THE CITY RESILIENT: A NEW FRONTIER OR A CONVERSATION REVISITED?

A MULTI-CITY EVALUATION OF CITY RESILIENCE PLAN POTENTIAL IMPACT

by

GABRIELLE PIERRE

(Under the Direction of Rosanna Rivero)

ABSTRACT

City resilience as it is applied today is both a novel concept and a culmination of past knowledge and current exacerbating issues coming to a head. The expanded definition of city resilience includes disaster risk reduction in addition to city resilience as an approach to improving city function. It suggests an understanding of cities and their issues with a holistic, systems thinking perspective. This thesis evaluates ten cities from Rockefeller's 100 Resilient Cities Network according to resilient urban system qualities such redundancy, modularity, diversity as the evaluation criteria (created by a review of urban and city resilience organization publications). Results indicate that those cities with long term adaptive strategies, generating significant changes tend to be more successful (according to the selected metric) than those that only generate small improvements. This thesis ends with a review of three case studies on green infrastructure as a successful strategy to achieve resilience.

INDEX WORDS: resilience, ecological resilience, city resilience, city-scale resilience, urban resilience, disaster risk reduction, 100 Resilient Cities, city-scale evaluation

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This season's Daffodil,
She never hears
What change, what chance, what chill,
Cut down last year's:
But with bold countenance,
And knowledge small,
Esteems her seven days' continuance
To be perpetual.

So Time that is o'er-kind
To all that be,
Ordains us e'en as blind,
As bold as she:
That in our very death,
And burial sure,
Shadow to shadow, well persuaded, saith,
'See how our works endure!'[1]

"Cities, and Thrones, and Powers"
Rudyard Kipling
Puck of Pook's Hill, 1906.

[1] Kipling, Rudyard. A Centurion of the Thirtieth. Morano, 1993. Excerpt (first stanza) seen in the introduction of 'The Resilient City' by Lawrence Vale. Entire poem here.

CHAPTER 1

INTRODUCTION

City resilience is commonly used as an approach for addressing disaster risk reduction. But, in practice, city resilience has taken on an expanded definition to include not only disaster risk reduction but also holistic city function and civic life improvement. The goal of this thesis is to identify how city resilience can most effectively be utilized for city function improvement coupled with disaster risk reduction. For the purposes of this thesis, effective utilization and/or implementation is defined by impact; that which actually builds resilience for interconnected, lasting impact.

Resilience being applied to cities and city function is still a young and burgeoning area of study, becoming popular only in the last two decades. Thus, exactly what successful outcomes look like in a variety of cities with differing stakeholders, socioeconomic conditions, and levels of organization and agency is still elusive. This thesis explores the imprecision and complexity of the term city resilience, evaluates how it is applied in ten cities in the 100 Resilient Cities Network, and concludes with recommendations or best practices for cities working on building resilience.

In order to begin discussing city resilience we must first discuss how the city functions, a topic which can be approached from a number of perspectives. The city can be understood as an arrangement of its individual components, as a combination of living components such as people, flora, and fauna, and inanimate components such as infrastructure, buildings, rivers, and air; studied according to arrangements or typologies of the individual components themselves.

Or, conversely, a city can be understood as a unique set of relationships and interactions, remaining pervasive in a geographic location. As cities grow and change over time, especially with the growing prevalence of the sprawling metropolis, understanding and modeling city function in order to inform policy decisions for the improvement of city life, the efficiency of city function and the mitigation of urban hazards becomes increasingly difficult. City resilience stems from an ecological understanding of resilience and recognition of cities as complex adaptive systems. For the purpose of this thesis, the mechanisms of city function can be understood within this complex adaptive system model framework. The complex adaptive city system is made up of abiotic and biotic components working together and interacting in a series of established relationships; creating new relationships and connections, yet retaining its fundamental structure. The city as a complex adaptive system is adaptive by nature of the city's dynamism and ability to respond and react to disturbance or change and complex by virtue of the innumerable components and flows that it consists of.

There are 1,692 cities in the world with a population of at least 300,000 inhabitants.[2] The majority of the world's population (54% as of 2014) now resides in or around urban metropolitan areas with cities as their centroid. This rapid urbanization and urban densification are projected to continue to increase with 2.5 billion more people living in urban areas by 2050.[3] This influx of population density has exacerbated centuries-old issues such as income inequality, resource

[2] United Nations Department of Economic and Social Affairs (UN-DESA). *The World's Cities in 2016 Data Booklet.*Publication. 2016. Accessed March 26, 2018.http://www.un.org/en/development/desa/population/publications/pdf/urbanization/the_worlds_cities_in_2016_data_booklet.pdf.

[3] United Nations Department of Economic and Social Affairs (UN-DESA). "World urbanization prospects: 2014 revision. Highlights." [accessed 2017 Nov 26] (2014). http://esa.un.org/unpd/wup/ Publications/Files/WUP2014-Highlights.pdf

scarcity and allocation, transportation, infrastructure and congestion, air, water and ambient environmental quality, and housing. Incoming lower-income populations often settle in hazard prone areas adding strain to city resources and increasing vulnerability during a disaster, often drawn by low prices or availability of land. The increasing frequency of large natural disaster events such as earthquakes, hurricanes, and superstorms threaten to further cripple the reinforcing relationships that keep cities working: 944 of the 1,692 cities with at least 300,000 inhabitants (56%) are at high risk of exposure to at least one of six types of natural disaster (cyclones, floods, droughts, earthquakes, landslides, and volcanic eruptions).[4] Although we live in a modern reality of disruption, this web of nuanced issues plaguing city planners of today have plagued societies for centuries. Some of the fundamental conundrums of our time are: how do we achieve sustainable growth and development, how do we improve the cities and urban areas in which we currently or will live in, especially now in a climate changing world, and how do we anticipate and prepare for disruption?

This well-documented conflict is reflected in the triangle of conflicting goals for planning originally discussed by Scott Campbell in 1996, "Green Cities, growing cities, just cities? Urban Planning and Contradictions of Sustainable Development." In this landmark paper, Campbell eloquently highlights how issues that initially seem dichotomous (man versus the environment, development versus conservation) are in fact more complex. His characterization of the planner as three mindsets (the equity planner, the environmental planner, the economic planner) addressing three main conflicts (the property conflict, the development conflict, the resource

[4] United Nations Department of Economic and Social Affairs (UN-DESA). *The World's Cities in 2016 Data Booklet.*Publication. 2016. Accessed March 26, 2018.http://www.un.org/en/development/desa/population/publications/pdf/urbanization/the_worlds_cities_in_2016_data_booklet.pdf.

conflict) provide a more holistic framework for understanding how we might start to improve cities, city function, and civic life. The very conflicts that he describes are still prevalent today and the worldwide trend of rapid urbanization and urban densification will only serve to continue to escalate and reinforce them.

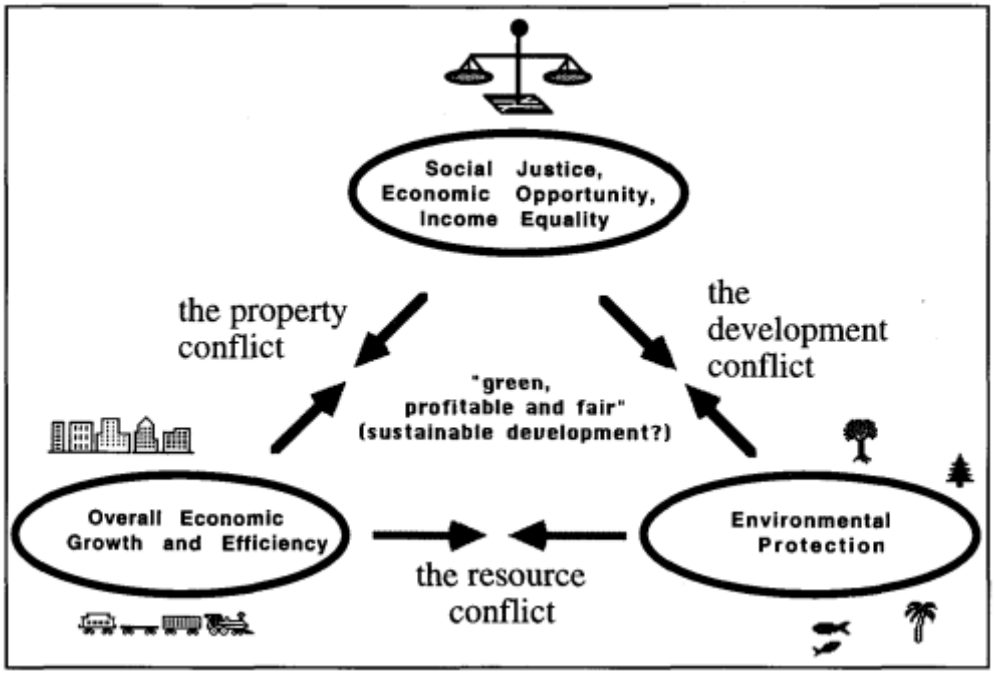

Figure 1. The Triangle of Conflicting Goals in Planning[5]

Traditionally, the proposed solution at the nexus of these three competing goals is sustainability. However, as Campbell highlights, understanding and achieving this city-scale sustainability has been elusive. The fail-safe (safe from failure) mentality of sustainability often seems unrealistic in a dynamic, climate-changing world because the goal of making cities

[5] Campbell, Scott. "Green cities, growing cities, just cities?: Urban planning and the contradictions of sustainable development." Journal of the American Planning Association 62, no. 3 (1996): 296-312.

themselves more sustainable does not necessarily spur radical change in norms or behaviors.[6] Though not completely static, the fail-safe mentality of sustainability does not leave room for major change and disturbance because, as the phrase implies, fail-safe sustainability seeks to grow and develop in a way that conserves and maintains certain features as they are for future generations. It often represents a far-off goal without obvious, immediate consequences for completely ignoring its relevance; which is probably why its widespread integration and implementation besides its use as an aggrandized buzzword has been lackluster. Sustainability also often allows for siloed, cosmetic solutions because people can trick themselves into believing that if they make themselves just a little more sustainable they can continue to live life as they currently do. Urban or city-scale resilience, in contrast, seeks to completely change how the city operates and completely challenges this complacency. The urban resilience mindset anticipates change and asks: 'What will that city look like? When we inevitably experience crisis, disaster, and unexpected events, how will the city weather them? How can we strengthen what already exists in the city and what new innovations can be incorporated to make it better and improve our ability to adapt and recover?' Crises will inevitably occur. Instead of ignoring risks and the chronic stresses facing cities, we can prepare our cities to be self-regulating, livable, interconnected, adaptable, resilient - so that the disruption is as brief, cost-effective, and minor in destruction as possible.

By definition, urban or city-scale resilience is " the ability of a city or urban system to withstand shocks and threats, to survive stresses, utilize them, reorganize, develop whilst retaining the essential same functions and identity, and to adapt to social, political, economic,

[6] Ahern, Jack. "From fail-safe to safe-to-fail: Sustainability and resilience in the new urban world." Landscape and urban Planning 100, no. 4 (2011): 341-343.

and environmental change.'[7] It has the potential to not only greatly improve disaster risk reduction but on a more nuanced note by making cities more resilient we can use nested solutions to solve a plethora of other city issues. For example, by reimagining and improving the efficiency, timeliness, network integration, and affordability of a city's public transportation system, not only can we develop a robust and redundant network to evacuate people during a crisis such as a mass shooting, terrorism attack, or natural disaster, but when executed with inclusivity and a holistic mindset, the city's facilities and services also become more accessible to everyone, especially the vulnerable who often need them most.

Nevertheless, for most, city resilience remains an inaccessible and imprecise term despite its potential; by virtue of confusion and meaning creep brought on by other existing definitions and connotations, and the gap in deep knowledge and understanding between scientists and the general public, stakeholders, and policy makers. The creep and divergence in meaning of the word resilience over the course of the past four centuries can be likened to a round of the children's game, "Chinese Telephone". In the game, a group of individuals sit in a line or a circle. A secret message is whispered to the first person in the line and passed from person to person until it reaches the last. Then, the final receiver repeats aloud what they believe to be the message. However, very rarely is the message or meaning of the received whispering the same as the original. The same phenomenon has taken place with several words in our 21st century vernacular, ie, words developing new connotations or entirely different meanings from their original. Resilience, like many other city planning buzzwords, is one of them. It has been used increasingly often in the news, media, and general conversation in recent decades because it

[7] Dodman, David, Loan Diep, and Sarah Colenbrander. "Making the case for the nexus between resilience and resource efficiency at the city scale." (2017): 97-106.

represents themes and goals that are popular; much like net-zero cities, green cities, sustainable cities before it and smart cities that has come after and been adopted in conjunction with resilient cities.

This popularity of the word resilience is not necessarily harmful to its application in city planning. In fact, the more that the public can internalize and understand urban resilience, the more beneficial urban resilience can be to everyday civic life. However, the meaning creep, ie, the development of connotations and definitions that differ from the original or intended meaning, is problematic as it pertains to urban or city resilience specifically because there is a loss of nuance. Contrarily, when most people hear the word resilience they associate it with other definitions and connotations such as ecological resilience, psychological resilience, engineering resilience, institutional resilience, disaster risk reduction resilience or social resilience. City resilience is an amalgamation of all of these types.

Urban resilience and ecological resilience, and with them the safe-to-fail mentality, have come to the forefront of policy and societal discussion because the uptick in superstorm and natural disaster frequency has forced the world to pay attention to ecological and environmental issues.[8] This increase in ecological consciousness has led to discussions about cities and neighbourhoods being understood as habitats and ecosystems, and in turn ecosystems as infrastructure.[9] Since urban resilience is so deeply rooted in an ecological and systems-thinking ethos, many of the proposed solutions also take a similar tone. One significant branch of these proposed solutions is green infrastructure. Green infrastructure has been widely adopted in many

[8] Ahern, Jack. 2011

[9] da Silva, José Maria Cardoso, and Emily Wheeler. "Ecosystems as infrastructure." Perspectives in Ecology and Conservation (2017).

ways, forms, and functions as an urban resilience solution. However, despite the holistic nature of the city-scale and urban resilience framework, the application of green infrastructure often remains very siloed; with implemented solutions often only addressing singular problems or functions - out of place in the multi-faceted cityscape. A systems thinking approach, using interconnectedness, emergence and feedback loops to create and embed solutions, to green infrastructure is important when using it as a city resilience solution because of urban resilience's origins in ecological resilience. A complex problem in the complex adaptive system of the city requires an equally complex solution.

Nevertheless, even though this resilient city movement represents a new beacon of hope for cities' future for some, urban and/city-scale resilience, similarly to sustainability and sustainable development, has faced difficulty in widespread implementation and adoption by the public, private, and not-for-profit sectors. The problem with incorporating urban and/or city-scale resilience or even sustainability is not just implementation. The fundamental issue at hand is how might these frameworks for city improvement be implemented in a meaningful way that results in impactful outcomes beyond the superficial and the cosmetic. Additionally, the challenges that the term and the movement of city-scale resilience face in widespread adoption, implementation, and recognition do not end with conflicting historical meanings and uses of the word resilience. There is also the naïveté and growing pains involved with establishing a new concept, the dangers of pushing promotion efforts of urban resilience without simply developing a new buzzword, distortion by commercialization, and the nuance of the urban or city-scale resilience concept itself.

