Engineering Livable, Sustainable and Resilient (LSR) Cities

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Background:

Many infrastructure assets in the older urban regions of the US reached the end of their lifecycle and are often in a state of triage. The constant need for maintenance, repair, and replacement disrupts their services, impacting the quality and productivity of urban life. Clean water, storm water and sewers; streets, tunnels and highways; rail and transit; gas, power and communication systems are in close proximity in urban environments, leading to the potential for cascading failures. There is a critical and strategic need for qualified civil engineers to understand infrastructures as highly complex, multi-scale systems with intertwined natural, engineered and social components, before they can take a leadership role in effectively revitalizing, renewing and managing these systems to ensure the **LSR** of urban regions. The current power outages affecting 270,000 customers in CA has been called for by PG&E, justified by a combination of drought, weather-and-wind conditions leading to a high risk of wild-fires expected when transmission lines fail is an example of how infrastructure reliability and services, long-term and short-term natural events, society and the economy are intertwined in complex manners. Following the devastation caused by the Camp Fire of 2018 under similar circumstances and which led to the bankruptcy of PG&E, a major rethinking of infrastructure design and human settlements is called for.

As the condition and capacity of our infrastructures are diminishing, increased urbanization is leading to growing demands for infrastructure services. Even relatively low-level, frequent hazards, such as storms, snow and fires often lead to loss of infrastructure services to large numbers of people for an extended period of time. Approaching the lifecycle and limits of effective performance of existing infrastructures is not a simple problem addressable by reductionism, engineers need to fully understand the complex nature of the geriatrics of aged built environments. On the other hand, engineers do have an obligation to coordinate addressing many of the challenges related to urban **LSR** concerns. Mainly because of the above reasons, improving urban infrastructures was selected as one of 14 Grand Challenges for Engineering by the National Academy of Engineering (NAE) in the US since 2008, and this has been echoed by the Engineering and Physical Sciences Research Council (EPSRC) in the UK, leading to initiatives such as the Future Infrastructures Forum.

The NAE, the National Science Foundation (NSF) and the Department of Homeland Security (DHS) have issued various statements and solicitations for research on infrastructures in the past decades, a summary of which is available from the Congressional Research Service (Moteff, 2010). DHS website offers an up-to-date description of each of the 16 critical infrastructure Sectors and the systems and elements of each Sector as well as the federal policies for their protection. A recent NSF Solicitation 18-523 (2017) articulated that: *"Infrastructures are networks of systems and processes that function cooperatively and synergistically to produce and distribute a continuous flow of essential goods and services. Infrastructures are evolving, as new technologies come on- line; Deteriorating, as physical components age; Operating at or near design limits; Interdependent, in that two or more infrastructures require each-others' services to function; Subject to a variety of risks and hazards over various spatial and temporal scales; and Producing and consuming an ever- broader range and volume of data."*

NSF (18-523) is soliciting: *"Integrated, multidisciplinary perspectives to provide insights on design, operation, prediction of interdependent critical infrastructure systems and processes, under normal through extraordinary conditions, in order to ensure economic and societal well-being."* Further, NSF requires proposals *"broadly integrate engineering and social, behavioral* *and/or economic sciences and encourages"* the incorporation of *"complementary perspectives from additional disciplines such as computing and data science, ecology, seismology, and statistics."* ***We note the absence of "architecture and urban planning" in the trans-disciplinary domains listed by the NSF. These disciplines also greatly impact the urban quality of life, land-use and infrastructure decisions in the US as discussed further in the paper.***

Perspectives on Infrastructures:

Aktan, Moon et al (2016) offered a civil engineered systems perspective of infrastructures and their services. Critical issues included: (a) culture and distribution of ownership, organizational systems and whether individual and organizational accountability are based on process or performance; (b) project delivery and lifecycle cost estimation, utility and feasibility analyses, permits and regulations; (c) finance and revenue mechanisms governing project delivery, lifecycle operations and preservation costs; (d) metrics for quality and robustness of infrastructure services and their operational and structural performance management; (e) multi-sector asset management for preserving those systems owned by different public and private agencies and utilities, but which may intersect and are also interdependent; (f) innovative paradigms & technology leveraging for objectively measured data-based approaches to asset-management decision-making; (g) mitigating and managing multi- hazards risks, emergencies and resilience needs for interdependent systems. Such a perspective resulted from several decades of field research on structural-identification of constructed systems, especially highway bridges operating at the intersection of highway, rail, water, power, communication and gas networks by forming academe-government-industry coalitions.

A complete holistic perspective on infrastructures should recognize the significance of the political, regulatory and legal processes which influence infrastructure policy, ownership (corporate, utility, Federal, State, Local), and financing; subjective and objective performance metrics (at the utility, functionality, serviceability, durability, safety, failure and resilience limit-states), economics and utility, and the organizational and socio-technical aspects of infrastructures; as well as the principal actors and processes that provide services - to infrastructures and their stakeholders. Any perspective would inevitably be associated with a **scale** (geometry and time) and **resolution** (a network and nodes vs pipes and manholes, or, a regional highway system vs all of the physical engineered, constructed and natural components, along with organizations, institutions, cultural influences and stakeholders). In addition to a broad systems engineering intuition, we would also need domain knowledge in the financing, revenue, ownership, operations, preservation and interdependency between various elements of different infrastructure systems.

