecological grounding in favour of social and process-based needs of the planning, design and implementation of sustainability initiatives beyond the building scale. Regenerative sustainability, then, "rests on the notion of 'procedural sustainability', which is rooted in the experience of collaborative planning for sustainable community development and, subsequently, a particular stream of constructivist social theory" (Robinson and Cole 2015: 135). In other words, a systems-based and participatory approach elevates regenerative design to the point at which design processes can be "collectively focused on enhancing life in all its manifestations—human, other species, ecological systems—through an enduring responsibility of stewardship" (Robinson and Cole 2015: 135), thus incorporating people and their history and cultural and political context. Regenerative sustainability seeks to maintain this stance well into the future, by engaging a process-based approach and by focusing on the capacity of human communities to sustain this ongoing program of work. Regenerative sustainability is: "based on the view that human activity does not necessarily have to be minimized because it is inherently harmful, but can instead contribute directly to both environmental and human well-being (i.e. net-positive outcomes). In keeping with a procedural approach, it is not rooted in any claims about absolute or necessary truth, but in an empirical process of societal discussion and negotiation, in which both goals and outcomes must emerge from that process." (Robinson and Cole 2015: 138)

A sustainable and climate-resilient development path that intentionally leverages the key insights from all five narratives above can be most fruitfully and successfully pursued with a regenerative sustainability approach, since the latter provides a normative directionality that can inform the detailed development path analysis. Also, because regenerative sustainability views sustainable outcomes as the emergent property of a public conversation about desired futures informed by some understanding of the consequences of different courses of action, the approach demands a continuous level of participation to ensure the continuous injection of new energy and ideas.

Adopting procedural approaches to sustainability suggests the importance of processes of public and community engagement, intended to provide opportunities for citizens to have structured discussions of desirable futures. Such participatory "backcasting" approaches complement more traditional forecasting and scenario analysis techniques (Quist 2007; Carlsson-Kanyama et al. 2008; Mander et al. 2008; Salter et al. 2010). They lend themselves to the exploration of participant preferences for alternative development pathways at the urban scale. Such approaches to developing desirable scenarios are typically led by government, and sometimes by third-party intervenors such as NGOs or researchers, e.g. initiating a process of local climate change visioning with both adaptation and mitigation scenarios (Cohen et al. 2012). However, actually moving toward such transformations requires more than government action: it also requires social mobilization of the public and consumers in making lifestyle changes, enacting appropriate changes in their neighbourhoods and businesses, and supporting associated policy changes. Such mobilization can be catalyzed by government through formal planning/engagement processes, through third party initiatives, or through less formalized grassroots movements or community-led planning within communities (Hopkins 2008; Bendor et al. 2012; Sheppard et al. 2015).

Within the practice of regenerative sustainability toward defining and recognizing new urban development paths that are climate resilient, there is considerable room for debate about the best means to proceed. Positions on these debates are embedded within people’s adherence to different ideas about the nature of transition needed to make our cities climate resilient, sustainable, and just. The existence of multiple incommensurable baselines, such as the five different development path narratives offered here, may entail completely divergent visions of the future resilient city. Participants in this ongoing struggle to define and realize our common future hold distinctive views on the nature of transitions we can pursue, as aspirations, compared to those effected by overarching or underlying forces within which we have no power of intervention, or sometimes even observation. We hold differing views on the relative power and interactive effects of intrinsic and hedonistic compared to external and altruistic motivations for behavior change.

5 Summarizing the Necessity of Transformative Change and Regenerative Sustainability

For the notion of urban transition toward resilience to be meaningful in the face of a changing climate, not to mention in the face of commitments to fossil fuel reduction recently made at the Paris Climate Summit, the form of transition that we envision, and explicitly try to achieve, should be sufficiently profound to be transformational to the city’s functioning (Burch et al. 2014). Moving away from a strict limits-to-growth approach to resilience, and toward a development path idea, is thus an important step in realizing a more politically effective politics of urban climate change and sustainability action. Seeking to further nudge and alter an existing development path toward a more sustainable development path, however, depends further upon the story of transformation that is being ascribed to. We have outlined five such development path narratives that are operating currently in different cities and different social understandings of the need for change, whether via basic demographic shifts, technology, leadership, green innovation, creativity, agency, self-help and grassroots organizing, new models of property ownership and occupation, in addition to resilience. We have offered the concept of regenerative sustainability as a means to deepen our understanding and motivation for change and broaden participation in our approach.