Research Questions and Thesis Structure

This thesis research sought to fill this gap in knowledge by answering two main questions:

1. Does the nuanced, imprecise, and somewhat novel nature of the term resilience in city-scale contexts affect the efficiency and outcomes of its implementation?
2. Can more fully embracing and utilizing the multi-functionality of green infrastructure improve city-scale resilience efforts?

The first research question is explored by conducting an evaluation of ten cities from the Rockefeller Foundation's 100 Resilient Cities Initiative using urban system performance qualities as the evaluation criteria. The evaluation of these cities revealed a set of distinguishing features for city resilience building approaches that will be probably be the most effective, as well as recommendations for policy-making and decision-making when resilience building.

The second question is explored by looking at how green infrastructure is approached as a city resilience strategy solution in the ten cities that were evaluated. The selected green infrastructure case studies are a small capsule of examples of what cities embracing and utilizing the multi-functionality of green infrastructure might look like based on information gleaned during the assessment of the cities and their city resilience strategies. These case studies show how approaching city solutions in the city as a complex adaptive system can have added benefits in contrast to linear or cosmetic solutions.

This thesis is separated into four chapters: Chapter 2 is the literature review. It defines resilience in general and how it relates to city resilience today as well as giving a deeper background of the progress made in city resilience building so far. It also further explains green infrastructure and the multi functionality of green infrastructure. Chapter 3 is the methodology

which describes in further detail the process by which the ten cities were chosen, steps in the assessment process, and the limitations of the methodology employed in this thesis. Chapter 4 outlines preliminary analysis and limitations of the 100 Resilient Cities initiative, the comparison of selected cities by shocks and stresses, the evaluation criteria and the scoring system, the final results and discussion, and the green infrastructure case studies. Finally, Chapter 5 is the conclusion and concludes the thesis, giving a recap of what was accomplished by this research, the implications for the study of city resilience and the scientific community and opportunities for further research in the future.

CHAPTER 2

LITERATURE REVIEW

This literature review is divided into two sections: 1) Resilience, its definitions, applications and the rising popularity and discussion of city resilience, 2) Green infrastructure, its definitions, where it came from and how its applied as a city resilience approach or solution. This first section will discuss the history of resilience and its implications leading up to urban resilience. It will also discuss urban resilience, the differences between urban resilience and other commonly cited types of resilience such as engineering resilience and ecological resilience. Finally, the second section of the literature review will introduce green infrastructure as a city resilience solution approach and on a micro-scale demonstrate how taking advantage of existing relationships and understanding cities as systems can create synergistic results.

1. Resilience: definitions and applications

Resilience and resiliency are synonyms, with the following modern definitions. This thesis will discuss resilience from an urban perspective and at a city scale. However, in order to fully capture how urban resilience is interpreted at present, particularly for urban purposes, we need to understand how those connotations came about.

RESILIENCE

1. The capacity to recover quickly from difficulties; toughness.

   "But as the day went on they started to find some resilience"

   'The panicky reaction of players at the US Open betrayed their lack of resilience in the face of adversity.'

   'New York has risen from the ashes with admirable resilience.'

2. The ability of a substance to spring back into shape; elasticity.

   'nylon is excellent in wearability, abrasion resistance and resilience'

   'Polypropylene is being used more and more widely in the manufacture of carpeting due to its high resilience to wear and stain proof properties.'

-The Oxford New Living Dictionary[10]

The Oxford Dictionary definition above references both of the prevailing meanings of resilience. The first, the ability to recover quickly, is often used synonymously with persistence or perseverance. However, the relationship between resilience and persistence or perseverance is

[10] *Oxford Living Dictionaries: English.*2018. Accessed January 11, 2018. https://en.oxforddictionaries.com/definition/resilience.

causal rather than synonymous. Resilience precedes persistence. Defined this way, persistence is really a consequence of resilience. The two characteristics can even be mutually exclusive. On the other hand, the second definition of resilience, elasticity or the ability of a substance to spring back into shape, also causes "meaning creep" because it connotes indestructibility and toughness. Resilience, of a substance or a material, does not equivalently mean indestructibility but rather that a resilient material can also be indestructible, or can be indestructible by virtue of its resilience. In this way, resilience, and its applications such as urban resilience, tend to be colloquially misunderstood; not necessarily because the term itself is poorly defined but because its connotations differ greatly from its actual meaning. However, the public may only understand a resilient building as one that didn't topple during a tsunami or hurricane. This nuanced difference in understanding or gap in knowledge between an academic's understanding of resilience and the public stakeholder or decision-maker's understanding of resilience is precisely what makes effective implementation and resilience building elusive.

Although the word resilience is believed to have first been introduced to the English-speaking society dialectic in the early 1620's, its roots are Latin; derived from the Latin words resilire or resilio meaning "to bounce","to leap", or "to retract".[11] Nevertheless, as aforementioned, in everyday discourse outside academic circles it has come to connote toughness, infallibility, perseverance, and even indestructibility.

The Latin words resilire and resilio were commonly used by Latin writers such as Cicero in reference to leaping or bouncing frogs, and to rebound from something unsavory. In 1529, the

[11] Alexander, D. E. "Resilience and disaster risk reduction: an etymological journey." *Natural Hazards and Earth System Sciences Discussions*1, no. 2 (2013): 1257-284. doi:10.5194/nhessd-1-1257-2013.

English verb resile appeared in State Papers from King Henry VIII in reference to discord with his first queen, meaning to retract, to rebound or to return to a former state (away from her).[12]

The word resilience was first coined in the middle of the 17th century as a physics and mechanics term. Bacon is credited with first using the term in 1625 to describe the persistence of echoes; qualifying them as resilient. By the 1850's, resilience was not only used to describe rebounding and elasticity but also as a mechanics term to qualify the strength and ductility of steel beams, ie, the ability of the steel to remain structurally sound, to return to its original state under stress. And in the 1950's, psychological resilience became popular. This application of resilience in the field of psychology typically is used to suggest that the person described has grit and perseverance and can weather through challenging experiences such as a natural disaster or a death in the family.[13]

[12] Alexander, D. E. "Resilience and disaster risk reduction: an etymological journey." *Natural Hazards and Earth System Sciences Discussions*1, no. 2 (2013): 1257-284. doi:10.5194/nhessd-1-1257-2013.

[13] Alexander, D. E. "Resilience and disaster risk reduction: an etymological journey." *Natural Hazards and Earth System Sciences Discussions*1, no. 2 (2013): 1257-284. doi:10.5194/nhessd-1-1257-2013.

ECOLOGICAL RESILIENCE

"a measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables."[14] In 1973, C.S. Holling adapted this term as an ecological concept. Holling's concept of ecological resilience and the stability of ecosystems was a landmark that impacted academic and social circles because it introduced the resilience of a system by virtue of the maintenance of its relationships and structure. It adds dynamism to the study of complex systems. If we use cities as an example of such an ecosystem, Holling's definition applied to city resilience is a city's ability to change, grow, and continue to exist and function despite disturbance and perturbations such as generational change, natural disaster, and climate change. It is beyond simply bouncing back or returning to an existing state but rather understanding ecosystems as being made up of complex relationships. What is so intrinsically important about Holling's work is the introduction of multiple possible equilibria and adaptation; where ecosystems and cities can exist at several different equilibria - where ecosystems and specifically urban, city-scale ecosystems can fail gracefully and adapt to change and disturbance. They are designed in such a way that they can be drastically disturbed and changed without destroying the vital relationships and infrastructure that keep them functioning.[15] Holling's definition of resilience takes the Oxford definition a step further by adding a layer of nuance with systems thinking.

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[14] Holling, C. S. "Resilience and Stability of Ecological Systems." *Annual Review of Ecology and Systematics* 4, no. 1 (1973): 1-23. doi:10.1146/annurev.es.04.110173.000245.

[15] Holling, C. S., Craig R. Allen, and Lance H. Gunderson. 2009. *Foundations of Ecological Resilience*. Washington, DC: Island Press, 2009. *eBook Collection (EBSCOhost)*, EBSCO*host* (accessed January 19, 2018).

The primary distinguishing difference between Holling's definition of ecological resilience and city-scale or urban resilience is the added social layer of power structures, socioeconomic factors, and institutions.[16] This manifests itself in the nature of disturbance. Disturbance in an ecological system is usually due to natural forces from abiotic or biotic features such as predation, natural disasters such as flooding, climate change. The social aspect adds another layer of complexity to city resilience. Disturbance in a city system can be economic disturbance such as a global financial crisis, social disturbance such as civil unrest or a mass shooting, or physical or environmental disturbance such as an earthquake or a tornado.

[16] Mazur, Laurie. "Bounce Forward: Urban Resilience in the Age of Climate Change." Strategy paper from Island Press and the Kresge Foundation (2015).

URBAN RESILIENCE

Several organizations have done considerable work to research, define and contribute to the body of knowledge on urban or city-scale resilience. These include the Kresge Foundation, the United Nations, Arup, Siemens, the World Bank, the Resilience Alliance, and the Rockefeller Foundation's 100 Resilient Cities. These publications on urban resilience and resilient cities were reviewed for gaining a deeper understanding of city's resilience, especially the difference between what is and what is not city resilience:

(City) Resilience is…

"Resilience is the capacity of a community to anticipate, plan for, and mitigate the dangers – and seize the opportunities – associated with environmental and social change."[17]

"In the context of cities, resilience translates into a new paradigm for urbanization and influences the way we understand and manage urban hazards, as well as urban planning in general. It provides practical rules of thumb that can guide stakeholders' decisions to incorporate the management of disasters and climate risks into urban investments."[18]

A part of culture and a way of life[19]

Resilience determines the persistence of relationships within a system and is a measure of the ability of these systems to absorb changes of state variables, driving variables, and parameters.[20]

Resilience is an on-going journey of adapting to a changing world.[21]

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[17] Mazur, Laurie. "Bounce Forward: Urban Resilience in the Age of Climate Change." Strategy paper from Island Press and the Kresge Foundation (2015).

[18] Jha, Abhas K., Todd W. Miner, and Zuzana Stanton-Geddes, eds. *Building Urban Resilience: Principles, Tools, and Practice*. Publication. World Bank.

[19] Rodin, Judith. *The resilience dividend: being strong in a world where things go wrong.* Public Affairs, 2014.

[20] Holling, C. S. "Resilience and Stability of Ecological Systems." *Annual Review of Ecology and Systematics* 4, no. 1 (1973): 1-23. doi:10.1146/annurev.es.04.110173.000245.

[21] Ramallah's city resilience plan

"Regardless of its application, the term resilience has a number of common characteristics such as the ability to absorb and then recover from an abnormal event, being ready and prepared to face threats and events which are abnormal in terms of their scale, form or timing, an ability and willingness to adapt to a changing and sometimes threatening environment; a tenacity and commitment to survive; and a willingness of communities and organizations to rally around a common cause and a shared set of values."[22]

"Resilience often involves trade-offs in the short, medium, and long-term; trade-offs between long-term investment versus short-term returns for example"[23]

(City) Resilience is not…

Resilience is not risk migration: "it increases not just preparedness but also capacity to respond to a disaster and swiftly recover from it."[24]

"Resilience is not a destination. It's a means by which we can determine our destination as well as providing us with the means of getting there."[25]

"Resilience is not an end state; it involves an iterative process of learning and adaptation."[26]

"The process of building resilience is not value-neutral; decisions about what to protect and strengthen reflect deeply entrenched values and power structures. Therefore, true resilience begins with a searching inventory of the systems that comprise cities, and of their capacity to meet human needs sustainably and equitably."[27]

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[22] McAslan, Alastair. "The concept of resilience: Understanding its origins, meaning and utility." *Adelaide: Torrens Resilience Institute* (2010): 1-13.

[23] Zurich. "How Your Business Could Be Linked To The Cape Town Water Crisis." Bloomberg.com. April 12, 2018. Accessed April 19, 2018. https://www.bloomberg.com/news/sponsors/zurich/how-your-business-could-be-linked-to-the-cape-town-water-crisis/?adv=6712&prx_t=jooDAAAAAAFEANA.

[24] Jha, Abhas K., Todd W. Miner, and Zuzana Stanton-Geddes, eds. *Building Urban Resilience: Principles, Tools, and Practice*. Publication. World Bank.

[25] Rodin, Judith. *The resilience dividend: being strong in a world where things go wrong.* Public Affairs, 2014.

[26] Mazur, Laurie. "Bounce Forward: Urban Resilience in the Age of Climate Change." Strategy paper from Island Press and the Kresge Foundation (2015).

[27] Mazur, Laurie. "Bounce Forward: Urban Resilience in the Age of Climate Change." Strategy paper from Island Press and the Kresge Foundation (2015).

"Resilience is not optimal engineering design."… "Cities ought to adopt a robust approach to uncertainty and unknown risks that uses a balance of ecosystem measures and land use options that incorporate more flexibility into engineering designs and take into account potential weak spots and failure. Urban planners must understand and incorporate natural ecosystem services into infrastructure and resilience projects. This approach will help keep cities from being locked into financing large-scale investments that might prove obsolete if in future the risks change."[28]

The preceding quotes describe some of the important concepts of city resilience. The variance in these definitions exhibits the very imprecision that is indetifiedd here. At a macro-scale, city resilience is a its ability or capacity to recover, to adapt, to persist in a changing world. It represents a new paradigm or new frontier and offers practical tools for decision making in the realm of urban investments. City resilience thinking forces us to think about the city over a myriad of time scales and make trade-off decisions as to whether new projects and initiatives will aim or need to be effective in just the short term, in the long term, or both. On a micro-scale, for city resilience to be successfully implemented, civic engagement and community involvement is vital because these communities are the ones that will sustain the change. Thus, a central element of city resilience is establishing a shared set of values or common cause around city improvement and city identity. The goal in building resilience at the social resilience level is to make it a part of culture and a way of life so it becomes something that citizens practice daily; so when a disaster or disruption arises everyone already knows what to do and will quickly respond in kind.

At the same time, city resilience is not simply risk migration or disaster risk reduction and there is not an end state that we are working towards by building city resilience. City resilience is not a disruption-proof destination, but rather an on-going process of better

[28] Jha, Abhas K., Todd W. Miner, and Zuzana Stanton-Geddes, eds. *Building Urban Resilience: Principles, Tools, and Practice*. Publication. World Bank.

understanding how the city functions as a complex adaptive system so that we can strengthen and improve it by strengthening those relationships and creating new relationships. Applying city resilience requires using an ecological lens to approach cities and their problems. However, this ecological systems thinking approach and the urban hazards involved are not new. So, although applying this knowledge in this way is novel, the knowledge and hazards themselves are old and are being revisited.

Finally, city resilience is not optimal engineering design which designs for one problem or prepares for a singular type of disruption. Instead, by focusing on modularity, responding appropriately to unpredictability, and ecological approaches, building city resilience equips cities to respond to a range of predicted and unpredicted disruptions and fail, adapt, recover, and respond. Building city resilience is about the institutions, the citizens, the organizations, the physical environment being able to bounce back and functioning better at present by having become more resilient.

