Cyclone Vardah hitting the coast of Chennai, Tamil Nadu in 2017 (Skymet Weather)

Energy Resiliency and Sustainability for Smart Cities in Developing Economies

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Introduction and Background

Urban environment resiliency is an increasingly important issue because of global climate change and urbanization. To address this problem, we need a clear understanding of the concept of resilience in urban systems. While the focus in this article is primarily from the large-scale perspective of the urban environment as a whole, the built environment can also be thought of as the combined effect of numerous individual buildings and infrastructure items. Individual buildings have their own specific design resiliency challenges, which would be the topic of a separate paper.

In the following pages, we first present an overview of urban resiliency, and then review common challenges to that resiliency, particularly among cities located in developing economies. Then, we focus on the particular challenge of energy consumption in the context of the build environment, and delve into the resiliency strategy of three Indian cities to highlight how they are addressing those challenges. Lastly, we discuss future trends in the contexts of smart and mega cities.

Overview of Urban Resilience

The concept of resiliency can be defined as the "Capacity of individuals, communities, institutions, businesses, and systems within a city to survive, adapt and grow, no matter what kinds of *chronic stresses* or *acute shocks* they experience" (100 Resilient Cities, 2018). Similar to a person's medical health, the built environment and urban systems can experience both chronic and acute problems. For urban systems, chronic stresses include long-term problems that weaken the fabric of a city on a day-to-day or cyclical basis. Example of these include high unemployment, inefficient public transportation, endemic violence, air and water pollution and chronic shortages in food, water and energy supply. Acute shocks are issues that happen suddenly, are large scale, and can threaten many in a city. Examples include earthquakes, floods, extreme weather events, disease outbreaks, and terrorist attacks.

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Resilient cities are characterized as being:

- Reflective: in the use of past experience to inform future decisions
- Resourceful: employing alternative ways to use resources
- Robust: with well-conceived, constructed and managed systems
- Redundant: having space capacity purposely created to accommodate disruption
- Responsive: able to deploy emergency services at the right time and place under an efficient and reliable emergency plan
- Flexible: willingness and ability to adopt alternative strategies to changing circumstances
- Inclusive: prioritizing and creating a broad sense of shared ownership, and
- Integrated: bringing together a range of distinct systems and institutions.

Figure 1: Road traffic congestion in New Delhi, India (Ovsyannykov, n.d.)

Worldwide Trends

We are now in an era where, in many countries, major cities are the dominant force at many levels: economically, politically and socially. It is estimated that by 2050, two-thirds of the world's population and over three quarters of global gross domestic product (GDP) will be in (or due to) urban areas (IEA, 2016). The world's urban areas already account for about two-thirds of global primary energy use and 70% of energy related CO_2 emissions.

The increasing concentration of people and the overall importance of cities in a country's society means that the susceptibility to chronic stresses or acute shocks is also increasing. Thus, there is a growing recognition of the need for resiliency, particularly in these urban areas.

Challenges for Urban Resiliency

Several key challenges exist for cities in regard to resiliency, particularly within developing economies. These include: (a) the changing climate; (b) air and water quality; (c) energy supply and consumption; and (d) transportation.

Changing Climate

Many of the world's major urban areas are located at or near coastal locations. Rising sea level destroys homes and other infrastructure, increases the number of refugees, and exacerbates ethnic conflicts and national tensions. Some have projected an additional 250,000 deaths per year between 2030 and 2050 due to increased heat exposure, diarrhea, malaria and childhood malnutrition. The International Monetary Fund's latest World Economic Outlook report predicts that developing economies, in particular, will suffer disproportionately from climate change and rise in temperatures since they are situated in relatively hot climates. Even the U.S. military considers climate change a major area of concern in terms of global stability and security (DOD, 2015).

Air and Water Quality

Cities in developing economies, particularly in the global South[1], face issues of poor air and water quality. Megacities in South Asia have, on average, over twice the concentration of $PM_{2.5}$ air pollutants relative to their counterparts in the global North. For example, Delhi has an average particulate contamination of over seven times that of New York or London. The recent extreme air quality events around Delhi demonstrate the short term economic and social impacts of poor air quality, with the closure of schools, restrictions on traffic, and airline flight cancellations.