It is natural for different disciplines and domains, as well as stakeholder groups to have varying perspectives on infrastructure systems. The resolution that is desirable and optimal for performing research on urban infrastructure systems and their services would be inevitably guided by the prevailing perspective. In many of the academic programs the US, civil engineering sub-domains remain highly fragmented and civil engineers seldom interact with urban planners, which limits the development of a holistic perspective. Further, most programs are still teaching civil engineering by focusing on the use of prescriptive code provisions for the design of new buildings and other structures without seeing their relationships within systems. Meanwhile, in Great Britain, municipal engineering remained as a special domain of civil engineering for urban civil engineering challenges, and collaborating with urban planners. In Japan, urban planning remains within civil engineering education and practice, and one cannot deny the Japanese accomplishments related to LSR of even mega-cities such as Tokyo.

Complex Systems Perspective for Infrastructures:

Municipal engineers Rogers, Bouch, Williams et al. in "Resistance and resilience - paradigms for critical local infrastructure" (Municipal Engineer, Volume 165 Issue ME2, 2011) structured urban infrastructure resilience under the categories of: "ecological resilience; economic resilience; engineering (engineered systems) resilience; community and social resilience; and, governance resilience," and asserted that all of these aspects of resilience are intertwined given the limit-state of performance and the characteristics of the incident or hazard in question. If we envision an urban region as the intersection of ecology, economy and society, the built environment, infrastructures and government services, we may then conceptualize it as a complex, intertwined, social-technical-natural system-of-systems. Sussmann (2005) identified urban transportation systems as "Complex, Large-Scale, Interconnected, Open, Socio-Technical (CLIOS) Systems."

CLIOS is an effective way to conceptualize infrastructure systems especially in the context of livability, sustainability and resilience of an urban region. Based on such a conceptual understanding, we may assert that: **urban infrastructures cannot/should not be detached from society, economy, the natural environment, the built and engineered environment, and finally government and infrastructure services since all of these systems have to come together and function - or perform - seamlessly to ensure the livability, sustainability and resilience of an urban region.**

We should also note that in many cities and multi-state urban regions in the US, urban planners remain as key professionals for the planning and regional design for livability, sustainability and resilience. One of the reasons for this may be the federally funded Metropolitan Planning Organizations which were formed under the 1962 Federal-Aid Highway Act for any urban area with a population greater than 50,000. MPO's are typically led by urban planners and serve a critical role in ranking and channeling federal funds to regional infrastructure projects, influencing many aspects of metropolitan life. Many MPO's serve important functions in addition to regional transportation planning, such as economic development, regional transportation related data and information warehousing and even resilience planning. A lack of close integration between architects, planners and civil engineers during education, research and practice naturally reflects on how planners and engineers collaborate at MPO's.

Objectives of this Forum Paper:

The importance of urbanization on the demographics of the Nation, as well as the significant contributions of urban regions and large cities to the national economy has been the subject of many discussions including Khanna (2016), Alberti (2017) and UN-Habitat 2016. Unless we find effective solutions to enhance urban **LSR** under the relentless pressures of urbanization which is over 80% in the US (2010 Census) our economy, natural assets and quality