As aforementioned, several organizations made considerable contributions to the study of urban resilience. However, the Rockefeller Foundation and the 100 Resilient Cities Initiative is one of the organizations that have made the most impact in mobilizing city-scale resiliency planning worldwide, in a more consistent and/or standardized way, as this thesis will explain. The organization has been able to establish a network of cities around the world supporting the development of resilience strategies in those cities chosen, and the recognition of their work by the American Planning Association.[29]

[29] Stromberg, Meghan. "Planning for Resilience." American Planning Association. May 7, 2017. Accessed April 16, 2018. https://www.planning.org/blog/blogpost/9124762/.

In 2014, the Rockefeller Foundation in collaboration with Arup (international engineering, architecture and design consulting firm) designed the City Resilience Framework and launched the 100 Resilient Cities initiative with the purpose of providing "a lens through which the complexity of cities and the drivers which contribute to a cities' resilience could be understood." The result is an international network of 100 identified cities with different challenges in shocks and stressors, each of which has appointed a City Resilience Officer to lead the charge to create a City Resilience Strategy and a very thoroughly created approach to building city resilience both for disaster risk reduction and improvement of everyday city function and civic life.[30] Some cities are further along than others at building their resilience.

[30] A shock is a sudden, acute debilitating event or disturbance such as a power outage, earthquake, flood, or mass shooting. A stressor or stress is chronic, constant debilitating disturbance that cripples a city over time such as income inequality, underdeveloped public transportation, or homelessness.

2. Green Infrastructure

Green infrastructure is "a network of natural, semi-natural and restored areas designed and managed at different spatial scales (from local to global), that encompasses all major types of ecosystems (marine, terrestrial and freshwater), and that aims to conserve biodiversity, mitigate emissions of greenhouse gases, enable societal adaptation to climate change, and deliver a wide range of other ecosystem services".[31]

It is a multi-functional approach for attempting to achieve urban resilience goals. The birth of green infrastructure and interconnected greenway systems as a method of providing ecosystem services and stormwater mitigation can be traced back to over 150 years ago with a movement concerned with incorporating and preserving nature with thought leaders like Henry David Thoreau and Frederick Law Olmsted, whose brain children include New York City's Central Park, Brooklyn's Prospect Park, and Boston's Emerald Necklace.[32] Even 150 years ago, before ecology had even become a discipline in a formal sense, he saw parks, green spaces and natural features not as isolated parts of a city, but rather as essential and fundamentally connected nodes of larger city ecosystems and the health and other co-benefits of their incorporation. For some time ecological infrastructure was used to describe natural and man-made greenway and park systems in this way and the focus was primarily on stormwater mitigation and human health and wellness.[33] However since 2004, green infrastructure has

[31]da Silva, José Maria Cardoso, and Emily Wheeler. (2017).

[32] Benedict, Mark A., Edward McMahon, and Va.) Conservation Fund (Arlington. 2006. Green Infrastructure : Linking Landscapes and Communities. Washington, DC: Island Press, 2006. eBook Collection (EBSCOhost), EBSCOhost (accessed April 17, 2018).

[33] Olmsted, Frederick Law. "Public parks and the enlargement of towns." The urban design reader(1870): 28-34.

become the dominant term used to describe the manmade infrastructure in the natural environment in scientific and policy circles (Figure 2). The term green infrastructure has evolved to perform several other functions such as urban heat island (UHI) reduction, climate adaptation, greenhouse gas and climate change mitigation, and biodiversity conservation.

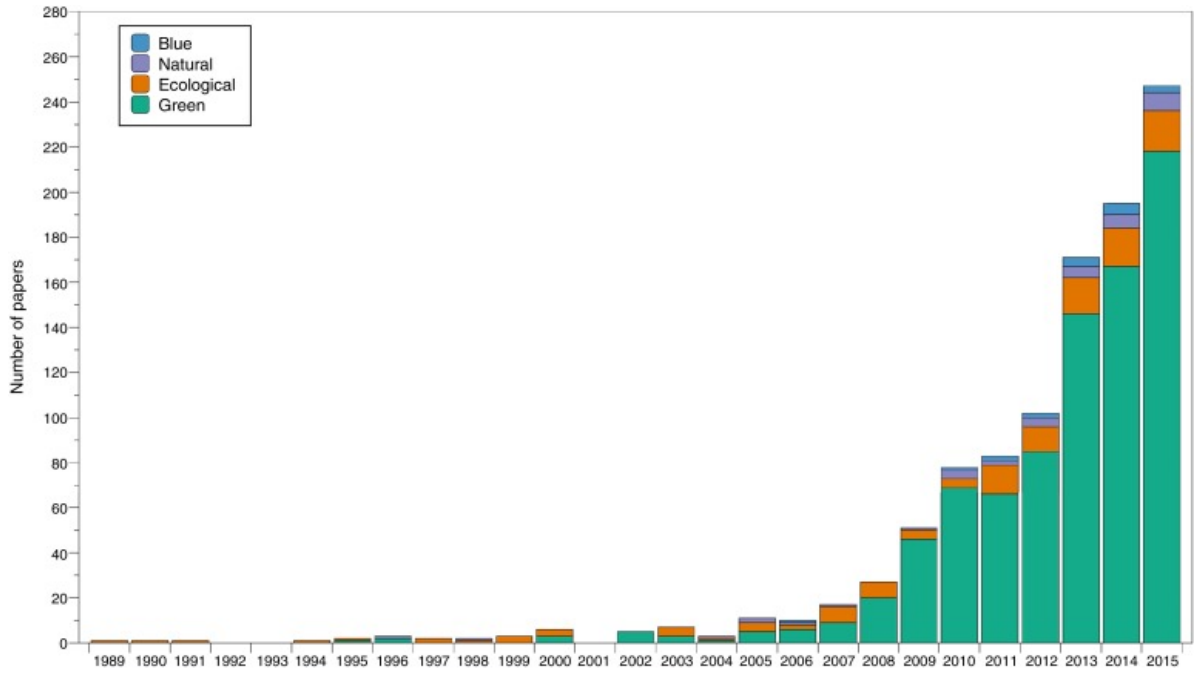


Figure 2. Frequency of Types of Infrastructure Mentioned in scientific literature[34]

In "Ecosystems as Infrastructure", after establishing green infrastructure's prevalence by sheer frequency, Da Silva and Wheeler go on to define green infrastructure to explicitly achieve these goals of city-scale resilience.[35]

[34] da Silva, José Maria Cardoso, and Emily Wheeler. "Ecosystems as infrastructure." (2017).

[35] Ibid.

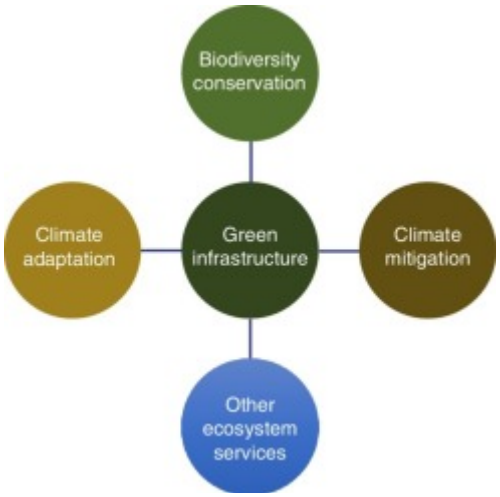


Figure 3. Green Infrastructure supporting model

Both the application of green infrastructure and resilience building principles are the most effective, robust, and result in co-benefits when approached using a systems thinking perspective, ie, focused on identifying, cultivating, and strengthening holistic networks. Beyond the initial green infrastructure component model presented by Da Silva and Wheeler, green infrastructure can be further broken down into more specific functions. Applications of green infrastructure as a city scale resilience solution tend to focus on climate mitigation and adaptation. However, for a holistic approach, investing in green infrastructure for a truly resilient city will require aiming to achieve all of these functions in an interconnected way rather than as cosmetic additions added at the end of a project.[36] For example, not just considering how to funnel stormwater out of a city or creating a greenway but also considering how stormwater can be used until it percolates, how it will percolate within the larger city water catchment system, and how the stormwater percolation system can have other functions in dry conditions.

[36] Benedict, Mark A., Edward McMahon, and Va.) Conservation Fund (Arlington. 2006. Green Infrastructure : Linking Landscapes and Communities. Washington, DC: Island Press, 2006. eBook Collection (EBSCOhost), EBSCOhost (accessed April 17, 2018).

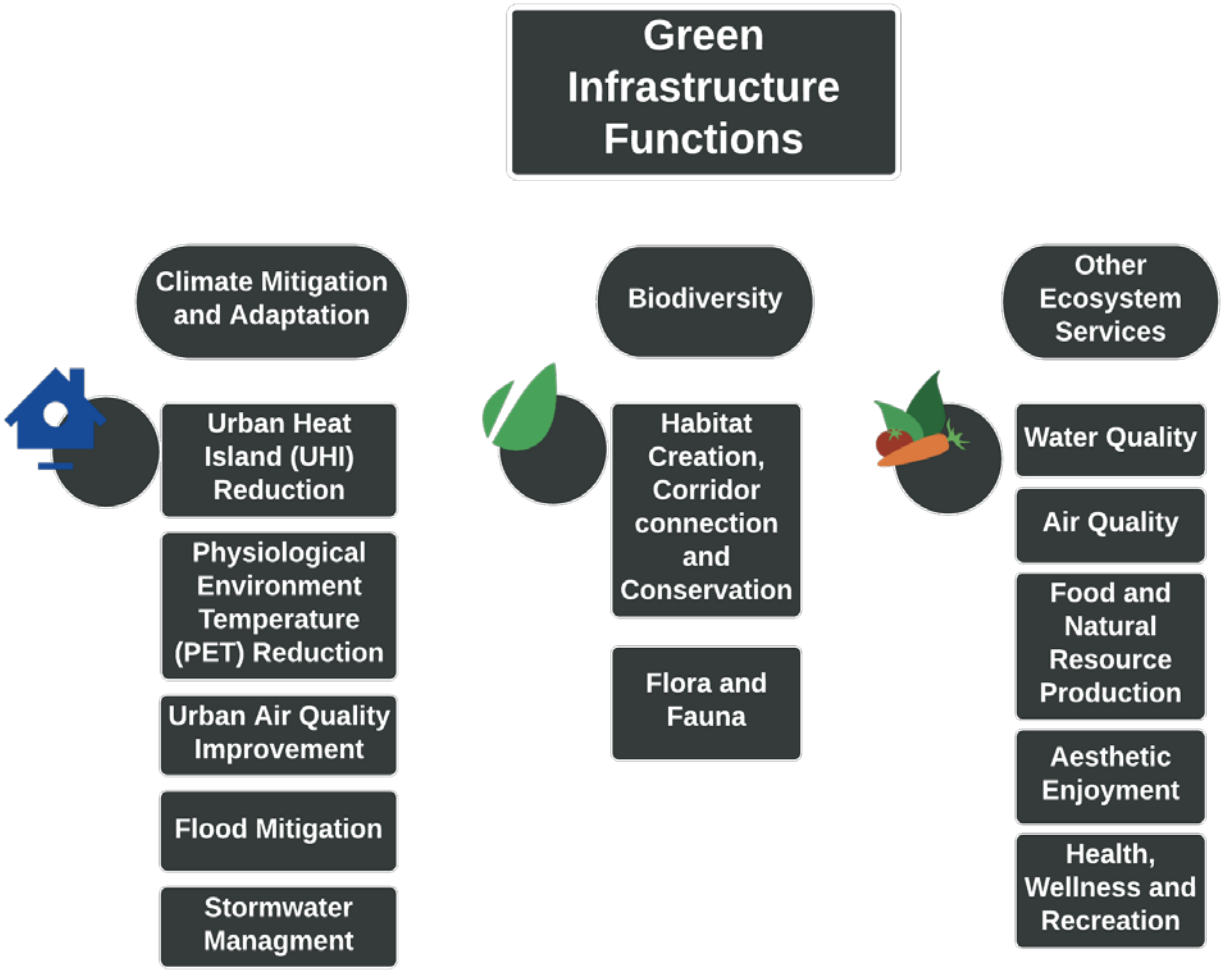


Figure 4. Multiple Functions of Modern Green Infrastructure[37]

Green infrastructure can be used to address climate mitigation and adaptation by strategically reducing the effects of UHI effect (creation of hot microclimates from trapped heat in urban hardscapes), improving air quality, and stormwater management by providing shade cover, evapotranspiration cooling, intercepting, absorbing and slowing down precipitation, storage of airborne pollutants and greenhouse gases, and water storage in wetlands, green cover,

[37] Figure created by Gabrielle Pierre using Lucidchart software.

green roofs, and artificial water storage systems.[38] Green infrastructure can also aid biodiversity and conservation efforts by creating, restoring, or protecting habitat areas in parks, green spaces and other green infrastructure methods. Other ecosystem services of green infrastructure include water and air quality, food production especially with urban agriculture, agroforestry and urban food forests, health, wellness, and recreation (Figure 4)[39].

Climate Mitigation and Adaptation: Physiological Equivalent Heat Reduction

With increasing heat stress in urban settings due to climate change driven temperature increases coupled with increasing urbanization and the associated built grey infrastructure that traps the heat, green infrastructure has been used to target and mitigate urban heat island issues. In a 2016 article about using green infrastructure for urban climate-proofing, a team in Munich studied pedestrian heat stress and how the installation or planting of trees, vegetated wall facades, and green roofs could affect physiological equivalent temperature (PET) reduction. They found that while tree cover and vegetated facades could significantly mitigate climate-change induced heat stress, green roofs were not effective in reducing heat island effects. At a micro-scale level, strategically placed trees and vegetated building facades reduced PET by providing shade and evapotranspiration benefits. However, the trees must be placed deliberately and intentionally because arbitrary increases in percentage tree cover will not necessarily bring

[38] "What Is Green Infrastructure?" EPA. August 14, 2017. Accessed April 22, 2018. https://www.epa.gov/green-infrastructure/what-green-infrastructure.

[39] Benedict, Mark A., Edward McMahon, and Va.) Conservation Fund (Arlington. 2006. Green Infrastructure : Linking Landscapes and Communities. Washington, DC: Island Press, 2006. eBook Collection (EBSCOhost), EBSCOhost (accessed April 17, 2018).

the desired climate mitigation benefits as there is a nonlinear relationship between the quantity of green infrastructure and PET reductions.[40]

Climate Mitigation and Adaptation: Urban Air Quality Improvement

With increased ambient pollution levels due to car emissions, refrigerant leakage, and industry concentrated in and around cities, green infrastructure has also been focused on addressing air quality improvement. Another study in 2017 used an i-Tree Eco model to assess the differing air pollutant uptake efficiencies of new and existing trees, green roofs, and vegetated walls. They found that although trees showed the highest net pollutant removal capabilities with relatively lower costs than green roofs and vegetated walls, green roofs and vegetated walls provided more local benefits such as energy savings.[41]

Climate Mitigation and Adaptation: Flood Risk Mitigation

Finally, it is well-known and documented that the hardscape and impermeable surfaces concentrated in cities and urban areas increase the rate of, volume of, and impurities in stormwater runoff. In 2007, Gill et al. found that in residential urban morphology types a green cover increase of 10% can result in a 4.9% reduction in runoff, a 10% increase in tree cover can

[40]Zölch, Teresa, Johannes Maderspacher, Christine Wamsler, and Stephan Pauleit. "Using green infrastructure for urban climate-proofing: An evaluation of heat mitigation measures at the micro-scale." Urban Forestry & Urban Greening 20 (2016): 305-316.