Energy Supply and Security

Energy security represents a significant threat to cities, particularly in developing economies. A fossil fuel-intensive path of growth, as was pursued in the global North, is not a viable future direction for developing economies. Currently, nearly half of the global North and South cities in the C40 cohort do not have direct control over their energy portfolios. Urban energy challenges include the need for: (a) clean, affordable and reliable energy sources; (b) meeting a growing electricity demand while correcting system inefficiencies and supply shortages; and (c) the decarbonization of energy supply. It is important to note also that these challenges are common to both developed and developing economies.

The lessons from 2017 hurricane season in the Caribbean should serve as a wakeup call for all. Many of the islands experienced devastation of their electrical grids, and in Puerto Rico as of mid-January 2018, i.e., four months after the combined impact of two major hurricanes, only two-thirds of the island residents had their power restored. The island had returned its electric generation capacity to about 95% of pre-storm levels at the time of this writing (early April 2018), but also experienced temporary setbacks due to power plant failures during the grid rebuilding process.

Transportation

An efficient transportation system that is able to withstand disruptions is vital to the overall resiliency of a city. This, unfortunately, is a common weakness area for cities and generally more likely so in developing economies. The transportation systems and issues experienced in India are a significant hindrance

[1] The term "Global South" is a term often given to developing countries in Africa, Latin America and Asia, regardless of their position in the northern or southern hemispheres.

to economic growth as well as a major contributor to air pollution problems in many cities.

Figure 2: The Bogotá Columbia TransMilenio Integrated Transportation System (Acosta, 2013)

Impact of Building Systems on Resiliency

By 2050, urban building energy consumption is projected to increase by 70%, and much of the increased demand is projected to come from cities in developing economies. The good news is that cities also represent the location of most of the cost-effective CO_2 emission abatement potential in the coming years, so an increased focus on energy efficiency in the built environment is vital.

Buildings represent about 40% of the global energy consumption, with often an even higher percentage in developing economies. In commercial buildings, heating, ventilation and air conditioning (HVAC) systems may typically represent approximately 50% of the building's total energy consumption. Improving the building envelope and other energy-efficiency upgrades could reduce the overall urban cooling demand by 50%, but that may be somewhat negated by a large increase in adoption of building air conditioning, particularly in developing economies like India.

It is apparent that there is an increased need to focus on energy efficiency in buildings, and not just on HVAC systems. Rapidly growing cities means a corresponding rapid increase in the number of buildings. Thus, we can increase the overall resiliency of our urban areas by giving a renewed focus on energy efficiency in the design and construction of new buildings, as well as improved operation and maintenance practices that will allow existing buildings (and the newly built 'more efficient' buildings) to use energy wisely. Care must be given to not make the building systems so complex such that the operations staff need an engineering degree just to keep the systems operating efficiently.

Examples of Resiliency at the City Level

This section provides examples of efforts made to improve urban resiliency, with a focus on Indian cities.

The 100 Resilient Cities Program

The 100 Resilient Cities (100RC) program was pioneered by the Rockefeller Foundation to help cities around the world improve resilience to physical, social and economic challenges of 21st century. The 100 cities were selected by a panel of expert judges, who reviewed over 1,000 applications from prospective cities. The judges looked for innovative leadership, a recent catalyst for change, a history of building partnerships, and an ability to work with a wide range of stakeholders. Through this program, selected cities receive financial and logistical guidance for establishing an innovative new position in their city government, a Chief Resilience Officer (CRO), who would be expected to lead the city's resilience efforts. Selected cities also receive technical support to develop a holistic resiliency strategy that reflects its distinct needs. Each city also receives access to a platform of private sector and NGO services to support their strategy development and implementation (2018a).