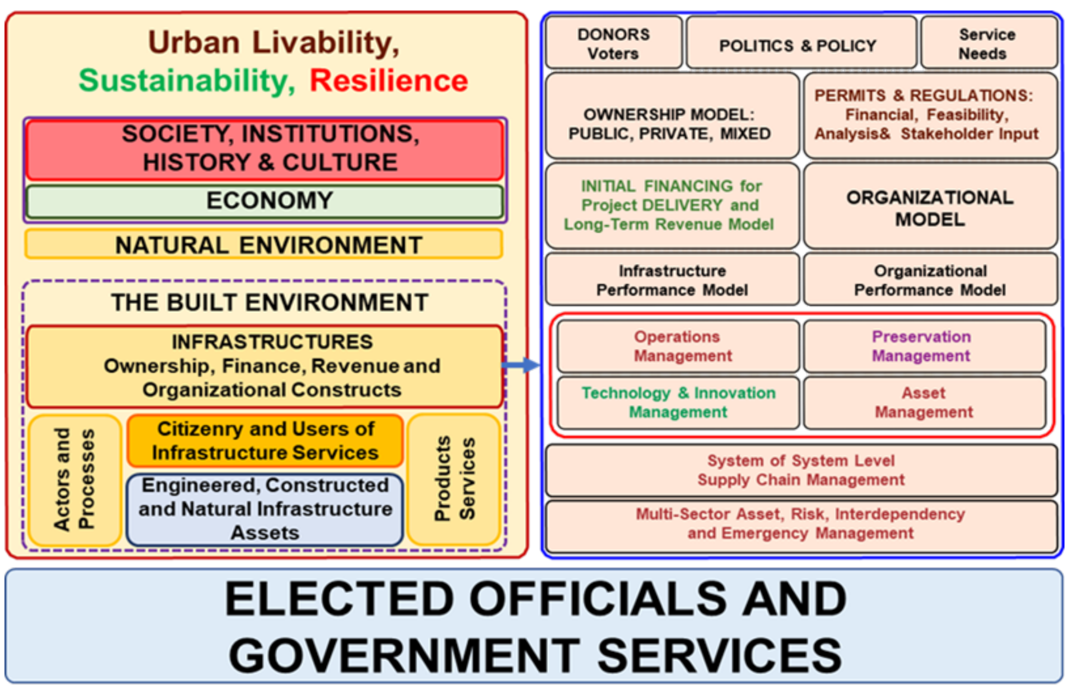

Figure 1 Complex Systems Making Up the LSR of Dense Urban Regions

of life will be negatively impacted.

The writers therefore hope to stimulate and even provoke discussions by engineers, planners, architects, social scientists and government officials who are concerned with infrastructures and the **LSR** of urban regions. There is a clear need for strong leadership and innovative, transparent governance by elected officials, in conjunction with an alliance of federal/state government regulatory agencies, public, private or semi-private infrastructure owners-operators, major industry, academic and community leaders in order to advance the **LSR** of urban regions throughout the US. One significant problem is the detachment between urban planners and civil engineers. Properly educated and experienced civil engineers may be at least as qualified as urban planners in planning and providing infrastructure asset management services and in constructing and preserving a built environment that can effectively serve the purpose of integrating LSR.

Further, in many urban regions and cities in the US (especially if they have not yet experienced a major disaster in recent decades) a lack of coordination and collaboration between the various stewards of **LSR** may be typical. Given that the natural, social and engineered systems (Fig. 1) underlying each of these concepts are the same, it makes sense for the corresponding communities to converge and work together in order to avoid conflicts, fragmentation of resources and even possible detriments to urban **LSR** objectives. Vision 2025 (ASCE, 2006) implies that civil engineers should consider themselves responsible for serving as coordinators and integrators towards urban **LSR**. However, whether the current state of the civil engineering education and practice is ready to rise to such a challenge and whether civil engineers have the “architecture and urban planning insights in their background” deserves to be questioned.

Writers advocate that ASCE considers to embrace urban LSR as a critical overarching need for reforming education and practice. One of the primary objectives of this paper is to convince practicing engineers, engineering educators, accreditation and professional licensing organizations as well as elected officials, urban planners and industry leaders ***to collaborate***. They should consider livability, sustainability and resilience as universal prerequisites to the additional specific objectives of any urban design problem, whether this involves new construction or the renewal of existing built systems and infrastructures. If the engineering profession reaches consensus on effectively mitigating urban **LSR** concerns it will be easier to convince elected officials at the federal, state and especially local levels to appoint qualified civil engineers to systematically and integrally participate in regional urban planning. There would be significant roles for urban higher education institutions to perform trans-disciplinary research and education on **LSR** by taking advantage of their proximity, in some cases by partnering with major research universities and the National Laboratories (even if the latter is not located at an urban region).

A further objective is exploring how we may leverage engineering design-thinking to dissect and enhance urban **LSR** in a systemic manner. In the design of complex systems, we have to reconcile multiple conflicting objectives, different types of hard and soft constraints and significant uncertainty in the impacts of policy and decisions that shape life in dense urban regions. Unless we take maximum advantage of cyber-infrastructure (sensing, imaging, communication and computing) tools, in addition to data management, analytics and visualization for interpretation as we perform research in urban laboratories to identify and simulate complex urban systems, innovative **LSR** solutions may remain oblivious. Domain knowledge on the built environment and various infrastructure systems and services is also essential. The writers hope that these ideas may resonate with some of the federal agencies and academic programs so that they will support a new breed of civil engineering education and practice capable of imaging, sensing, modeling and simulating the built environment and infrastructures as complex systems for managing these as envisioned in Fig. 1.

Consensus Definitions for LSR:

Livability (including **inclusivity**), **sustainability** and **resilience** (**LSR**) are now widely recognized as the three guiding principles of modern urban design (Maddox (2013), Ryser (2014), UN Habitat (2016), Cederoth and Brown (2018)). Advancing and integrating these principles to serve as the objectives of innovative urban planning and the execution of urban designs is discussed by Alberti (2017).

In Great Britain, municipal civil engineers and urban planners have traditionally worked together to better integrate urban infrastructures with urban planning and design (Rogers, 2017). In the US, however, significant gaps remain between various civil engineering domains and urban planners. Today in North America, urban livability, sustainability and resilience remains in the custody of somewhat separated communities – **livability** as a beacon for planners, architects, public health officials and social services (AARP (2018), Milken Institute (2014); **sustainability** as a beacon for environmentalists (Our Common Future, 1987) by the UN World Commission on Environment and Development); and the contemporary environmentalism following Elkington (2014) based on balancing the social, environmental and economic (triple) bottom lines.