[41] Jayasooriya, V. M., A. W. M. Ng, S. Muthukumaran, and B. J. C. Perera. "Green infrastructure practices for improvement of urban air quality." Urban Forestry & Urban Greening 21 (2017): 34-47.

reduce runoff by 5.7%, and adding green roofs to all the buildings in town centres, residential, and high-density residential urban morphology types can reduce runoff by 17 to 19.9%.[42]

As exhibited by the previous examples of how green infrastructure can be applied in an urban setting for climate mitigation and adaptation, there are demonstrated benefits to this approach of addressing city-scale resilience. However, green infrastructure is not a catch-all solution and cannot address all of the problems in an urban setting. It is only one tool in a toolbox of tools that we have for using physical solutions for urban resilience. For example, green infrastructure can reduce the effects of heat stress and decrease stormwater runoff and subsequent flooding but it cannot completely eliminate them.

At the same time, green infrastructure can be criticized as manipulating nature to achieve desired anthropocentric goals. We should be cautious and meticulous about how we approach using green infrastructure to alleviate the ill effects of climate change and to build urban resilience because it is misinformed human manipulation that caused a majority of the complex problems that we face today.

Additionally, for green infrastructure to be as effective as possible in achieving urban resilience and thus ecological resilience for city ecosystems, we will need a more holistic approach. Current green infrastructure approaches are quite reductionist in nature. They attempt to address one or two functions at a time instead of full-blown multi-functionality. A more

[42] Gill, Susannah E., John F. Handley, A. Roland Ennos, and Stephan Pauleit. "Adapting cities for climate change: the role of the green infrastructure." Built environment 33, no. 1 (2007): 115-133.

multifunctional approach would both mimic ecosystems and nature and also possibly be significantly more effective since there are existing overlaps in the functions themselves.[43]

Finally, the use of the term green infrastructure and its meaning varies depending on what discipline is studying or implementing the practices: engineers and landscape architects might use green infrastructure to refer to stormwater and climate mitigation solutions, ecologists will use green infrastructure to refer to eco-restoration, a lawyer might see the public green space and economic incentives and energy saving. Further research could consider social resilience applications of green infrastructure and how it might be integrated with a more holistic approach.

[43] Sussams, L. W., W. R. Sheate, and R. P. Eales. "Green infrastructure as a climate change adaptation policy intervention: Muddying the waters or clearing a path to a more secure future?." Journal of environmental management147 (2015): 184-193.

CHAPTER 3

METHODOLOGY

This chapter outlines the methodology used in this thesis research in order to arrive at some answers to the original research questions:

a. Does the nuanced, imprecise, and somewhat novel nature of the term resilience in city-scale contexts affect the efficiency and outcomes of its implementation?
b. Can fully embracing and utilizing the multi-functionality of green infrastructure improve city-scale resilience efforts?

In the multi-city resilience strategy evaluation, ten cities were selected from the 100 Resilient Cities Network according to a set of criteria which are described in this chapter. These city resilience strategies were reviewed and compared by shocks and stresses that they might face. Then, the city resilience strategies were evaluated more rigorously using a derived set of resilient urban system qualities as evaluation criteria to score their feasibility and the potential impact of their initiatives. The final result of this evaluation is a scorecard that is presented in the analysis chapter.

This chapter is divided into five sections which correspond with the four main steps in the methodology and a final sections discussing the limitations of this approach.

1. Selection of Cities for City-scale/Urban Resilience Analysis
2. Review of the city resilience strategies of the selected cities and preliminary analysis by comparison of the ten (10) cities by shocks and stresses
3. City Resilience Strategy Analysis by urban system performance qualities
4. Comparative Analysis of selected cities by case studies of green infrastructure implementation and approaches
5. Limitations of this methodology

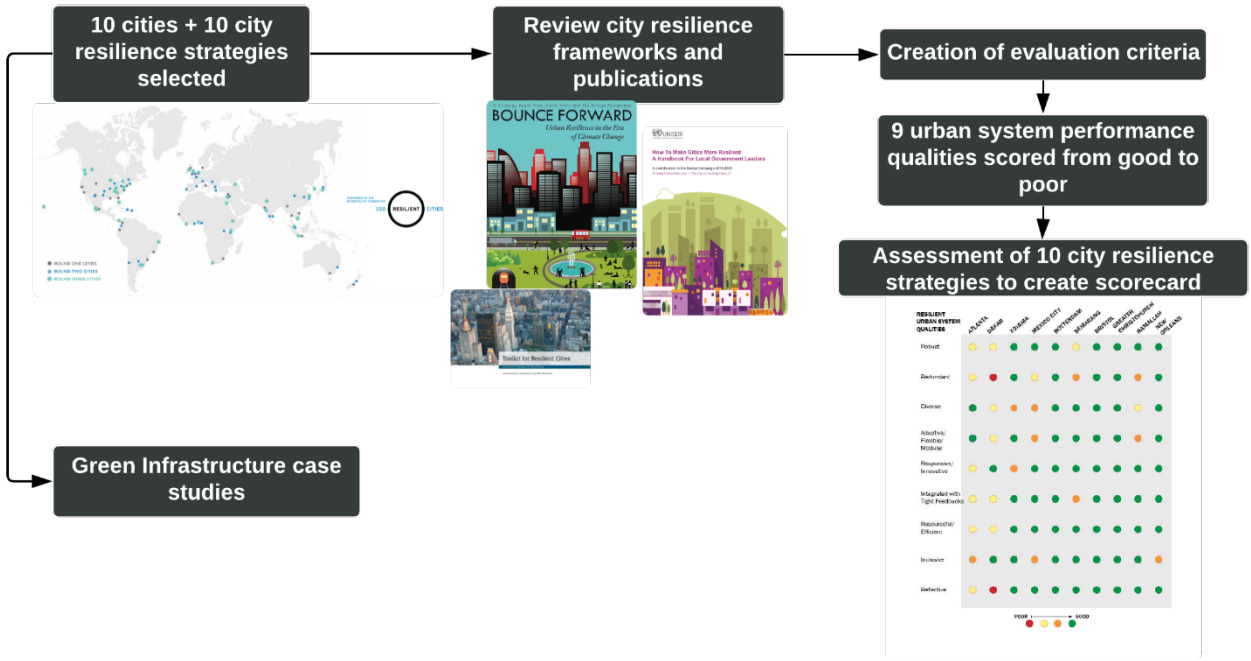


Figure 5. Flowchart showing methodology steps for the multi-city evaluation

1. Selection of Cities for City-Scale/Urban Resilience Analysis

Overall, ten cities were selected for analysis. The scope of this thesis was limited to ten cities for the purposes of scope management. However, further research would broaden the scope to all of the cities in the 100 Resilient Cities Network. The cities were selected for analysis using the following metrics and considerations:

A. The 100 Resilient Cities (100RC) member cities were selected as the study group that would be sampled for further analysis.

The case study and analysis cities were selected from the group of cities participating in the Rockefeller Foundation's 100 RC project for several reasons including ease of availability of information, the impact 100 RC has made in mobilizing city-scale resiliency planning as indicated by the establishment of a city network, their success in actively supporting resilience building in the cities chosen, and the recognition of their work thus far by the American Planning Association.[44]. Several foundations and movements have made attempts at capturing and studying urban and/or city-scale resilience or resilience in general, such as the Kresge Foundation, the United Nations Office for Disaster Risk Reduction (UNISDR), the Resilience Alliance. However, none have done so as comprehensively or brought it to the forefront of the public consciousness at the scale of the Rockefeller's Foundation's 100 RC initiative efforts. Most recently the United Nations has relaunched and revamped its City Resilience Profiling Tool as an international Urban Resilience Hub with several cities participating in their urban resilience workshops.

[44] Stromberg, Meghan. "Planning for Resilience." American Planning Association. May 7, 2017. Accessed April 16, 2018. https://www.planning.org/blog/blogpost/9124762/.

Beyond simply studying resilience and city resilience, in 2013 the Rockefeller Foundation 100 RC commissioned a deep dive study of resilience and specifically urban resilience and city resilience from Arup, an internationally renowned engineering, architecture, and economic development firm.[45] Then, they created a global network of cities committed to analyzing and improving their own resilience using a city resilience index and framework as a guide. Each city will publish a city resilience strategy outlining their commitments and on-going projects. As of March 2, 2018, there are 37 published city resilience strategies and 99 member cities in the network. The 100RC movement has attracted worldwide media attention because of the level of financial backing from the Rockefeller Foundation and this landmark attempt to reimagine cities and better equip them for climate change, natural disasters, migration and rapid urbanization etc.

The most significant achievement of the City Resilience Index created by the Rockefeller Foundation in conjunction with Arup is the level of nuance achieved in their description and framing of city resilience that is absent from a majority of the other authorities on the subject and making a complex and nuanced approach to city function and preparedness improvement accessible to pivotal citizens, stakeholders, and decision makers. Many of the other reports or studies focus on one aspect of city resilience such as How to Make Cities More Resilient: A Handbook for Local Government Leaders by UNISDR which focuses on disaster risk reduction or the Toolkit for Resilient Cities: Infrastructure, Technology and Urban Planning, a research project carried out by Arup and Siemens which focuses on critical infrastructure resilience. The 100 RC initiative seeks not only to address disaster risk reduction and aging infrastructure but

[45] Arup. "City Resilience Index - Arup." City Resilience Index - Arup. 2017. Accessed February 23, 2018. https://www.arup.com/perspectives/themes/cities/city-resilience-index.

also the chronic stresses that cities also face. They are concerned with improving the quality of civic life in cities and urban areas now and for generations to come; not simply when faced by disaster. Nevertheless, there are some limitations to using the 100RC movement city resilience strategies as the main data source in this analysis. The primary limitation is the inheritance of any biases made in the initial selection process to select the 99 current member cities from over 4000 applicant cities. These biases and limitations are explored and addressed later on as a part of the analysis chapter.

B. Ten cities were selected from the 99 member cities for further analysis.

This selection was conducted by considering the following factors and limitations:

i. Completion and publication of a city resilience strategy.

Only cities that had published city resilience strategies were considered for further analysis due to the availability and access to information afforded by using the city resilience strategies as the focal points of the research. It would have been difficult to find a similar depth or quality of information otherwise. All 99 cities in the network are working towards a city resilience strategy. However, as previously noted only 37 have been published as of March 2, 2018. Thus, this reduced the data set to 37 cities. At the time of download for analysis on December 5, 2017 only 36 city resilience strategies were published. So the original dataset in this analysis was actually these 36 cities with published city resilience strategies.

ii. Language of publication

The language in which the city resilience strategies were published was a limitation because six of the city resilience strategies were published in a language other than English; namely:

a. Paris, France published only in French
b. Porto Alegre, Brazil published only in Portuguese
c. Quito, Ecuador published only in Spanish
d. Santa Fe, Argentina published only in Spanish
e. Santiago de Chile published only in Spanish
f. Vejle, Denmark published only in Danish

The documents were too large to be translated into English using online translating software and were thus eliminated from the dataset selection pool. This reduced the potential cities for analysis to 30 cities.

iii. Diversity of region, wealth, GDP and/or resources, and of population size etc.

In order to glean the most insight from this analysis, a diverse sample is desirable so that the final conclusions are as impartial and as comprehensive as possible. Data was gathered and tabulated for all 99 cities for wealth, geographical region, country, and metropolitan population size. Additionally, there were three rounds of cities announced over the course of four years of the 100RC initiative. So, for the purposes of representing city strategies created across the life of the initiative at least one city from each round of the 100 RC initiative is represented in the final selection.

The final city selection represents a spread of both wealthier cities and unranked cities in terms of wealth, island nations, mainland cities, coastal cities, landlocked cities, some of the most populous cities (Mexico City) and the least populated cities (Ramallah, Palestine), and cities from all three rounds of the 100RC initiative.

iv. Green infrastructure playing a major role in their city resilience strategy

The final consideration when there were cities of similar geographic region, 100 RC round etc. was whether green infrastructure played a major role in the city resilience strategy since this role of green infrastructure as a city resilience solution was a topic of particular interest in this thesis research.

The ten cities selected for analysis are:

1. Atlanta, USA
2. New Orleans, USA
3. Rotterdam, The Netherlands
4. Dakar, Senegal
5. Semarang, Indonesia
6. Greater Christchurch, New Zealand
7. Toyama, Japan
8. Mexico City, Mexico
9. Ramallah, Palestine
10. Bristol, UK

Figure 6. Map of the ten cities included in the evaluation of city resilience strategies

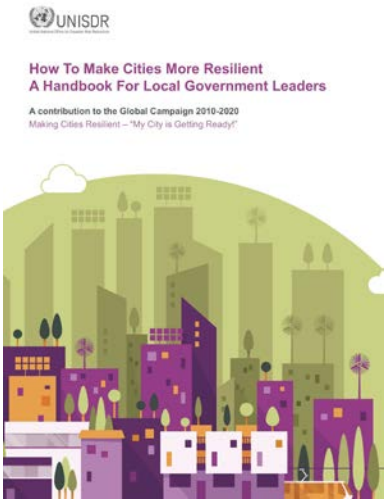
2. Review of the city resilience strategies and preliminary analysis by comparison of the ten (10) cities by shocks and stresses.

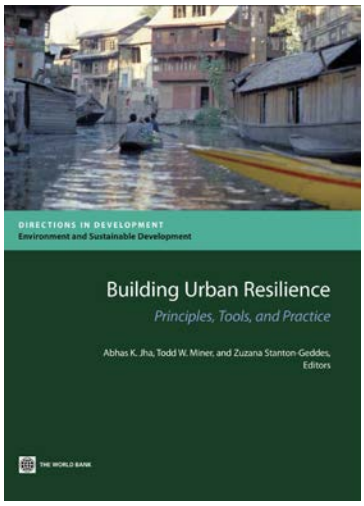
The city resilience strategies were reviewed and the shocks and stresses of each city was summarized in a table for side-by-side comparison. Similarities and differences in shocks and stresses were noted.

3. City Resilience Strategy Analysis

The city resilience strategy analysis consisted of the following steps:

1) Literature review of resilience, city resilience and urban resilience
2) Review of original reports created by Arup on city resilience and the creation of the city resilience framework, the Urban Resilience in the Era of Climate Change Report by the Kresge Foundation, Building Urban Resilience Report by the World Bank, the Toolkit for Resilient Cities research project by Siemens, Arup, and RPA etc. in order to create evaluation criteria for the evaluation of the city resilience strategies.





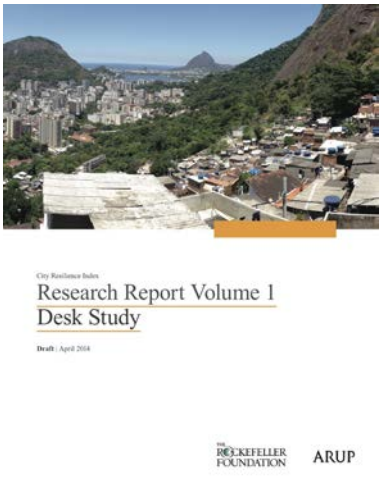


Figure 7. City and urban resilience authority publications that were reviewed

3) Categorizing of the city resilience strategies under the 12 city resilience goals in the original Arup city resilience reports. Each city resilience strategy is broken down into initiatives and actions to achieve overarching goals and themes. Some cities adhere closely to the format of goals prescribed by the 100RC initiative and others created their own amendments. But for ease of comparison, the city strategies were categorized or classified into the 12 overarching goals published in the 2016 update of the City Resilience Framework used by the 100RC member cities to aid in the evaluation process later on.