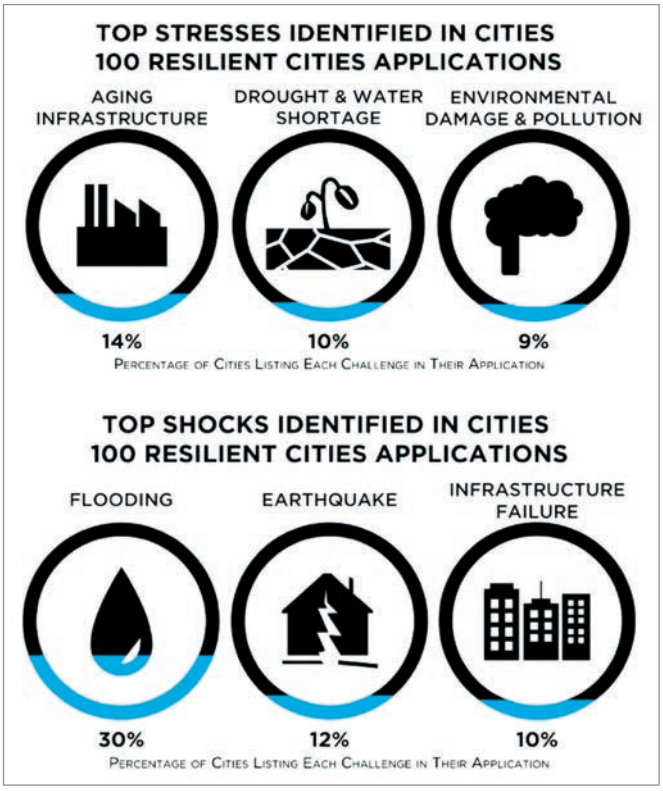

Figure 3: Primary 100RC stresses and shocks (100 Resilient Cities, 2018c)

Of the 100 selected cities, five are located in India (Bangalore, Jaipur, Pune, Chennai, and Surat). We briefly review the commitments that three of these cities have made toward embedding greater resiliency in their built environment, especially as it concerns their energy systems.

Chennai

Located on the coast of India's southernmost state of Tamil Nadu, Chennai experiences chronic and acute shocks ranging from aging and failing infrastructure and economic inequality to frequent hurricanes, typhoons, and cyclones. As the state's capital, Chennai experiences rapid urbanization and is the fourth largest city in India (100 Resilient Cities, 2018b). It has a 2018 population

of 10,705,000 that is projected to increase at an average annual growth rate of approximately 3% (World Population Review, 2017). Between 1998 and 2008, the city saw 6% to 17% annual road traffic growth and pedestrian volumes ranging from 4,200 to 1,200,000 during peak hours (Greeshma & Kumar, 2016). Chennai is India's second largest exporter of IT, ITES, and software (World Population Review, 2017).

The Greater Chennai Corporation recently identified priorities in improving water systems, governance, civic engagement, service delivery to vulnerable and low-income groups, and finance for building programs (The Times of India, 2018). On the whole, the city suffers from frequent cyclones, tsunamis, and flooding. In the last 50 years, Chennai's coast was hit with 29 cyclones and the major 2004 tsunami, whose flooding impacts made the city especially vulnerable in densely populated areas. These chronic and acute shocks are likely to occur with increasing frequency (Greeshma & Kumar, 2016).

The Tamil Nadu Energy Development Agency pioneers energy efficiency and renewable energy projects – from mandatory rainwater harvesting and solar heating systems in large commercial buildings. Bharat Sanchar Nigam Ltd., the state-owned telecommunications company headquartered in New Delhi, requires all its telecom buildings to include optimal lighting and air conditioning systems. Real estate developers K Raheja Corp and Unitech Group have facilitated LEED certification for large commercial and residential facilities (ASCI & NRDC, 2012). In 2007, the Indian Bureau of Energy Efficiency (BEE) established the first country-wide Energy Conservation Building Code (ECBC) for commercial buildings to be implemented at the state level (GBPN, 2013). In 2012, the Tamil Nadu Electrical Inspectorate (TNEI), Chennai Municipal Development Authority, Pollution Control Board and other organizations began adopting ECBC into municipal code. Further, the Tamil Nadu Legislative Assembly Complex has been recognized as the largest LEED Gold certified government building (and first parliamentary facility) in India (ASCI & NRDC, 2012).

Pune

Pune is the ninth largest city in India. Located in the southwest portion of the state of Maharashtra, Pune has a 2018 population of 6,192,000 that is projected to increase at an average annual growth rate of approximately 3% (World Population Review, 2017b). Pune is also the country's sixth most earthquake-prone city. The frequency and intensity of earthquakes has increased recently, and the landscape – fractured by sustained growth in traditional manufacturing and IT sectors, inadequate public transportation (with wait times over 20 minutes on 84% of bus routes), gridlock traffic and four municipal reservoir dams upstream – has reached the point where even a magnitude 7.0 earthquake could have debilitating effects. Other chronic and acute shocks include unaffordable housing, rainfall flooding, poor air quality, and disease outbreak (100 Resilient Cities, 2018d).