We do not currently know how to measure the outcomes of our efforts toward regenerative sustainability—increasing our capacity to give back more than we receive. We cannot predict the best outcomes of a regenerative project in advance; acceptance of uncertainty is needed, as implied in a procedural approach to sustainability. Moreover, not all human activity can be regenerative, and in many cases harm reduction and damage limitation is the best we can do, and is urgently needed. The power dynamics that inhere to public conversations about long-term alternative futures, when these alternative futures threaten existing power dynamics, remain poorly understood. New research and ideas on this front are needed, and should draw from insights not just in planning and urban theory based on multi-level governance, transitions to sustainability and resilience thinking, but also social practice theory, narrativity, complexity studies, political ecology, science studies, and critical pragmatism. But several decades of work on engaging citizens about sustainable futures suggests that citizens are keen to be engaged in this kind of discussion (Robinson et al. 2011; Holden 2011; Haas-Lyons et al. 2014).

Just as more research is needed, the regenerative approach offered here also suggests an important role for planners and other urban activists: to induce experiments and innovations, at different scales, locations, and levels of flexibility, to respond to obduracy or lock-in. Much work is needed in making the processes accessible and welcoming to people who don't fit that narrow profile of the usual suspects in urban public participation processes, respectful of different starting points to the conversation, and constructive across growing gaps of social difference. Such experiments can themselves become a means of building up adaptive capacity. Still, the need remains for a context-specific conversation about the normative ends of resilience, which is not provided by resilience itself, but is provided by the notion of regenerative sustainability. That conversation has to be open; where it starts depends upon the amount of social license help by a process leader in a particular city, toward a particular goal. It should be based on a recognition that the vision will change over time, and that such change will need to be facilitated. Processes of group-based, participatory scenario analysis can permit more, ongoing exploration of the steps we can take from where we have begun, and the degrees of choice available to us, in trying to achieve our preferred, collective futures.

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Prof. Robinson's research focuses on the intersection of climate change mitigation, adaptation and sustainability; the use of visualization, modeling, and citizen engagement to explore sustainable futures; sustainable buildings and urban design; creating partnerships for sustainability with non-academic partners; and, generally, the intersection of sustainability, social and technological change, behaviour change, and community engagement processes.

In 2012 Dr. Robinson received the Metro Vancouver Architecture Canada Architecture Advocacy Award and was named Environmental Scientist of the Year by *Canadian Geographic* magazine. In 2011, he received the Canada Green Building Council Education Leadership Award, and in 2010 he was given BC Hydro's Larry Bell Award for advancing energy conservation in British Columbia. He was a Fellow of the Pierre Elliot Trudeau Foundation from 2008 to 2011, and, as a Lead Author, he contributed to the 1995, 2001 and 2007 reports of the Intergovernmental Panel on Climate Change, which won the Nobel Peace Prize in 2007 with Al Gore.

Dr. Stephen Sheppard teaches sustainable landscape planning and community engagement on climate change, in the Faculty of Forestry. He received a BA/MA in Agricultural and Forest Sciences at Oxford, an M.Sc. in Forestry at UBC, and a Ph.D. in Environmental Planning at UC Berkeley. He directs the Collaborative for Advanced Landscape Planning (CALP), an interdisciplinary research group using participatory processes and visualization tools to support public awareness and planning on climate change and sustainability issues.

He has more than 30 years' experience in environmental assessment, aesthetics, and public involvement internationally. He recently published Visualizing Climate Change: A Guide to Visual Communication of Climate Change and Developing Local Solutions. Stephen has also led development of the new Urban Forestry undergraduate degree at UBC's Faculty of Forestry. His current research interests lie in developing low-carbon resilient communities through renewable energy, urban forestry, and social mobilization, supported by engagement tools such as educational video games.

For more information: www.calp.forestry.ubc.ca*and*www.futuredelta2.ca.

For more information on "*Visualizing Climate Change*": http://visualizingclimatechange.ca.