The 12 city resilience goals are: 1) Minimal Human Vulnerability, 2) Diverse Livelihood & Employment, 3) Effective Safeguards to Human Health & Life, 4) Collective Identity and Community Support, 5) Comprehensive Security & Rules of Law, 6) Sustainable Economy, 7) Reduced Exposure & Fragility, 8) Effective Provision of Critical Services, 9) Reliable Mobility & Communication, 10) Effective Leadership & Management, 11) Empowered Stakeholders, 12) Integrated Development Planning.

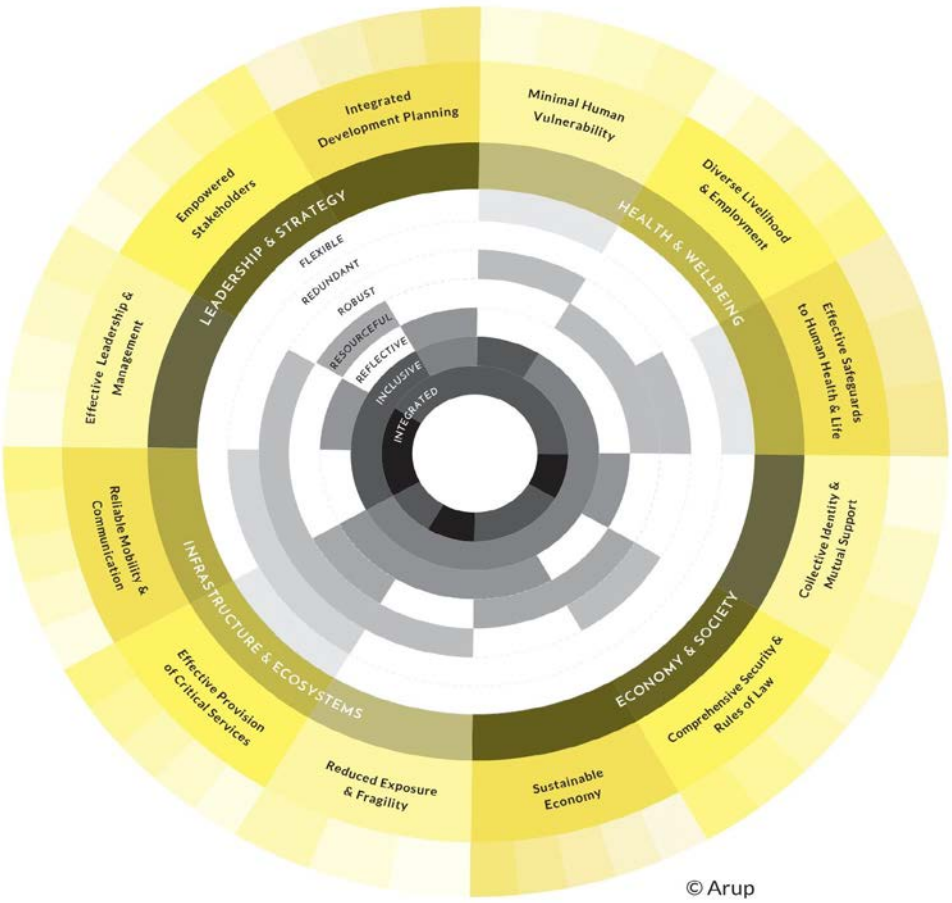


Figure 8. City Resilience Framework Lens showing the breakdown of city resilience goals [46]

4) Evaluation of the categorized initiatives of city resilience strategies according to the evaluation criteria to create a city resilience scorecard for each city. The process of creating the evaluation criteria and the results of this analysis are outlined in the following analysis chapter.

[46] Nancy Kete, "How to Build a Resilient City: The City Resilience Framework" (paper presented at the Women in Clean Energy Symposium, 2014).

4. Development of green infrastructure case studies of city strategies that indicate a nuanced understanding of city resilience

Green infrastructure case studies were created for some of the analyzed cities. These case studies highlight what the city has done and plans to do in the realm of green infrastructure. Each case study includes existing conditions and future planned development discussed in the city resilience strategy as well as additional research using outside sources such as local urban planning authorities, green infrastructure plans and stormwater management organizations. These case studies were chosen as examples of what fully embracing and utilizing the multi-functionality of green infrastructure can look like.

5. Limitations of the methodology

There are several limitations to this methodology namely:

a) Completely different cities with different populations, government structures and social hierarchies are very difficult to compare or evaluate comparatively
b) Cities starting at different stages of building resilience making them difficult to compare
c) City resilience being an imprecise concept with several interpretations. The concept is still a work in progress and the array of approaches and interpretations in its application evidences this point
d) The stakeholders and decision makers involved in each city are variable in terms of objectives and urban planning and/or ecological understanding and background and this is a considerable determinant in how the individual city resilience strategies developed.

CHAPTER 4

ANALYSIS

This chapter presents the analysis undertaken in this research thesis. It consists of five sections. During the city selection process, some preliminary observations and criticisms were revealed about how the 100 Resilient Cities Initiative selected the 99 pilot cities. These preliminary findings and limitations are noted in the first section. The second section presents the comparison of the cities by shocks and stresses they might face and overall similarities and differences. The third section outlines how the evaluation criteria were developed, the resilient urban system qualities themselves, and the scoring system. The fourth section presents the final results, the resilient urban system quality scorecard and discusses the results. Finally, section five of the analysis presents selected green infrastructure case studies from the ten city resilience strategies evaluated.

Analysis and Limitations of the 100RC selection process

Information and data about the member cities of the 100RC initiative of the Rockefeller Foundation was sourced and collated in order to create data tables for preliminary analysis of the 100 member cities involved, to identify and correct for limitations and biases as a precursor to the analysis of the city-scale resilience strategies, and to inform the selection process of the cities that will be used for further analysis.

The Rockefeller Foundation's 100 Resilient City (100RC) initiative is used as the focal point for the research and analysis in this thesis because they have spent the past five years, from late 2013 to present, cultivating a worldwide resilient city movement and network. Although there are several other organizations studying city resilience, the Rockefeller Foundation and 100 RC has effectively established themselves as the world expert in urban and city-scale resilience and created an unparalleled network for intercity collaboration on city resilience.

Nevertheless, there are some limitations and critique that were identified in the 100 Resilient Cities Initiative and its selection process. The identified limitations and critique of the selection of the 100 member cities and the 100RC initiative in general include:

1) The haphazard and biased nature of the city selection process

Overall, the nature of the city selection process seems somewhat haphazard and biased at first glance. In the Rockefeller Foundation's own words, the selection process is as follows:

"The 100 Resilient Cities Challenge was the application process by which cities join our network. 100RC selected a first group of 32 cities in December 2013, a second group of 35 in 2014, and its final round of winners in May 2016.

Members of the 100 Resilient Cities team and a panel of expert judges reviewed applications from prospective cities. The judges looked for innovative mayors, a recent catalyst for change, a history of building partnerships and an ability to work with a wide range of stakeholders."[47]

100 RC Frequently Asked Questions,

Which cities are part of the 100RC network? How does a city become a member?

[47] The Rockefeller Foundation. "Frequently Asked Questions (FAQ) About 100 Resilient Cites." 100 Resilient Cities. Accessed January 23, 2018. http://www.100resilientcities.org/100RC-FAQ/#/-_/.

This initiative was posed as a competition or a challenge. The selection process chose cities which "demonstrated a dedicated commitment to building their own capacities to prepare for, withstand, and bounce back rapidly from shocks and stresses." However, this selection process neglects other criteria such as identification of vulnerabilities and resilience challenges. Cities were only selected if they were projected to be success stories and have successful resilience strategy outcomes. Additionally, the competition model favors cities that already have resources to produce a high quality application package. Some of the cities that are extremely vulnerable to shocks and stresses may not have been able to do so; excluding them from this initial opportunity when they severely need the help. This is a fair position for 100RC to take since they are investing so much money (an initial investment pledge of 100 million USD) into this worldwide initiative and this stage is a pilot program creating a powerful intercity network that was previously unheard of. Nevertheless, the movement may not be as revolutionary as they would like to make it seem. The $1 million investment per city from the Rockefeller foundation primarily goes towards hiring a Chief Resilience Officer for 2 to 3 years and producing the resilience strategies. The resilience changes are then left largely to the city and its local, regional, and international partners to fund and implement - as it should be. Otherwise, this initiative would run the risk of colonialist activity. At the same time, the overall selection process focused solely on impact and outcomes calls the credibility and motives of the 100 RC into question because there is certainly some amount of bias and exclusion involved; whether malicious or completely unintended in nature.

2) The role that politics and democratic ideals played in the selection process

Although there are some potentially controversial or diverse additions to the selected group of 100 cities, most notably Ramallah in Palestine and Tel Aviv in Israel, politics and the perpetuation of democratic ideals seemed to play a central role in the selection the 100 RC cities and ousting of six cities along the way. In fact, the name 100 resilient cities is misleading because as of present, there are only 99 remaining member cities in the network as shown below and in the list on the following page:

Figure 9. Map showing the 99 cities in the 100 Resilient Cities Network[48]

[48] *Athens, Greece Resilience Strategy.*Publication. June 13, 2017. The Rockefeller Foundation. "Frequently Asked Questions (FAQ) About 100 Resilient Cites." 100 Resilient Cities. Accessed January 23, 2018. http://www.100resilientcities.org/100RC-FAQ/#/-_/.

1. Accra, Ghana
2. Addis Ababa, Ethiopia
3. Amman, Jordan
4. Athens, Greece
5. Atlanta, USA
6. Bangalore, India
7. Bangkok, Thailand
8. Barcelona, Spain
9. Belfast, United Kingdom
10. Belgrade, Serbia
11. Berkeley, USA
12. Boston, USA
13. Boulder, USA
14. Bristol, United Kingdom
15. Buenos Aires, Argentina
16. Byblos, Lebanon
17. Calgary, Canada
18. Cali, Colombia
19. Can Tho, Vietnam
20. Cape Town, South Africa
21. Chennai, India
22. Chicago, USA
23. Christchurch, New Zealand
24. Colima, Mexico
25. Da Nang, Vietnam
26. Dakar, Senegal
27. Dallas, USA
28. Deyang, China
29. Durban, South Africa
30. El Paso, USA
31. Glasgow, Scotland
32. Guadalajara (Metro), Mexico
33. Haiyan, China
34. Honolulu, USA
35. Huangshi, China
36. Jaipur, India
37. Jakarta, Indonesia
38. Juarez, Mexico
39. Kigali, Rwanda
40. Kyoto, Japan
41. Lagos, Nigeria
42. Lisbon, Portugal
43. London, England
44. Los Angeles, USA
45. Louisville, USA
46. Luxor, Egypt
47. Greater Manchester, England
48. Mandalay, Myanmar
49. Medellin, Colombia
50. Melaka, Malaysia
51. Melbourne, Australia
52. Mexico City, Mexico
53. Greater Miami and the Beaches, USA
54. Milan, Italy
55. Minneapolis, USA
56. Montevideo, Uruguay
57. Montreal, Canada
58. Nairobi, Kenya
59. Nashville, USA
60. New Orleans, USA
61. New York, USA
62. Norfolk, USA
63. Oakland, USA
64. Panama City, Panama
65. Paris, France
66. Paynesville, Liberia
67. Pittsburgh, USA
68. Porto Alegre, Brazil
69. Pune, India
70. Quito, Ecuador
71. Ramallah, Palestine
72. Rio de Janeiro, Brazil
73. Rome, Italy
74. Rotterdam, The Netherlands
75. Salvador, Brazil
76. San Francisco, USA
77. San Juan, Puerto Rico
78. Santa Fe, Argentina
79. Santiago de los Caballeros, Dominican Republic
80. Santiago (Metro), Chile
81. Seattle, USA
82. Semarang, Indonesia
83. Seoul, South Korea
84. Singapore, Singapore
85. St. Louis, USA
86. Surat, India
87. Sydney, Australia
88. Tbilisi, Georgia
89. Tel Aviv, Israel
90. The Hague, The Netherlands
91. Thessaloniki, Greece
92. Toronto, Canada
93. Toyama, Japan
94. Tulsa, USA
95. Vancouver, Canada
96. Vejle, Denmark
97. Washington, DC, USA
98. Wellington, New Zealand
99. Yiwu, China

Table 1. Cities in the 100 Resilient Cities Network[49]

[49] The Rockefeller Foundation. "Frequently Asked Questions (FAQ) About 100 Resilient Cites." 100 Resilient Cities. Accessed January 23, 2018. http://www.100resilientcities.org/100RC-FAQ/#/-_/.

The six cities that were removed from the network are:

Alameda, USA

Arusha, Tanzania

Ashkelon, Israel

Bengalaru, India

Jacksonville, USA

Phnom Penh, Cambodia

Jacksonville, Florida, upon further research was removed when the democratic mayor of the city was replaced with a republican one in the mayoral election, without any further explanation.[50] Any city removed from the list was quietly and swiftly taken down from the 100RC website with no public notice or explanation. After contacting 100RC for more information about the reasons for these removed cities leaving, there has been no response.