The Pune Municipal Corporation (PMC) established the first eco-housing program in India in 2008. Through support provided by the United States Agency for International Development (USAID) US Asia Environmental Partnership Program, Science and Technology Park (Scitech Park), University of Pune and the International Institute for Energy Conservation (IIEC), PMC has led initiatives to incentivize sustainable housing development (EcoHousing, n.d.). Projects are concentrated in urban, overpopulated areas of the state of Maharashtra (Scitech Park, n.d.). Scitech Park developed training and capacity building efforts to educate developers, policy makers, architects, and consumers on eco-housing certification criteria (a total of 88 categories and 1000 points) and building construction guidelines (e.g. energy conservation building code, development control rules, environmental incentive structures) (EcoHousing, n.d.).

The eco-housing program specifically focuses on four major areas: solar and wind energy, solids and wastewater recycling, rainwater harvesting and construction materials (Friestedt & Sjövall, 2006). The voluntary rating and certification program quantifies the environmental performance of housing structures and provides a baseline for green design practices (PMC, n.d.). The housing program incentivizes the use of renewable power through floor space incentives (FSI) for developers. PMC permits taller construction of and a 50% discount towards high rise apartment buildings utilizing solar and wind power, adding real estate size and value (EcoHousing, n.d)

Figure 4: Green building plans for MVRDV's Amanora Apartment Vertical City Apartments developed by City Corporation in Pune, Maharashtra (Pham, 2011)

Apart from the increasing population residing in high-rise, gated housing communities, about 36% of Pune's population inhabits 486 slum areas. Of these households, 90% have electricity connection, and 33% are located on mixed-ownership land, which poses challenges for slum rehabilitation (Butsch et al. 2017).

Between 2010 and 2012, seven companies in Pune participated in a public-private partnership (PPP) called Resource and Energy Efficiency Network (REEF) to boost ecologically responsible growth. The organizations implemented 72 measures, including reducing furnace capacities, replacing induction heating pumps, retrofitting fluorescent lighting, etc. They reduced energy consumption by more than 47,233,531 kWh and 49,000 m^3 of water, and decreased CO_2 emissions by 12,571,130kg and costs by 86,713,130 INR.

The participating companies were: Bharat Forge Ltd., Mercedes-Benz India Pvt. Ltd., Micro Supreme Auto Ind. (I) Pvt. Ltd., RSB Transmissions (I) Ltd., Sauer-Danfoss India Pvt. Ltd.,Thermax Ltd., and WIKA Instruments India Pvt. Ltd. (Arqum GmbH, 2011).

Surat

Surat is a city of about 5 million inhabitants located in the western part of India (on the banks of the Tapi river), in the state of Gujarat. It is most renowned for its diamond cutting and polishing industry. Surat has seen an unprecedented growth of its population in the last four decades, recording a 10-fold rise.

Its chronic stresses include traffic jams; affordable housing; water quality and quantity; and heavy dependence on only two economic sectors (diamond and textile) that have faced global decline. The ecosystem surrounding the city and its surrounding areas is also at stake, as both industrial and population growth have put pressure on its environment. Social cohesion and social networks are known to be weak in Surat; although communities are at peace, they suffer from a lack of connection. Lastly, public health is also a vulnerability in that there is a lack of skilled and specialized human resources to face increasing urban health challenges, such as waterborne diseases.

In terms of acute shocks, Surat faces risks of both sea level rise and flooding. During the last two decades, Surat and the surrounding metropolitan region has witnessed major floods. In recent years, Surat has experienced 23 floods, such as in 2013, and a plague outbreak in 1994. Of top priority is building community and social resilience to deploy early response to floods, prevent vector-borne illness, boost nutrition and improve electric grid connectivity (Ravi, 2015).

Figure 5: Preventable flooding in Surat, Gujarat after a dam release in 2006 (Chatterjee, 2015)

To address the chronic stress imposed by a lack of affordable housing to cater to the migrant population, Surat has explored many initiatives, such as leveraging affordable and innovative building techniques (by design and engineering intervention) and cut down average cost per unit without compromising the usable area and quality of services. The city will secure land to construct sample houses using these techniques, and through innovative landscaping and building designs, Surat hopes to offer a better, livable environment for its citizens.

Other initiatives to increase thermal comforts of buildings will include pilot projects to test cool roofs and passive ventilation, especially during summers. An inventory of government buildings will be carried out in the city to demonstrate the efficiency of these techniques. These pilots will give quantitative outputs of thermal comfort techniques and will be useful for replication at the community level.