More recently **resilience** emerged as a beacon for environmentalists (**ecological resilience**), urban planners and social scientists (**community resilience**), economists and insurers (**economic resilience**) and, elected officials, public security officials, emergency managers, first responders and civil engineers specializing in multi hazards risk mitigation (**disaster resilience**).

Unfortunately, communities researching and implementing these areas in the US have not yet developed a common language (ontology) and have not yet come together under the principle of integrating livability, sustainability and resilience. Further, there are many cities and urban regions that have not yet experienced major natural disasters. Consequently, their elected officials, industry and community leaders may have not yet recognized the significance and payoff of investing in resilience. It is important to recognize that disasters are not only due to natural hazards, and many slowly occurring ecological, economic and social disasters may not even be recognized in a timely manner. The complex and dynamic intertwining between man-caused and natural disasters are discussed further in the following.

Disaster Resilience:

The events of 9/11/2001 in NY City, followed by Hurricane Katrina in 2005 and Hurricane Sandy in 2012 led to US government, national academies and various foundations to advocate for improved **resilience.** Many cities came together under the Rockefeller Foundation's 100 resilient cities initiative (2013). The National Science Foundation (NSF), US Department of Homeland Security (DHS), and the National Institute of Standards and Technology (NIST) are some of the federal agencies in US that started sponsoring research on disaster resilience. NIST recently developed guidelines for Community Resilience Planning (NIST, 2015), which focused on disaster resilience. Meanwhile, in the Great Britain, the Government Office for Science (2011, 2012), the Overseas Development Office (2012) and the Institution for Civil Engineers (2012) published vision statements, risk analyses and policy statements related to infrastructures and their role in community resilience.

Resilience has now become a guiding concept for civil engineers engaged in civil infrastructure and lifeline systems, multi-hazards characterization, natural disasters, risk assessment, hazards mitigation, infrastructure protection and emergency response. ASCE formed a Division on Infrastructure Resilience in 2014. Many structural engineers specializing in the area of reliability theory and its applications to natural hazards mitigation, infrastructure fragility and critical infrastructure protection have embraced the need for resilience. However, an overarching definition of hazards (natural and manmade) and how they may interact and impact the resilience of dense urban regions is missing. Recent advances in understanding and mitigating high impact low probability risks (Blackett Review of High Impact Low Probability Risks, by the UK Government Office for Science, 2012) need to be recognized by the US researchers, especially regarding regions that have not yet experienced major disasters.

FEMA and NIST's efforts seem to be focused on community resilience under natural hazards without making distinctions between midsize cities and dense urban regions (such as the Northeast Corridor or the San Francisco Bay Area). DHS's infrastructure protection program seems focused on protecting infrastructure assets against manmade hazards. No other federal agency except the NAE and NSF (to some extent) seem to have embraced the significance of considering LSR of a dense urban region as a critical integrative urban planning and engineering design problem involving complex systems, and how livability, sustainability and resilience are in fact closely linked. Rather than fragmenting the resilience of various urban systems, we should be focusing on **urban resilience** as the capacity of individuals, communities, institutions, industry and businesses within a city or region to survive, adapt, and grow no matter what kinds of chronic stresses and acute shocks they experience. Urban resilience requires stakeholders to ensure that the natural environment, economy, society, the built environment and infrastructure services, and government services are all made resilient and the integrity, transparency, accountability and inclusiveness is championed and exercised by elected leaders in state and local governance.

NAE (2012, 2015) in "Disaster Resilience: A National Imperative, and in "Developing a Framework for Measuring Community Resilience" emphasized "Information" and "connectedness" as vital for resilience. More recently NSF 16-140 (2016) offered an overview of the "Smart and Connected Communities (S&CC)" initiative of this agency and its relationship to the White House "National Smart Cities Initiative" and the President's Council of Advisors on Science and Technology (PCAST) report on "Technology and the Future of Cities" (NSF 16610 (2016). These efforts are all inspired by and confirm the attention urban LSR deserves.

The most recent LSR initiative was launched by the White House (Sep 2015) as the Smart Cities Initiative. NSF, US Departments of Energy, Defense and Transportation, NIST and various other agencies are participating in this initiative (NSF 16-140, 2016) that is especially driven by information technology and the intrinsic promise of Internet of Things (**IoT**). These initiatives may offer significant rewards in the future. Meanwhile, we should recognize that utility, functionality, serviceability and durability are some of the performance limit-states for infrastructures and constructed systems that are in fact closely related to livability, but they are often lost in the practice of design by code provisions as opposed to performance-based design.

Urban Resilience:

The complex, dynamic, interactive processes of relentless change in cities and the three principles of Livability, Sustainability, and Resilience demand a continual process of collective learning (Comfort, 2018). How this learning is expected to occur, who has responsibility for leading and guiding the process and what technical mechanisms enable social and organizational learning remain key questions that need to be addressed with explicit strategies for collective action in urban regions. Especially, the core problem of uncertainty in urban planning to create livable, sustainable and resilient cities, and the explicit task of reducing the degree of uncertainty in metropolitan regions will require detailed data collection, measurement, and modeling (Comfort, 2018).