3) The skewed representation of US cities by sheer frequency

Twenty-four of the total 99 selected cities are located in the United States of America or its territories. This skewed distribution of represented cities may not be intentional but it is certainly concerning. It almost makes the other selected cities seem tokenized for the purpose of being a global movement and ticking off regional boxes. While the United States is one the largest economies and populations in the world, the spread of cities in the selection is blatantly americentric because of some obvious world powers and regions that are excluded such as Germany or Russia. Other noticeably excluded and sparsely represented areas included much of

[50] Benk, Ryan. "Jacksonville Drops Out of Rockefeller Foundation's 100 Resilient Cities." WJCT. February 3, 2016. http://news.wjct.org/post/jacksonville-drops-out-rockefeller-foundations-100-resilient-cities.

the African continent, Southeast Asia, and South America and the Caribbean. This is especially concerning because these regions are urbanizing at the highest rates and were most affected by disasters between 1985 and 2015 as shown in the diagram below.[51]

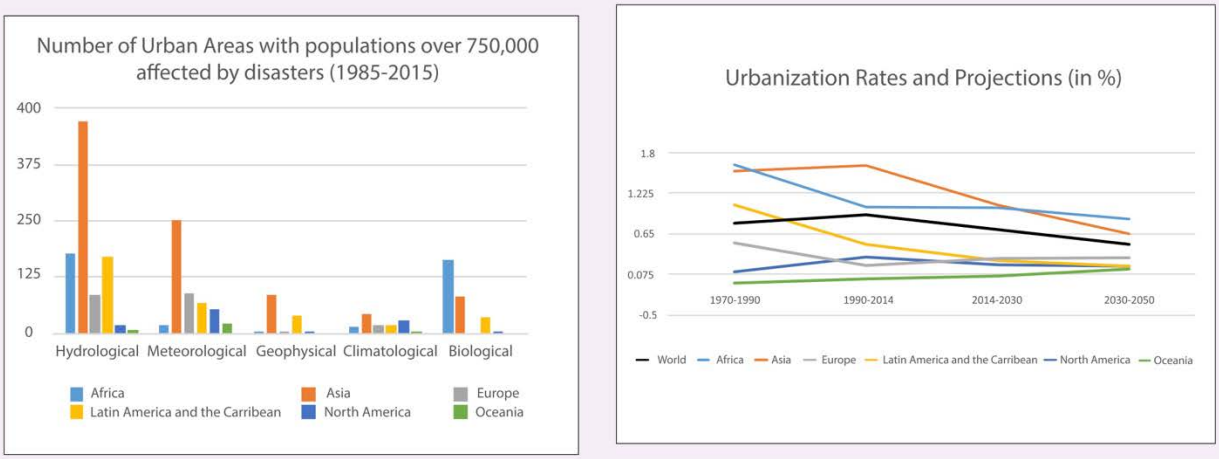


Figure 1:Urban areas in Asia, followed by those in Africa and the Latin America and the Caribbean regions have been the most affected by disasters that took place between 1985 and 2015.
Credit: CUDRR+R (Based on Data on 2014 World Urbanization Prospects, UN-DESA and EM-DAT, CRED)

Figure 10. Graphic representation that between 1985 and 2015 urban areas in Asia, Africa, Latin America and the Caribbean have been most affected by disasters[51]

4) The surprising absence of island nations represented in the list of the cities

Urban resilience is a framework for addressing several issues at the city-scale such as economic inequality, climate change mitigation and adaptation, and natural disaster risk reduction. Island nation countries are arguably some of the most vulnerable to rising sea levels, increases in ambient air temperature, socioeconomic vulnerability, and widespread destruction by any major disturbance such as a tsunami or a hurricane or global economic recession; a lot of the issues that the 100 RC initiative claims it intends to address. Yet, although several low lying

[51] United Nations Office for Disaster Risk Reduction, How to Make Cities More Resilient Handbook (Geneva 2012).

cities, coastal cities, and vulnerable cities are represented, a first pass of analysis revealed that island nations are largely absent from the list of cities represented in the 100 RC.

Of the 195 existing countries in the world, 46 of them are island nation countries. Many of which are already battling the effects of climate change and other city resilience challenges and remain the most vulnerable to these issues as aforementioned. They represent 24% of the world's countries and have a combined population of 654,171,525 (over 650 million) people - 8.6% of the worldwide populace.[52] Of the 100 member cities selected, only 13 cities out of 100 (13%) reside on true islands and only 6 island nations are represented out of a total of 46 represented countries. For comparison, of the selected cities, 24% of them are located in the USA.

This is especially apparent when you compare the selected cities in the USA in comparison to the glaring absence of cities selected in the island nations of Southeast Asia.

Figure 11. Map highlighting absence of selected cities in Southeast Asia in comparison to US selected cities

[52] World Atlas. Which Are the Island Countries in the World? 2018. https://www.worldatlas.com/articles/which-are-the-island-countries-of-the-world.html.

City	Country	Region	Island Type
Belfast	UK	Europe	
Bristol	UK	Europe	
Greater Christchurch	New Zealand	Australasia	
Greater Manchester	UK	Europe	
Honolulu	USA	North America	Asian Pacific Island
Jakarta	Indonesia	Asia	Indian Ocean Island
Kyoto	Japan	Asia	Asian Pacific Island
Melaka	Malaysia	Asia	Indian Ocean Island
San Juan	USA (Puerto Rico)	North America	Caribbean Island
Santiago de los Caballeros	Dominican Republic	LatAm	Caribbean Island
Semarang	Indonesia	Asia	Asian Pacific Island
Toyama	Japan	Asia	Asian Pacific Island
Wellington City	New Zealand	Australasia	

Table 2. Island nations in the 100 Resilient Cities network

5) The existing wealth of a majority of the cities represented

A majority of the cities represented in the 100 RC are quite wealthy. 46% of the member cities are among the projected 2020 top 150 richest cities in the world.[53] These cities indeed face several resilience challenges and since many are country-wide or regional economic centers, in many ways the survival of these cities in the future will determine the socioeconomic survival of the entire world. Nevertheless, as stated previously with the island nation cities, it is concerning what cities were overlooked in order to primarily focus on these powerhouses.

City	Country	Region	Richest City Ranking
Cape Town	South Africa	Africa	70
Lagos	Nigeria	Africa	98
Nairobi	Kenya	Africa	146
Addis Ababa	Ethiopia	Africa	147
Seoul	South Korea	Asia	17
Jakarta	Indonesia	Asia	33
Singapore	Singapore	Asia	40
Bangkok	Thailand	Asia	46
Chennai	India	Asia	84
Pune	India	Asia	97
Surat	India	Asia	119
Jaipur	India	Asia	137
Sydney	Australia	Australasia	32
Melbourne	Australia	Australasia	43
London	UK	Europe	4
Paris	France	Europe	6
Barcelona	Spain	Europe	42
Rome	Italy	Europe	45

[53] City Mayors: Richest Cities in the World in 2020 by GDP. Accessed January 23, 2018. http://www.citymayors.com/statistics/richest-cities-2020.html.

City	Country	Region	Richest City ranking
Milan	Italy	Europe	48
Lisbon	Portugal	Europe	61
Athens	Greece	Europe	85
Rotterdam	The Netherlands	Europe	120
Mexico City	Mexico	LatAm	7
Buenos Aires	Argentina	LatAm	11
Rio de Janeiro	Brazil	LatAm	31
Santiago de Chile	Chile	LatAm	53
Porto Alegre	Brazil	LatAm	91
Medellin	Colombia	LatAm	112
Tel Aviv	Israel	Middle East	56
New York City	USA	North America	2
Los Angeles	USA	North America	3
Chicago	USA	North America	5
Washington D.C.	USA	North America	10
Boston	USA	North America	12
Dallas	USA	North America	15
Atlanta	USA	North America	18
Oakland	USA	North America	19
San Francisco	USA	North America	19
Greater Miami and the Beaches	USA	North America	21
Toronto	Canada	North America	22
Seattle	USA	North America	28
Minneapolis	USA	North America	37
Montreal	Canada	North America	47
Vancouver	Canada	North America	69
Guadalajara	Mexico	North America	72
Pittsburgh	USA	North America	73

Table 3. 48 cities in the 100 Resilient Cities Network included in the PWC world's richest cities rankings

Concluding Thoughts on Preliminary Findings

Despite the initial bias, the 100RC initiative and the Rockefeller Foundation, does intend to bring this network, collective learnings, and resources to other cities besides these first 99 in its pilot program:

"100 is just the beginning. There's a great deal of work ahead to bring this movement to 1,000, then 10,000 cities. In the meantime, we look forward to working side-by-side with these 100 visionaries to build their own resilience, and in the process, a more resilient world for all."[54]

However, only time will tell whether the 100 RC initiative takes steps to curb its own blatant biases, become more transparent, and to rectify the discrepancies between its rhetoric and international self-promotion, and its actions. Additionally, further analysis of the 10 selected cities will hopefully shed more light on the work that has been done thus far.

[54] Berkowitz, Michael. "The First 100 Cities." 100 Resilient Cities. July 19, 2017. Accessed January 23, 2018. http://www.100resilientcities.org/the-first-100-cities/#/-_/.

Comparison of the Selected Cities by Shocks and Stresses

The following shocks and stresses were collected and tabulated from the individual city resilience strategies themselves as well as the 100 Resilient Cities Initiative.

Country	Shocks	Stresses
Atlanta	- Cyber Attack - Rainfall Flooding -Infrastructure Failure - Drought -Terrorist Attack	- Aging Infrastructure - Economic Inequality
Dakar	- Infrastructure Failure - Rainfall Flooding	- Poverty - Environmental Degradation - Informal Housing/Settlements - Sea Level Rise/Coastal Erosion
Greater Christchurch	-Rainfall Flooding -Coastal/ Tidal Flooding -Disease Outbreak	-Aging Infrastructure -Sea Level Rise/Coastal Erosion - Coastal/Tidal Flooding
Mexico City	-Drought -Earthquake -Landslide - Rainfall Flooding -Riot/Civil Unrest - Storm Surge -Subsidence	-Aging Infrastructure -Crime/Violence -Economic Equality - Environmental Degradation -Inadequate Public Transportation Systems -Inadequate Sanitation Systems - Informal Housing Settlements -Lack of social cohesion -Poor Air Quality -Poor Governance/ Regulatory Climate -Poverty - Uncontrolled Urban Development -Traffic Congestion - Population growth/ Overpopulation
Toyama	-Earthquakes -Flood -Landslides -Infrastructure Failure	-Aging Infrastructure -Economic resilience -Declining city revenue -Economic prosperity -Underdeveloped transport system -Environmental degradation - Diversifying/Centralizing Energy Supply
Bristol	-Disease Outbreak - Financial/Economic Crisis - Hazardous Materials Accident -Infrastructure Failure -Rainfall flooding -Riot/Civil Unrest -Terrorist Attack	-Aging Infrastructure -Aging Population -Climate Change - Economic Inequality -Energy Insecurity -Environmental Degradation -Food Insecurity -Inadequate Health Systems - Inadequate Infrastructure -Lack of Affordable Housing -Lack of Social Cohesion -Population Growth/Overpopulation - Traffic congestion -Traffic injuries -Unemployment -Water Insecurity
Ramallah	-Blizzard -Disease Outbreak - Drought -Power Outage -Rainfall Flooding - Fire -Riot/ Civil Unrest -Terrorist Attack	-Aging Infrastructure -Climate Change -Lack of green space - Poverty -Ethnic Inequality -Inadequate Educational Systems -Infrastructure Failure -Political Instability -Poor governance/ regulatory climate -Traffic congestion - Unemployment -Water Insecurity
New Orleans	-Coastal/Tidal Flooding -Drought -Disease Outbreak -Extreme Heat -Hazardous Materials Accident - Hurricane/Typhoon/Cyclone - Infrastructure Failure -Rainfall Flooding -Severe Storms -Terrorist Attack	-Aging Infrastructure -Inadequate Public Transportation Systems -Lack of Affordable Housing -Climate Change - Crime/Violence -Economic Inequality -Inadequate Educational Systems -Inadequate Health Systems -Sea Level Rise/Coastal Erosion -Structural Racism -Subsidence - Uncontrolled Urban Development

Rotterdam	-Cyber Attack -Infrastructure Failure	-Climate Change -Coastal/ Tidal Flooding -Displaced Populations/ Migrants -Economic Inequality -Energy Insecurity -Lack of social insecurity -Shifting Macroeconomic trends
Semarang	-Flash Flooding from upstream areas -Tidal Flooding -Power outage	- Sea Level Rise/Coastal Erosion - Coastal/ Tidal Flooding -Congestion -Water Insecurity -River Pollution -Unemployment -Landslides -Subsidence -Excessive groundwater use

Table 4. Ten selected cities' shocks and stresses as self-identified in the city resilience strategies

Observations:

- A majority of the cities cite aging infrastructure and infrastructure failure, and flooding from rainfall, rivers, or coasts and/or tides as major shocks and stresses
- Larger cities state overpopulation or population growth as a major stress.
- Uncontrolled urban development threatens both the more populated cities and the less populated cities.

Development of the Evaluation Criteria

The evaluation criteria system was created by referencing and compiling existing resources and research on resilient urban system performance qualities. These resilient urban system performance qualities and their sources are summarized below.

Urban System Performance Qualities	Source
Robustness, Redundancy, Diversity and flexibility, Responsiveness, Coordination	Toolkit for Resilient Cities: Infrastructure, Technology and Urban Planning A research project carried out by Arup, RPA, and Siemens[55]
Flexible, Dynamic, Response and Recovery, Risk Management, Vulnerability Reduction, Redundancy, Modularity	Building Urban Resilience: Principles, Tools, and Practice The World Bank[56]
Diverse, Redundant, Modular, Tight feedbacks, Social capital, Agency, Equity, Inclusiveness, Innovation	Urban Resilience in the Era of Climate Change The Kresge Foundation, Island Press, The JPB Foundation[57]
Integrated, Inclusive, Reflective, Resourceful, Robust, Redundant, Flexible	City Resilience Index The Rockefeller Foundation, Arup 2016[58]
Accepting of uncertainty and change, Reflective, Adaptive, Robust, Resourceful/Efficient, Integrated, Diverse, Inclusive	City Resilience Index Research Report Volume 1 - Desk Study The Rockefeller Foundation, Arup 2014

[55] Arup, Regional Planning Association, and Siemens. "Resilient Cities." Toolkit for Resilient Cities. October 21, 2013. Accessed January 10, 2018. https://www.siemens.com/global/en/home/company/topic-areas/intelligent-infrastructure/resilient-cities.html.

[56] Jha, Abhas K., Todd W. Miner, and Zuzana Stanton-Geddes, eds. *Building Urban Resilience: Principles, Tools, and Practice*. Publication. World Bank.

[57] Mazur, Laurie. "Bounce Forward: Urban Resilience in the Age of Climate Change." Strategy paper from Island Press and the Kresge Foundation (2015).

[58] Arup. "City Resilience Index - Arup." City Resilience Index - Arup. 2017. Accessed February 23, 2018. https://www.arup.com/perspectives/themes/cities/city-resilience-index.

Aware, Diverse, Integrated, Self-regulating, Adaptive	The Resilience Dividend Judith Rodin, 2014[59]
Disaster response, Infrastructure resilience, Disaster resilience, Financial capacity, Societal capacity, Institutional Capacity, Natural Buffer Capacity (robustness)	The Sendai Framework & How to Make Cities More Resilient: A Handbook for Local Government Leaders UNISDR, United Nations[60]

Table 5. Evaluation criteria and their source publications

These urban system performance qualities were then compiled to form the following criteria and scorecard.

Resilient Urban Systems should be:

1. Robust
2. Redundant
3. Diverse
4. Adaptive, Flexible and Modular
5. Responsive and Innovative
6. Integrated with Tight Feedbacks
7. Resourceful and Efficient
8. Inclusive
9. Reflective

These resilient urban system qualities were developed with an equal weight from each of the resilience authority publications; the publications themselves may not have used the same words to describe qualities of these systems or may have focused more on disaster risk reduction or on

[59] Rodin, Judith. *The resilience dividend: being strong in a world where things go wrong.* Public Affairs, 2014.

[60] United Nations Office for Disaster Risk Reduction, How to Make Cities More Resilient Handbook (Geneva 2012).

social resilience. The goal in creating these resilient urban system qualities was to be as comprehensive as possible.

These qualities are scored from good to poor for each of the city resilience strategies for the ten cities chosen, using a color coding system as follows:

Good: Indicative of lasting change and feasible initiatives

Less Bad/Neutral: Indicative of improvement from status quo but initiatives are not feasible and are not likely to create lasting change.

Poor: Indicative of little or no attempt to embody this resilient urban system quality

The scoring system was approached qualitatively. A quantitative numbering system could be misleading since a majority of these initiatives are not yet implemented, the stakeholders and starting conditions vary, and each city has different cultural and social norms, varying levels of wealth and development; all of these affect their ability to build resilience. Thus, a color coding system is used to visually represent the differences in feasibility and projected effectiveness of the city resilience strategies broken down into urban resilient system qualities.