Making Cities Smart

Cities face two major problems in addressing the challenges of resiliency: urbanization and global climate change. For urban areas, the catch-all phrase is 'smart city.' The general notion of a smart city is the application of technology, principally information technology, to address the range of problems it faces, as illustrated by the review of the three preceding Indian metropolises. However, technology is only a part of the solution and should be thought of as a complement to initiatives such as policy development and effective management. To see the smart city agenda more broadly, we need a comprehensive organizing framework for understanding the possibilities, as shown in *Figure 6*.

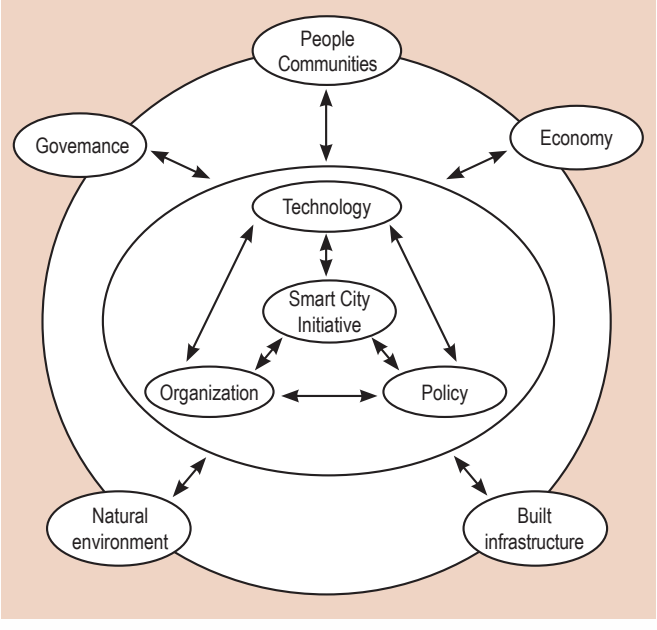

Figure 6: SystemSmart city initiatives framework (Chourabi et al., 2012)

A smart city puts people and communities first, as predominantly shown in the framework given in *Figure 6*. It must meet the short and long terms needs of its residents. The other elements must contribute towards this goal. For example, a city needs economic investment that creates jobs that enable social progress for many of its citizens.

We must also keep in mind that a city is a self-organizing ecosystem, such that all initiatives (especially in a large democracy such as India) take place in a dynamic market. Effective governance cannot be dictated, but rather must be negotiated. However, self-organizing ecosystems are resilient and, all things being equal, are more suitable for handling change

than a hierarchical centrally controlled economy. Self-organizing ecosystems are also inherently smarter than hierarchies because they are a collection of minds solving daily problems they understand intimately.

We must learn how to blend the guidance provided by frameworks and an understanding of self-organizing ecosystems to enable smart cities to emerge. The priorities for each city and its self-organizing ecosystem are different, but the need is common for all – to provide a better life for its residents.

Conclusion

Resiliency is not a new goal for cities. They have survived, in some cases for thousands of years, by continually adapting to changing natural and human events. The difference today is in scale and cities' overall impact on people, on local and global economies, and on our entire planet. Three facets should be highlighted. First, cities are now much larger and are continuing to grow because of the attractions and economic benefits of urban life. Second, cities require massive inflows every day of food, water and energy to function. At the same time, long and broad supply chains are more susceptible to disruption because they have many interrelated components. Third, global climate change is increasing the likelihood of extreme weather events, while sea levels are rising. Many major cities are on or near coastlines, making them even more vulnerable.

Nearly every city is taking multiple actions to increase resiliency by working on being smarter. The challenge for industry, government and academic researchers is to learn from each of these many actions to synthesize what works under what circumstance and disseminate best practices. The 100RC project is a model for such research, and it can be augmented by scholars across a range of fields. For example, engineers can study how the Internet of Things makes the build infrastructure more energy efficient. Political scientists can learn what governance structures and policies advance resiliency. There can also be regional integrated research projects that, for example, study the major cities in India and create mechanisms for effective sharing of knowledge among them.

Most importantly, we assert that cities need to recognize that their energy supply is the foundation of resiliency. We are highly dependent on energy to operate water and food supplies. Stable and inexpensive energy enables a city to meet many of its citizens needs and can attract economic activity. The grand resiliency challenge for cities is to convert from fossil to renewable fuels, to combat global climate change, and in parallel to craft a green energy supply system that enhances resiliency. Buildings and the built environment can incorporate measures that improve their resiliency as well as overall sustainability, thus can be a significant contributor to the overall resiliency of cities worldwide.

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