In the ongoing process of improving the **LSR** of existing cities, the information infrastructure essential to support continuing observation, monitoring, aggregation, and analysis of data in order to guide the learning process requires a substantial infrastructure system in itself. It also likely influences the interaction among the other component systems in either positive or negative ways. Without a coherent overview of this 'system of systems,' it becomes difficult to capture clearly the vision of **LSR** in practice. It is helpful to visualize this process as it operates differently for different communities, groups and organizations in cities. While natural disasters offer an excellent incentive for collective learning on how to improve LSR, cities and regions that have not experienced natural disasters cannot ignore the importance of urban **LSR** principles. The Smart Cities initiative (2015) offers great opportunities for such cities and regions.

Infrastructure Performance Management:

An important need in urban **LSR** is establishing metrics for the performance of engineered and constructed systems and their custodian organizations. In 2017 Hurricanes Harvey, Irma and Maria, and more recently Alberto, Michael and Dorian, changed parts of Texas, Florida, Carolinas and the Caribbean. Regions and cities with experience in disasters, expert planning, and investment into their infrastructures recovered relatively quickly while the conditions at Puerto Rico and other developing areas of the Caribbean serve as examples of how the fragility and disutility of infrastructures and a lack of resilience of the built environment all negatively impact disaster recovery.

The performance limit states (LS) illustrated in Fig. 2 for the built environment are Utility, Serviceability, Life Safety and Resilience Limit-States. These correspond to events and demands expected with the return periods of every day; 5-20 years; 75-2500 years; and greater than 1000 years; respectively. The Utility Limit State performance is characterized by the level of service or whether peak demand exceeds capacity during day-to-day operations. Additionally, a positive lifecycle benefit/cost of operating the facility would be expected.

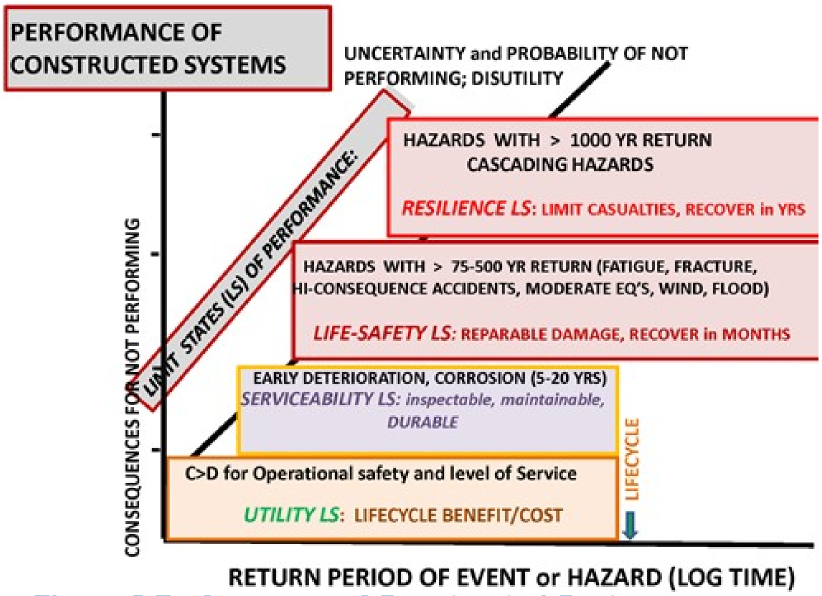

Figure 2 Performance of Constructed Systems

At the Serviceability Limit State, we expect that a system can be inspected and maintained routinely at a reasonable cost while the durability of that system would be such that it should not require any rehabilitation and renewal for at least 20 years. The Life Safety Limit State performance calls for a system to have greater strength and energy dissipation capacity than required to meet the demands of hazards with return periods up to 2500 years. In addition, constructed systems should have controlled failure modes so that human life will be protected and the facility will suffer only reparable damage (so that it may be returned to service in a matter of months). Finally, for extremely rare, low probability events, with return periods exceeding 1,000 years, we expect the system to have sufficient robustness and resilience so that casualties remain limited and recovery would not take longer than a few years. Figure 2 further illustrates that the disutility probability and associated uncertainty increases with the return period of demands.

A critical challenge to the management of the built environment is the fragmentation that currently governs how different infrastructures are owned, financed, operated and managed. Although the failure of one infrastructure component or system often leads to cascading failures of other components and systems, the fragmentation in the ownership and management of individual infrastructure systems persist in many urban regions. In fact, the operation, condition evaluation, maintenance, preservation, renewal and resilience management of the same infrastructure system may be commonly delegated to different silos within the same organization.

In innovative cities the need for an integrated or coordinated management of all infrastructures (known as cross- sector asset management) for resilience is beginning to be appreciated. In many other cities, however, various infrastructure managers come together at the emergency response center if called for by the mayor or emergency manager of a city. Until we can develop mechanisms to systematically and continuously connect all infrastructure planners, managers and regulators within a metropolitan region for proper functionality and preservation in addition to resilience planning and management, we cannot be assured of even attaining the minimum performance we expect from the built environment. As discussed earlier, some metropolitan planning organizations have been more successful than others in leading the integration of all planning activities and infrastructure organizations in their regions. Again, the smart cities initiative may offer tools such as real-time sensing, imaging, communication and computing systems and associated information technology tools for an integrated approach to asset management of different infrastructures.