1. ROBUST

Score	Description
	Infrastructure and social network designs anticipate and plan for failure. Physical assets are well-conceived, constructed, managed or reimagined so that they can withstand hazard events without significant damage or loss of function. Critical transportation, electricity, gas, and water infrastructure are well-maintained and there is a disaster plan or mode for assets and networks.
	Vulnerabilities to critical infrastructure are considered but only partially mitigated or addressed. There is some consideration of future hazards and plans for updating critical transportation at the end of its useful life.
	Aging infrastructure is not addressed or only addressed superficially. Critical infrastructure is created and maintained without consideration of vulnerabilities. There is an over reliance on a single asset.

2. REDUNDANT

Score	Description
	Spare or buffer capacity has been created so that the urban system can operate despite disruption without significant damage or function loss. There are multiple ways to perform the same basic function.
	Failure is not considered or only considered superficially. There is more than one mode of critical assets but there will still be significant damage and loss of function when the system is disturbed. There is some consideration of future hazards. However, beyond being mentioned, they are not actually addressed.
	There is an over-reliance on a single mode of transportation or energy distribution. The failure of any one component would cause the system to crash. The city resilience strategy is focused only on past or current experience. The city may not be prepared for future change.

3. DIVERSE

Score	Description
	Functional Diversity: A wide variety of approaches and are taken to understand and address urban resilience in governance and decision making. Solutions are multifaceted and multifunctional. Spatial Diversity: Assets are distributed throughout the city instead of in one place. Exhibition of a deep understanding of how different areas and different sub-cultures are affected by disaster events and hazards. Consideration of a wide-range of potential threats and hazards.
	Some combination of decentralized and radial infrastructure systems but not implemented on a large scale or not in consideration of the most vulnerable. Only one solution considered for one group of people. Some variation considered but scope is limited.
	Economic base is vulnerable to economic upheaval because it is monopolized by a single industry. No attempts made to diversify the urban system's economic, social, political, and physical assets. Components in the system are likely to all fail at once (cascading failure) due to over-reliance.

4. ADAPTIVE, FLEXIBLE AND MODULAR

Score	Description
	Individual, self-sufficient units designed to exist within a larger system and can operate as part of the system normally or independently from the system in times of crisis. Systems are designed to evolve, change and adapt when needed. Solutions reflect cognizance of a wide range of timescales, ie, what is needed in a year, 5 years, 20-30 years or 50 years in the future.
	There is some modularity or flexibility in the system in one area or one asset but creating more has not been addressed.
	The concepts of modularity or flexibility are absent from the city resilience strategy. The urban systems and city resilience strategy exhibit rigidity or inflexibility.

5. RESPONSIVE AND INNOVATIVE

Score	Description
	Investment in data monitoring, collection, and network creation. Fast response times and embedded rapid communication across sectors and stakeholder groups. Not only are the decision makers educated about warning signs but the public is also educated to understand warnings, when and how to take appropriate action. Exhibits an ability and willingness to try new things. Creation of an environment that encourages novel responses to the dynamism and unpredictability of the urban system
	Some plans for responsiveness and innovation but not accessible to a wide range of stakeholders. Responsive but not innovative or innovative but not responsive.
	Responsiveness or innovation plans absent from city resilience strategy.

6. INTEGRATED WITH TIGHT FEEDBACKS

Score	Description
	Exhibits a deep understanding of how urban system components interact with each other and makes provisions to prevent cascading failures and co-location failures. Tight feedbacks that enable real-time responses in changing conditions. The multiple mechanisms engaged across different scales. Nested solutions.
	Integrated social, political and physical network planning without tight feedbacks. Some tight feedback loops strengthened or established in communities, between stakeholders or among assets; however approach is not completely integrated.
	The system remains siloed and uncoordinated. Proposed solutions in the city resilience strategy itself are siloed and uncoordinated.

7. RESOURCEFUL AND EFFICIENT

Score	Description
	There is access and availability of resources for people and institutions in light of a disturbance or disaster. There is efficient management of resources across all levels (community, neighborhood, municipal etc.). Inefficiencies are actively identified and reduced.
	Some physical, human, and financial resources are available during disaster but with disproportionate accessibility. The resources are there but people do not have the mobility or the information to access them.
	The city resilience strategy does not improve the efficiency or resourcefulness of the urban systems.

8. INCLUSIVE

Score	Description
	Marginalized groups are included in the decision making process. There is an exerted effort to encourage local identity, agency and engagement in the resilience process. The public will be educated about urban resilience and involved in the urban resilience process.
	Shocks and stresses of one group are addressed in isolation. Solutions lack holistic and inclusive nuance.
	The city resilience strategy excludes some stakeholders or some communities by omission, siloed solutions that only address some parts of vulnerable communities but doesn't address their needs holistically or fully, or do so unsustainably.

9. REFLECTIVE

Score	**Description**
	Resilience strategy includes a plan to explain the long-term cost savings of resilience to communities and various stakeholders. Exhibits an acceptance of uncertainty and change. Reflects on past experiences and uses this knowledge to inform future

	decision making.
	City resilience strategy only addresses past and current issues and does not take into account future possibilities.
	City resilience strategy does not respond to the city's past. Does not internalize potential learnings

Table 6. Resilient Urban System Qualities annotated with their criteria descriptions

Evaluation Results and Discussion

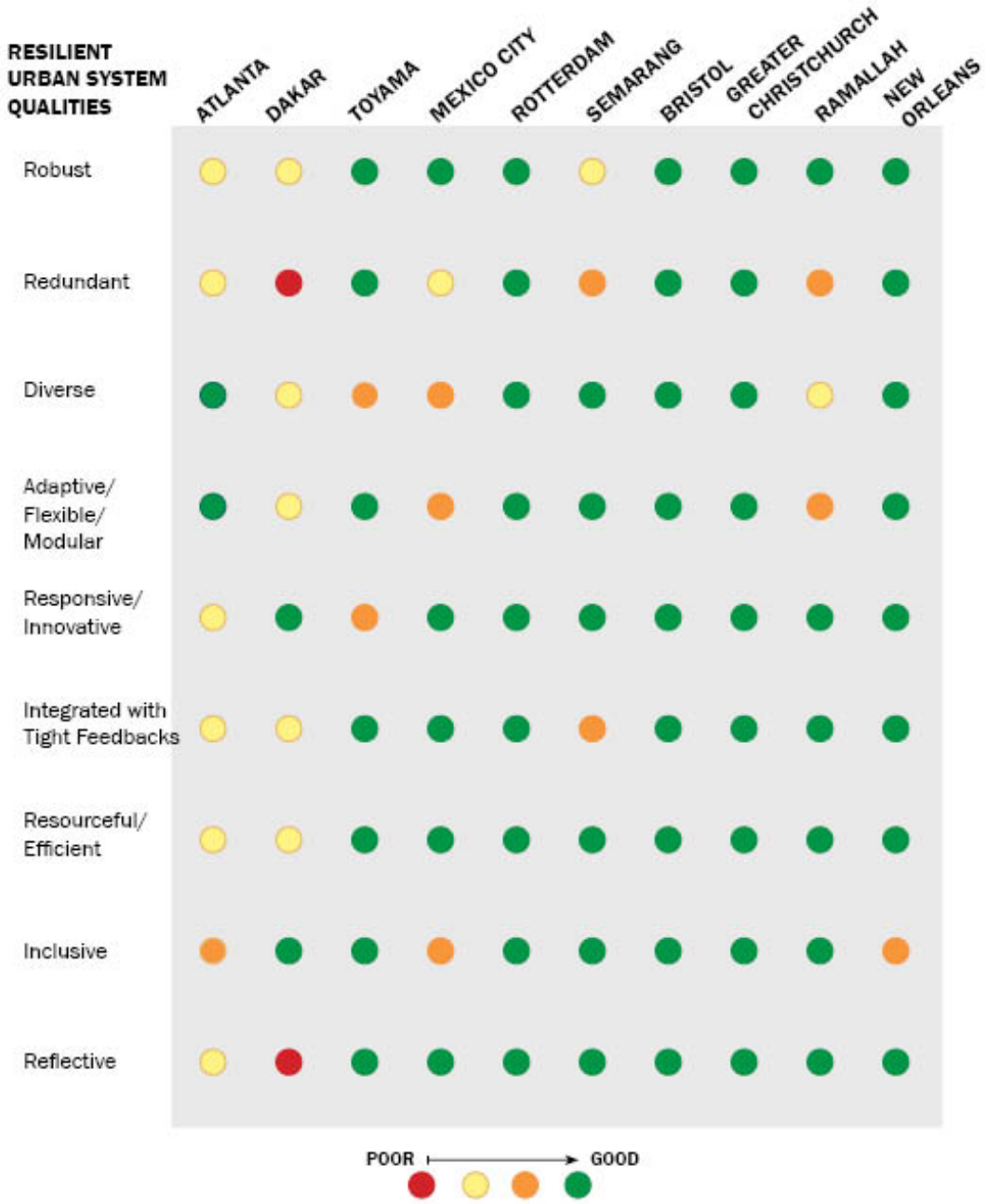


Figure 12. Multi-city Resilient Urban System Quality Scorecard

If a city resilience strategy received a lower score it indicates that this strategy did not address some of its shocks and stresses adequately - or not at all, or that the strategy seemed too siloed (there were opportunities for synergies, co-benefits, and cost-saving efficiencies that were neglected). It also indicates that the city did not take a long-sighted view of what they might need in the future or was missing a certain level of self-reflection and response to past disasters and experiences.

The scores instead indicate where the city is on its way to achieving resilience. One limitation of studying and comparing cities and city resilience in this way is that each city is so fundamentally different that it is misleading to directly compare their scores in a traditional ranking. A major difference between ecological resilience and urban resilience is the introduction of socioeconomic pressure and power structures. Each city has a unique starting point and a unique socioeconomic and sociopolitical context. Some cities were already working on building resilience before they joined the 100 RC network and others did not begin reimagining their cities in this way until the international initiative began. Annotated versions of this scorecard broken down for each city is provided in the appendices.

The higher scoring city resilience strategies tended to correspond with cities that had recently suffered from major disruptions or natural disasters that seemed to drive them to change. New Orleans responded to Hurricane Katrina, Greater Christchurch responded to a major earthquake, Rotterdam responded to its subsidence and life-threatening flooding issues.

Nevertheless, the evaluation criteria and scorecard does specifically reward cities which have taken a truly transformative approach to city resilience. This research revealed that there definitely is a distinguishing understanding of city resilience that makes the difference between a city resilience plan that will probably make cities better or just make cities less bad or will

probably never be implemented at all. The distinguishing nuance between those cities that received average scores and excellent scores on the scorecard was a combination of several factors:

i. The city has learned from its past experiences. Past disasters are understood as possible again and not as flukes. They are addressed.

ii. The city actively educates its citizens about resilience and embeds these actions into the educational system to produce a future society that will sustain these actions and continue to work to improve.

iii. Solutions are nested (several solutions overlap and work together) and each nested solution is functional on several levels. Many solutions serve a recreational, a protective, an ecological, and an accessibility function.

iv. The city resilience strategy as a whole reflects a consideration of several potential scenarios and the city as a whole has been planned flexibly to function in multiple scenarios.

v. Social resilience and community cohesion are strengthened and social issues such as homelessness, poverty and income inequality, structural racism etc. are addressed in a meaningful way. Vulnerable communities are identified and the solutions presented preserve their dignity, improve their livelihood and access to resources, and equip the vulnerable with the

resources and the information to act when disaster strikes and to improve their lives during business as usual.

vi. Solutions are systemic and holistic in nature instead of cosmetic. For example, when addressing food insecurity and food deserts, a cosmetic solution is to simply to create a network of temporary urban agriculture versus engaging a network of solutions such as accessibility, corporate agreements, affordability of food, job security etc.

vii. Solutions are multi-pronged, multi-dimensional, and multifunctional, ie, complex and integrated solutions for complex and deeply ingrained problems.

viii. The role of governance and inefficiencies within governance are streamlined to enable and embolden citizen and private sector agency, innovation, and engagement within the public sector. “Red-tape” is reduced so that it does not hinder resilience efforts.

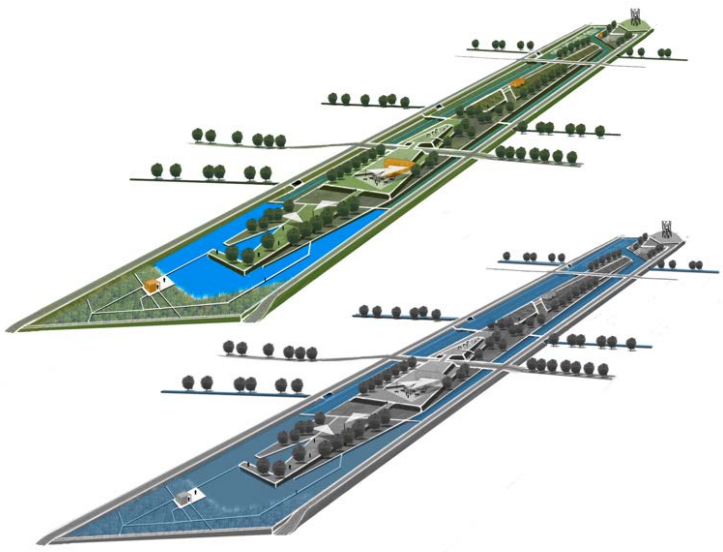
These absence or presence of these factors was determined from reading and evaluating the city resilience strategies. It is important to note that it is not possible to be sure whether these city resilience plans will be implemented as planned. This thesis evaluated the city resilience strategies published between 2015 and the end of 2017. In order to make conclusive statements on these cities’ resilience building efforts would require returning to this research in ten years to monitor progress made on these plans.

Green Infrastructure Strategy Case Studies

The following are some green infrastructure case studies highlighting some innovative applications of green infrastructure approaches that embody effective utilization of the multi-functionality of green infrastructure that were discovered during the evaluation of the city resilience strategies.

New Orleans – This city strategy exhibits a nuanced level of holistic thinking in response to Hurricane Katrina and the gradual subsidence of the New Orleans downtown area. Their green infrastructure plan in the city resilience strategy outlines an integrated living water system that encompasses several urban resilience urban performance qualities such as redundancy, diversity, responsiveness and flexibility, among others.