Complex Systems:

In complex systems the whole (system) is more than the sum of its components and the collective behavior of components cannot be inferred from the individual properties of the parts. Recognition of the properties of complex systems (such as emergent behaviors, non-stationary internal structures, adaptation, evolution, and uncertainty) and the need for a new methodology to study them started in the 2000's. An Interagency Working Group, with members from various US Government agencies issued a position paper (2013): "Transforming the Practice of Engineering for Large Complex Systems," indicating that "a fundamental rethinking of engineering methodologies is urgently needed if our nation is to ensure that the large complex systems critical to our national security, economy, and quality of life are resilient in the face of natural disasters, creative adversaries, and an unforeseeable future."

The foundational and complex (or CLIOS) systems that make up urban **LSR** therefore point to a need to recognize the challenges in "the engineering of complex adaptive systems" and how cross- disciplinary research for new knowledge and tools for reliable simulation of such systems has emerged as a paramount concern. We recall the role civil engineers should aspire for enhancing the **LSR** of dense urban regions and mega-cities. This points to a need for grounding in systems engineering, which has been a dynamic and evolving field since its origin in the Bell Labs in the 1940's. The need to identify and manipulate the properties of a system as a whole, which may differ greatly from the sum of the component properties, has motivated academics, industries, and government agencies to explore the applications of systems engineering starting from the 1950's with many higher education institutions in the United States offering related courses. Now over 75 university programs offer degrees in systems engineering, many as a specialization under industrial engineering.

Rinaldi et al (Critical Infrastructure Interdependencies, IEEE Control Systems Magazine, Dec. 2001), Sussman, et al (The Concept of the CLIOS Process, 2005), (Dodder et al. 2004), and DOE's LANL Researchers (Toroczkai and Eubank, Agent-Based Modeling as a Decision-Making Tool, The Bridge, 2005) have contributed to our understanding of adaptive complex systems as an emerging research and application area. In addition to common systems engineering tools, a number of mathematical tools (e.g. Pareto optimization, graph theory, chaos theory, game theory, Bayesian networks and agent-based models to name but a few) have been proposed for the data-driven modeling and analysis of various natural and multi-domain complex systems.

While systems engineering based on models following laws of physics, economics, etc. has been maturing through the last decade, applications to systems as large and complex as a dense urban region remain as a particular challenge. The construction of multi-scale, multi-resolution, and multi- domain models of an urban region while utilizing the concept of system-identification for their validation and calibration offers promise for advancing the state-of-the-art in the simulation of complex systems. Advances in analytical, numerical, and computational modeling of dense urban environments are critical for paving the way to better policy and more informed, effective and fair investment decisions.

Hazards, Risk and Planning for Resilience:

In 2015, NIST issued a guide called "Community Resilience Planning Guide", which puts forth a general methodology for enhancing community resilience. Resilience planning offers an excellent opportunity to initiate an integrated planning of all **LSR** systems and not just for natural disaster resilience. **LSR** systems are intertwined and interdependent. Further, both the nature of hazards impacting the urban regions, and our understanding of the risks due to these hazards have been fast changing. The hazard mitigation and emergency management community has been conditioned by earthquake, hurricane, and tornado risk before 9/11/2001, and by man-made risks afterwards until Hurricane Sandy in 2012. Some man-made and natural hazards we are now aware of are listed in Table 1.

More recently, climate change induced cascading weather anomalies, such as extreme droughts followed by brush-fires, followed by mud-slides in addition to frequent super-storms, are being recognized as relevant hazards. However, there are other long-term, slowly-increasing and socially driven hazards, such as infrastructure and organizational failures leading to service disruptions, mismanagement leading to deterioration and infrastructure disutility; accidents due to weather and infrastructure inadequacy; long-term economic disruptions such as loss of manufacturing leading to increasing disparity of income and wealth between the residents of a dense urban region; blight, etc. which are usually ignored in considering resilience. Such socially driven hazards, especially when coupled with others listed in Table 1 need to be fully recognized and incorporated under the umbrella of LSR by planners, multi-hazards experts, engineers and public health specialists during resilience planning.

Table 1 – Summary of man-made and natural hazards

Man-made Hazards	Natural Hazards
Climate change	Earthquakes
Power disruption & blackout	Landslides & debris flow
Nuclear power – Radioactive waste	Drought and water shortage
Radiological emergencies	Extreme heat
Chemical threats and bio-weapons	Thunderstorms and lighting
Cyber attacks	Tornadoes
Terrorist Attacks	Tsunamis
Civil unrest	Major Wildfires and Forest Fires
Hazardous materials	Winter and ice storms
Infrastructure Disutility	Sinkholes
Emergency diseases, contagions	Floods and flash floods
Ignorance and Corruption	Hail and Damaging Windstorms
Agricultural diseases & pests	Hurricanes and Tropical storms

Urban LSR planning would provide a great opportunity to consider all of the man-made and natural hazards with their inter-relationships and cascading potential in order to design mitigation as well as emergency response in an integrated, coordinated manner. We have to recognize that our experiences in multi-hazards mitigation and response planning has been mainly driven by earthquake, hurricane and flood, and yet the **risk due to man-made hazards** at dense urban regions (especially those that have not yet experienced a natural disaster) may be far greater for communities which have experienced and prepared for natural hazards.