Coastal protection and restoration is advanced beyond just coastal wetlands by using a combination of structural flood protection in the form of levees, flood walls, pump stations and wetland restorations and non-structural protection including home elevations and flood proofing measures. Additionally, within the city itself, urban water studies and designs have been done to design an interconnected network of channels, auxiliary structures, and recreational areas that instead of pushing water out of the city as quickly as possible, slow down and store water during flooding



and storm events to alleviate coastal erosion and property damage as well as restore and maintain soil water content to reverse the land subsidence issue.[61]

The innovative circulating canal system is shown below:

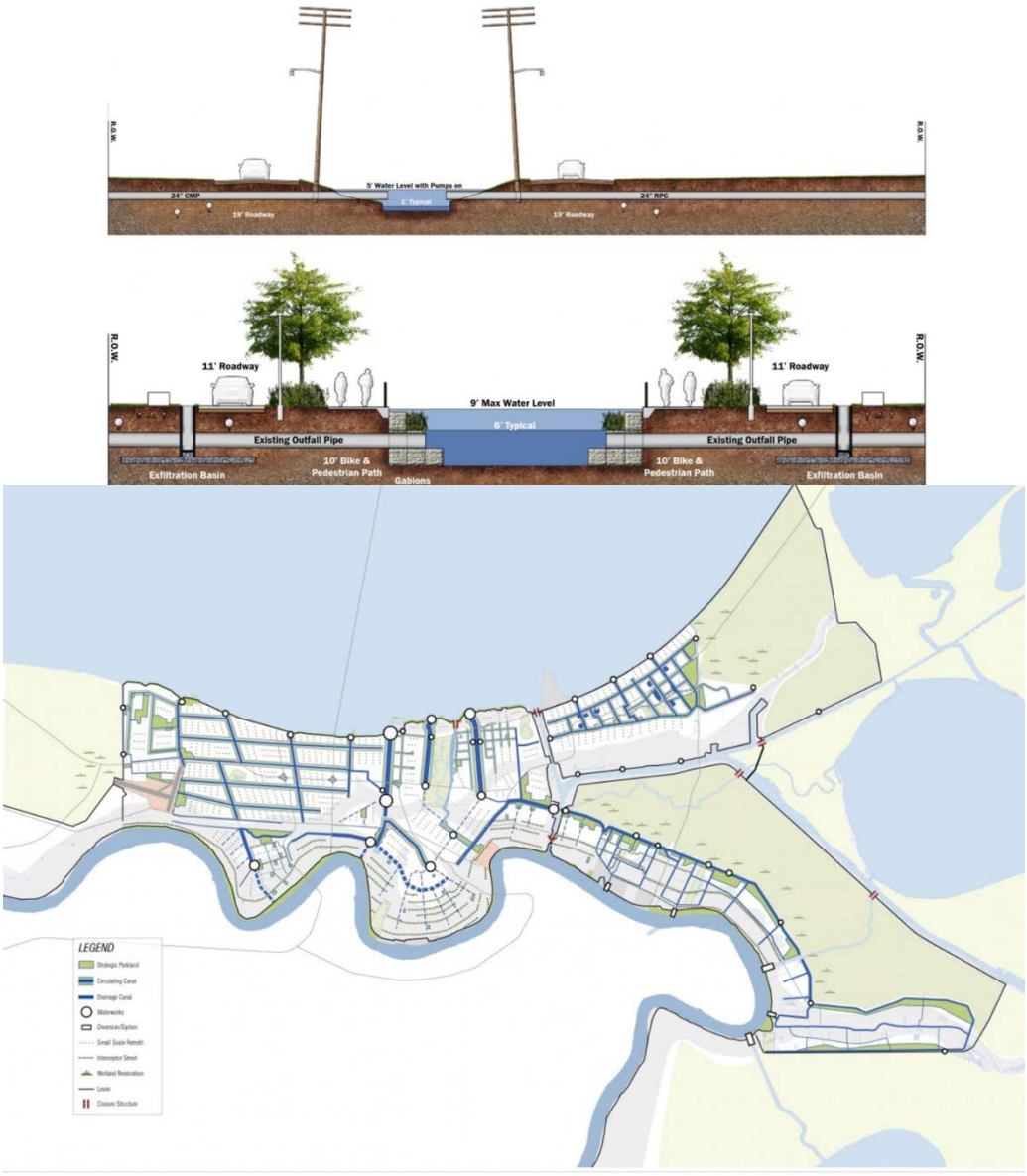


Figure 13 a, b, and c. New Orleans Canal Network Plan and Elevation Drawings from the Greater New Orleans Urban Water Plan[61]

[61] New Orleans' City Resilience Strategy. Publication. August 28, 2015. The Rockefeller Foundation.

Semarang, Indonesia – Semarang is faced with flash floods and landslides from upstream river areas and river pollution affecting their sources of clean water. The city resilience strategy of Semarang has a three pronged approach to improving river health and water quality using watershed ecology methods. Looking at the whole stream, Semarang is increasing the performance of basic water management by creating river pollution sanctions and monitoring, restoration and protection of the upstream watershed and controlling water loss in the supply system, and controlling and limiting excessive ground water consumption by industry, trade, and services to allow the groundwater sources to properly recharge. Restoring the upstream rivers also serves to prevent landslides and create fresh water green space areas for the residents who live nearby in the pollution they were once exposed to.[62] Recognizing that half of their population is not served by municipal water services, susceptible to water insecurity causing depletion of groundwater and subsidence, the city of Semarang has built over 100 rain water harvesting systems for public use. This is a nested solution with several co-benefits. It addresses flash flooding and landslides by stormwater runoff reduction, water insecurity by creating localized water storage, educates locals about water stewardship and management, prevents

[62] Semarang's Resilience Strategy. Publication. May 23, 2016. The Rockefeller Foundation.

subsidence by harvesting surface water for personal use and allowing groundwater to recharge.

Figure 14. Mangrove regrowth with tire seawall and a fisherman in Semarang[63]

Finally, Semarang has also been continually using green infrastructure methods to protect their coast from severe storms and coastal erosion by creating 196 hectares of mangroves to reclaim lost fish ponds planted and maintained in conjunction with sea walls.[64]

[63] Khairunnisa, Arfiana, Kaitlyn Harris, and Nyoman Prayoga. "The Link between Mangrove Ecosystem Services and Increased Coastal Urban Resilience: The Case of Semarang, Indonesia." ACCCRN. April 28, 2017. Accessed April 23, 2018. https://www.acccrn.net/blog/link-between-mangrove-ecosystem-services-and-increased-coastal-urban-resilience-case-semarang.

[64] "SEMARANG | WWF URBAN SOLUTIONS." WWF International. Accessed February 23, 2018.http://wwf.panda.org/what_we_do/footprint/one_planet_cities/urban_solutions/semarang_us_2016/.

Rotterdam, The Netherlands – Rotterdam is a historic port city in the Netherlands that lies largely below sea-level and protected using a series of dykes. Rotterdam focused on becoming a water sensitive Rotterdam moving further and closer to fully integrated water cycle management, by "embedding climate adaptation into the urban fabric of the city" and finding synergies with other resilience actions. One example of how they have done this is the installation of multifunctional Waterplein Benthemplein or "Water Plazas" and the Zoho: The 1st Climate Proof District. The Water Plaza is a network of multifunctional park space which provides green space and outdoor public space and the health and ecosystem benefits that come with that as well as a series of flood storage features that become water storage and water bodies for infiltration during flood and rain events. After the success of the waterplein, Zoho, which has become a bustling commercial district, is now used as a testing ground for using climate adaptation to promote and strengthen community and social cohesion.

Figure 15. Water Plaza in Rotterdam[65]

[65] Rotterdam's City Resilience Strategy. Publication. May 19, 2016. The Rockefeller Foundation.

They have also identified all of the flood-prone areas and are working with developers to develop water safety plans as urban development occurs in Feijenoord which is vulnerable to flooding from the river. Other initiatives include vertical evacuation planning and multi-layer safety (prevention, spatial adaptation, and evacuation) and their innovative floating city designs which include a successful Floating Pavilion, floating houses, floating farms, and floating water treatment plant.

Additionally, Rotterdam has made a plan to evaluate the level of automation in their water management system in order to make it cyber proof both from terrorist attack but also for back up protection so that basic function such as clean water is available during a crisis.[66]

Whether fully embracing and utilizing the multi-functionality of green infrastructure will ultimately revolutionize the way that green infrastructure will be implemented in favor of complete systems and holistic networks is yet to be seen. Further research will have to be done to determine the benefits, advantages and unintended consequences of the developments described here.

Additionally, green infrastructure plays an important role in overall city resilience because of how vital water and environment are to the success of a city both functionally and aesthetically. This case studies were in reference to one of the initial research questions:

Can fully embracing and utilizing the multi-functionality of green infrastructure improve city-scale resilience efforts?

[66] Rotterdam's City Resilience Strategy. Publication. May 19, 2016. The Rockefeller Foundation.

Through exploring green infrastructure efforts internationally, it can be inferred that holistic and multifunctional green infrastructure plans indeed seem to improve city-scale resilience efforts. More definitive conclusions would require more in-depth monitoring and quantitative analysis beyond the case studies explored here.

CHAPTER 5

CONCLUSION

We have underestimated the interconnectedness of our world and what that means for the nature and ramifications of unpredicted future disruption:

"The nature of global risk has changed since the financial crisis, with environmental, social, political and technological risk becoming inextricably linked, leading to fears of a domino effect that could trigger a new international crisis."[67]

Thus, the urgency to understand cities and approach problems as the complex adaptive systems that they are is vital in order to meaningfully improve everyday life and change the way we react to and prepare for disruption.

This thesis sought to answer two main questions:

a. Does the nuanced, imprecise, and somewhat novel nature of the term resilience in city-scale contexts affect the efficiency and outcomes of its implementation?
b. Can fully embracing and utilizing the multi-functionality of green infrastructure improve city-scale resilience efforts?

Even though there are several definitions and connotations of the concept of resilience, the meanings and applications do converge and overlap.[68] Several of these cities have managed to design and implement resilience building activities that emulate a similar level of nuance. This

[67] Zurich. "How Your Business Could Be Linked To The Cape Town Water Crisis." Bloomberg.com. April 12, 2018. Accessed April 19, 2018. https://www.bloomberg.com/news/sponsors/zurich/how-your-business-could-be-linked-to-the-cape-town-water-crisis/?adv=6712&prx_t=jooDAAAAAAFEANA.

[68] McAslan, Alastair. "The concept of resilience: Understanding its origins, meaning and utility." *Adelaide: Torrens Resilience Institute* (2010): 1-13.

is encouraging because traditionally there is a gap in understanding of resilience between scientists and researchers, and the general public, stakeholders, and policy makers. In some ways, the nuanced, imprecise, and somewhat novel nature of the term resilience in city-scale contexts does affect the efficiency and outcomes of its implementation as observed by the range in interpretation, understanding and persistence of the city resilience plans studied during this project. However, the future of city resilience being an effective framework for disaster risk reduction and city improvement is optimistic and fully embracing and utilizing the multi-functionality of green infrastructure will play a major role in achieving these goals.

Resilience is not a new notion in the academic world. It is something that has been discussed quite frequently in the past few years; especially in ecology and city planning circles. Designing climate resilient city options has even become more widely accepted and common place for planning practice. However, it is not without critics. Many argue that resilience is simply just the new buzzword to replace sustainability. Nevertheless, city resilience is a bit more specific in terms of actionable items to prevent tangible threats. Unfortunately for sustainability, the long term threat of climate change seems much less tangible and much farther off than creating concrete solutions for the issues at hand. Sudden disaster events such as extreme storm events can seem more tangible than the abstraction of climate change; even though extreme storm events and climate change are intrinsically linked. But, sustainability is also intrinsically different from city-scale resilience. Sustainability has an emphasis on using resources in way that preserves them for future generations. In a sense, keeping things the way they are. Resilience emphasizes new opportunities for growth, development, and adaptation. The fundamental premise is that things are always changing and that as we change we settle into new equilibria,

never the same one. Despite all of this, sustainability remains the more popularly published term as it pertains to cities:

Figure 16. Comparison of historical publication frequency between sustainable and resilient cities (Data Source: Google Ngram Viewer Database)[69]

Historically, the last time cities were hit by an epoch of renewal brought on by shocks and stressors such as aging infrastructure, overburdened transportation, environmental and health problems, and flooding was in the first half of the 20th century. It was just following the industrial era and the renewing transition was called the City Beautiful Movement. "Seen as a means of curing an environmental problem and an eyesore", the City Beautiful movement was a

[69] Jean-Baptiste Michel*, Yuan Kui Shen, Aviva Presser Aiden, Adrian Veres, Matthew K. Gray, William Brockman, The Google Books Team, Joseph P. Pickett, Dale Hoiberg, Dan Clancy, Peter Norvig, Jon Orwant, Steven Pinker, Martin A. Nowak, and Erez Lieberman Aiden*. *Quantitative Analysis of Culture Using Millions of Digitized Books*. **Science** (Published online ahead of print: 12/16/2010)

fundamental shift in how we saw and planned cities.[70] In efforts to achieve the modernity, transportation, and civic success of mid-19th century Paris, American planners and landscape architects scrambled to learn as much as they could about the benefits of wider streets, underground sewer systems, central city parks and greenways etc. and implement them in cities around the US to address the glaring issues of rapid urbanization. A good example is the Emerald Necklace in Boston, Massachusetts; an interconnected greenway of parks, rivers, walking, riding, and jogging paths, protected and buffered lakes and ponds, rock formations, and waterfalls that is laced around the Boston Metropolitan Area. The implementation of this project was motivated by Boston's flooding problem which was causing a lot of public health issues such as waterlogged sewage lines causing sewage to run into the streets. Now, a little over a century later we are faced with similar problems in a more nuanced form. Not only are the cities rapidly urbanizing again, but this rapid urbanization is coupled with new issues such as climate change and extreme storm events in addition to the age-old tropes of economic inequality and overburdened transportation systems. And, in order to address it, we are seeing a rise in a new movement of planners and researchers working on disaster management, resilient infrastructure, and city resilience. This movement or shift in ideology can be called The City Resilient or Resilient City movement. In this way city resilience as we're seeing it implemented today is not particularly a brand new idea but more so the culmination of decades old ideas and thought about how cities should be built; the field being built upon not just by researchers and scientists, but also by scholars, policy-makers, citizens. In some ways, city resilience is a conversation revisited; drawing on traditions and prior knowledge to strengthen connections and problem

[70] Elizabeth Bralow Rogers, *Landscape Design: A Cultural and Architectural History* (New York: Harry N. Abrams Inc, 2001).

solve for issues of tomorrow. Nevertheless, the level of nuance which is indicated by a sophisticated level of holistic and integrated vision has never been done before now; suggesting a new frontier. City resilience is where several fields and definitions of resilience uniquely converge. It is the amalgamation of disaster resilience, social resilience, ecological resilience, infrastructure resilience, and institutional resilience working together with nested solutions to achieve co-benefits. Green Infrastructure is an underutilized tool in city resilience and sustainability efforts and similarly to city resilience often misses the nuanced design of nested solutions to achieve a variety of co-benefits.

At the same time, urban and city-scale resilience join a long legacy of commercialized buzzwords in the environmental movement such as net-zero, green and sustainable. Businesses have profited by pandering to a newly environmentally friendly base of the young working class. It has become fashionable, even, to be environmentally friendly. Only time will tell whether city resilience will suffer the same fate. This thesis explored how city resilience can be best implemented and attempted to differentiate between what methods or approaches will actually build resilience that will hold up in uncertainty and unpredictability in the long run.

In conclusion, city resilience is neither necessarily a new frontier nor a conversation revisited but rather a combination of both. Further research would delve more into how best to communicate city resilience to public audiences, how to improve the integration of green infrastructure plans into city resilience strategies, and fully describing city resilience and its solutions. Additionally, to improve upon the research already done in this thesis would require monitoring of the implementation of these ten cities and their city resilience strategies in order to determine how effective the proposed initiatives actually end up being, visiting the cities themselves, and expanding the assessment to other cities inside and outside the 100 resilient

cities network. Finally, it would also be informative and insightful to further delve into resilience communication and the gap in deep resilience knowledge and understanding between the scientific/academic community and the public.

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