Risk:

In the broadest sense risk is defined as the probability of an event occurring multiplied by the resulting cost or benefit associated with the event (Dantzig, 1956). In disaster planning, risk is a subjective and relative concept depending on the uncertainty, scale, return period and nature of hazard, past experiences and culture of a community, including leadership, vision and rigor in the planning, mitigation and preparation for risk. Renn (2008) developed a new system of risk categorization and evaluation described by the German Advisory Council on Global Change (WBGU, 2000). In order to achieve a balanced and reasonable judgment on the acceptability of risks, a more comprehensive set of attributes were sought to reflect public concerns and acknowledge the inherent uncertainty and assumptions in risk assessment.

The WBGU report outlines nine criteria for hazards classification *(UK Gov Office for Science, 2011): "(a) extent of damage, (b) probability of occurrence, (c) incertitude, (d) ubiquity, (e) persistency, (f) reversibility, (g) delay effect, (h) violation of equity, and (i) potential of mobilization.*

Renn distilled these nine criteria into six genuine risk classes, and assigned names from Greek mythology to signify the complex issues associated with the new self-awareness of creating manageable risks, rather than just being exposed to fate. These vary according to potential for damage, probability (or certainty), public concern and timescale.

Writers agree with the need to characterize risks but also propose to classify hazards into only three distinct groups, based on the associated uncertainty, cause and return period of hazard:

(1) Risks due to "black-swan" events with very high uncertainty and very low probability of occurrence but with extremely high consequences, with return periods of >1000 years;
(2) Risks due to the occurrence of "recurring" natural hazards such as hurricane, flood and earthquake with return periods of 75-2500 Years (may be characterized as White Swan events); (3) Risks due to frequent Neon-swan events that are obvious but immensely important and near statistical certainty, as further illustrated in Fig. 3. Some of the man-made hazards in Table 1, such as cyber-attacks and civil unrest would fall into this category.

While the above classification is less granular than Renn's, it may help guide elected officials as well as emergency planning to begin to recognize the hazards that fall under the neon-swan category. Also note that some hazards that may lead to a cascading failure are especially critical for planning and preparation. For example, climate change – whether entirely man-made or aggravated by natural events, is considered to be associated with drought, heat and flood and agricultural diseases at various regions. Similarly, extended periods of economic contraction are known to lead to blight, addiction, disease and civil unrest.

Figure 3: Proposed Classification of Hazards for LSR Planning

The **LSR** community needs to acknowledge that man-made and natural hazards and risks due to these are complex concepts that have already been studied in greater mathematical rigor in fields such as defense, manufacturing, medicine, pharmacology, economics, banking and insurance. For example, a different metric for risk, the "Risk Exposure Index," was proposed by Simchi-Levi (2005) in relation to supply-chain operations based on "the time to recovery from and the cost of a disruption." This index may be useful in ranking low-probability/high-impact risks. These types of risk are difficult to predict and quantify and therefore are extremely difficult to manage.

Urban LSR as a New Discipline:

Based on the discussion above, there is a critical and strategic need for an integrative discipline which focuses on the challenges associated with **LSR** of urban regions. The **LSR** of a region requires proper functioning and performance of infrastructures and infrastructure services, however, the planning, engineering, and managing of an urban region as a complex system with the objective of **LSR** should be considered as the actual parent "design" problem that deserves the collaborative efforts of engineers, architects, planners and scientists.

Research and Education for Urban LSR:

NSF recently released a new initiative on Smart and Connected Communities (NSF 16-20, 2016) whose goal is to:

1. improve understanding *and* support the design of smart and connected communities,
2. foster development of a multidisciplinary and diverse research community that fully involves social, economic and behavioral sciences together with information sciences and engineering, and,
3. support research capacity building to address opportunities and challenges of present and future smart connected communities,

In particular, the solicitation calls for activities that contribute to meaningful engagement with communities in accomplishing the above objectives.

We infer that coordinated and integrative research, education and demonstrations of urban LSR require bringing together at least the following domains:
(1) Urban Planning and Architecture;
(2) Engineering, Operation and Preservation Management of the Engineered Environment – including engineered and constructed buildings and infrastructure elements;
(3) Environmental Engineering and Science;
(4) Social, behavioral and information sciences;
(5) Economics, Finance and Organizational systems;
(6) Health Sciences;
(7) Infrastructure and Social Services – including Government, Education, Health, Housing, Water, Energy and Fuels, Transportation, Communication, Internet, Food, etc. and,
(8) Innovative knowledge and information, computing, sensing and imaging, communication, modeling and simulation and decision technology integration.

A research and education program on urban **LSR** by a cross-disciplinary team may include:

(1) Observation, study, understanding, and modeling-simulation of urban regions as complex systems-of-systems. This would require an integration of various modeling approaches such as: meta-models, agents (rule-based and intelligent-learning), nodes-and-network models, Bayesian networks, multi-physics models, and many others. We note that although Model- Based Systems Engineering (MBSE) has been maturing through the last decade, applying its tools to systems as complex and large as a city remains a particular challenge. Sophisticated models require highly trained academics or consultants while most operators have neither the time nor the training to approach scenario simulation for decision-making.

(2) Planning, design, and development of "smart city" systems by leveraging "internet of things" and cyber-physical systems.

(3) Strategies and methods of renewing the existing built environment while offering green-spaces, urban farming, energy conservation, new jobs and public health opportunities.

(4) Transformation into renewable energy sources for zero fossil-energy footprints for buildings, transportation, and industrial production.

(5) **Cross-sector asset management** of critical transportation, water, runoff, sewer, energy, power, and communication infrastructures.

(6) Partnership with management consulting industries, such as McKinsey and Frost and Sullivan, currently ongoing smart-city initiatives in Europe, the Far East, and the Americas, academic institutions and industries that are focused on this topic, and the federal agencies included in the "smart and connected community's framework" (White House Press Secretary, 2016).
(7) Living laboratories – urban region(s) with elected officials, infrastructure agencies/utilities, academe, businesses and industries all supporting and participating in urban LSR planning, education and research.

Conclusions and Recommendations:

Urban regions are complex systems of systems that often straddle multiple states, political districts, local governments, a multitude of public and private infrastructure agencies with different organizational systems, varied public and private enterprises, and multiple shared natural and built environmental assets. In the US, where home-rule is a cherished tradition for municipalities, townships, counties and states, the integration of planning is a particularly formidable challenge. To address this challenge, Metropolitan Planning Organizations in the US are established and funded by federal law to facilitate integrative and multi-mode "regional transportation planning." Meanwhile some cities are appointing "Resilience Czars" and/or "Planning Czars." These individuals recognize the need for a holistic approach to planning and management of the built environment, especially when it comes to LSR, but the regional history, politics, culture and economy often pose formidable challenges to integrative approaches.

While urban planners and policy-makers are expected to lead the efforts for providing LSR, they **cannot/should not** function without involving experienced engineers who design, maintain and manage critical infrastructures and infrastructure services. However only a few engineers are trained as systems engineers and most engineers who are engaged in the management and renewal of the built environment are trained in reductionist approaches with little or no background in complex systems and/or multi-disciplinary design-thinking. States, cities, planning and infrastructure agencies often trust the planning and management of their built environment to engineers with specific domain knowledge. They are often unaware of the importance of including systems engineers with expertise in LSR (and even if they were cognizant of this need, finding such individuals is a significant challenge in and of itself).

LSR are closely coupled goals that are influenced by natural and built environments, society, economy, infrastructure services, information and government. Unless LSR of a city is explicitly recognized within the planning activities in an integrated and holistic manner, long-term success may be compromised since there is evidence that disconnected, piecewise, or loosely connected plans for urban revitalization or hazards mitigation often render them ineffective. We must overcome piecemeal and single-discipline silo thinking and shift to a holistic and cross-disciplinary systems synthesis methodology. We need to identify and apply systems engineering methodologies that have scaled effectively in field settings to enhance LSR. This requires research leveraging actual cities as living field laboratories to observe and understand elements and systems behavior in some depth.

Writers also recommend that any investment into hazards mitigation, emergency response and resilience planning also consider **all hazards and their probable combinations** – and not separate natural hazards from man-made hazards. What we consider as a hazard changes as society and economy change over time. It is recommended to seriously consider mitigating the hazards that are Neon-Swan events which occur several times each year with statistical near- certainty; Planning and mitigation for events with return periods of 75-2500 years such as hurricane, flood and earthquakes; and, events that are in the realm of Black-Swan events with return periods of 1,000 years or longer would be different. Long-term changes such as climate change, infrastructure disutility, economic and demographic shifts, and the resulting man-made hazards, as well as many variables related to history and culture should impact how we approach LSR planning and multi-hazards mitigation in the 21st Century.

A first step forward often is to seek data and information that help public and private sector users gain situational understanding. In the US, cities and regional agencies seem to be taking the lead on this, with the best of them setting up open data repositories that permit users to find out the state of infrastructure systems, how well services are running, what LSR needs are still unmet, and much more. Open data provided by governments potentially create opportunities for businesses to innovate and profit by enhancing the data, offering more useful data, and creating new services for governments, businesses and consumers. In this era of big data analytics, open data are most welcome, but their use also relies on open data standards and sensitivity to privacy concerns.

A new discipline we may call “urban science and engineering,” including integrative planning and engineering for the design and management of LSR at urban regions is urgently needed. A similar argument was made by Alberti (2017) but excluded engineers. Experts within this discipline would be coordinating and integrating the products of architects and planners, social scientists and engineers and scientists from many other disciplines towards LSR of the built and natural environments at dense urban regions. Urban universities, in collaboration with government and industry champions, have a responsibility to urgently start responding to this need.

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