International Journal of Mass Emergencies and Disasters
August 2012, Vol. 32, No. 2, pp. 197–211.

The Role of the Built Environment in the Recovery of Cities and Communities from Extreme Events

Daniel J. Alesch
University of Wisconsin, Green Bay

William Siembieda
California Polytechnic State University, San Luis Obispo

Email: aleschd@uwgb.edu

This article contributes to the development of a theory of recovery of a city from a disaster generated by an extreme event. It focuses on the functions performed by the built environment in an urban system and the recovery of that system. The city is viewed as a complex, self-organizing system. A disaster results when the parts of the system are damaged to an extent that they are unable to perform their respective functions effectively and the relationships among those parts are disrupted. Recovery occurs as the parts of the system regain their functions and as critical relationships among the parts are restored based on the new conditions created by the extreme event. Rebuilding or restoring the built environment is necessary but only rarely sufficient for system recovery. Recovery processes are perhaps best depicted in terms of agent-based models.

Keywords: Disaster recovery, built environment, recovery theory, self-organizing systems, agent-based models

The Focus of the Paper

This paper examines how restoring, repairing, or replacing the built environment contributes to long-term community recovery. The purpose for examining this subject is to contribute to the development of recovery theory. To date, thinking about recovery has been done by looking at past events and how governments and societies have responded to the events. “Recovery activities” have been documented, but “recovery theory” was not well developed or even referenced. Recovery was something that happened, not explained. In contrast, physics begins with theory and the experiments are done to support the theory, while in biology it is the experiment that counts, as this generates the data to classify observations. Theory follows experiments in biology and is not a leading instrument in the field. Except for structural engineering, disasters do not lend themselves to experimentation. Nonetheless, post-event studies of disasters are typically uncontrolled, not well documented, and not conducted with similar methodologies. The need to develop theory for disaster recovery is even more pressing given that, thus far, studies of both mitigation and recovery activities have yielded too little information to reliably inform policy or people's behavior.

Historically, restoring, repairing, or replacing the built environment has often been equated with recovery. We now understand that those activities are necessary, but not sufficient for achieving long-term recovery. Despite that understanding, no one has yet clearly articulated the ways in which rebuilding the physical artifact contributes to overall, long-term community recovery. This paper's focus is on theory building: it is an attempt to integrate the how and the why of the built environment's contribution to recovery.

The term "community" is in such common usage that it may not have a generally accepted definition, even among sociologists. In this paper, we choose to use the term "city" rather than community. Community, to us, implies a collection of persons and formal and informal organizations existing within a generally defined space, having relatively persistent patterns of social interaction and connections, and significant commonality of interest. For us, the term "city", as used here, does not refer to a governmental entity, but, instead, to an urban settlement existing within a defined geographic area, operating as an open system, with relatively persistent patterned interaction, with significant differentiation among participating organizations and individuals, but without the necessity of shared significant social commonalities or interests. For us, it is the shared social commonalties that distinguish communities from cities and we have the sense that community recovery is significantly different from the recovery of cities. Finally, we choose, for purposes of this paper, to use "city" and "urban" interchangeably. Small towns and villages often comprise communities and we choose, again, to separate consideration of community recovery from aggregate urban recovery.

How Extreme Events Become Disasters

It is singularly important for those concerned with mitigation and recovery to understand how an extreme event creates significant discontinuities in urban systems. Based on the research Alesch et al. (2009) performed in more than two dozen urban settlements that experienced disasters, they came to believe that significant discontinuities unfold in communities over days, weeks, and months rather than during the duration of the triggering event. They have referred to these unfolding consequences as cascading consequences and sequential failure. As one or more of the elements of the human settlement system are ruptured or rendered ineffective, others that are dependent on reciprocal relationships with those damaged elements may also find themselves experiencing difficulty in performing their functions sufficiently well to help maintain the integrity of the city system.

Cascading Consequences

Structural engineers have the ability to examine a ruined a bridge or building and to reconstruct how and why the structure failed. They debate between whether it was caused by progressive or cascading failure, ground deformation, inadequacies of steel welds, and so forth. Social scientists find it more difficult to explain the failure of social institutions – whether there are threshold effects, cascading failures, and so forth. It is possible to describe what happened in individual cases. Economists have developed tools for assessing some of the macro-economic impacts of extreme events on communities, but we have not yet seen in the literature much about means for recovery of the component parts and the whole should the exogenous shock exceed the city's resistance and resilience to extreme exogenous or even internal perturbations.

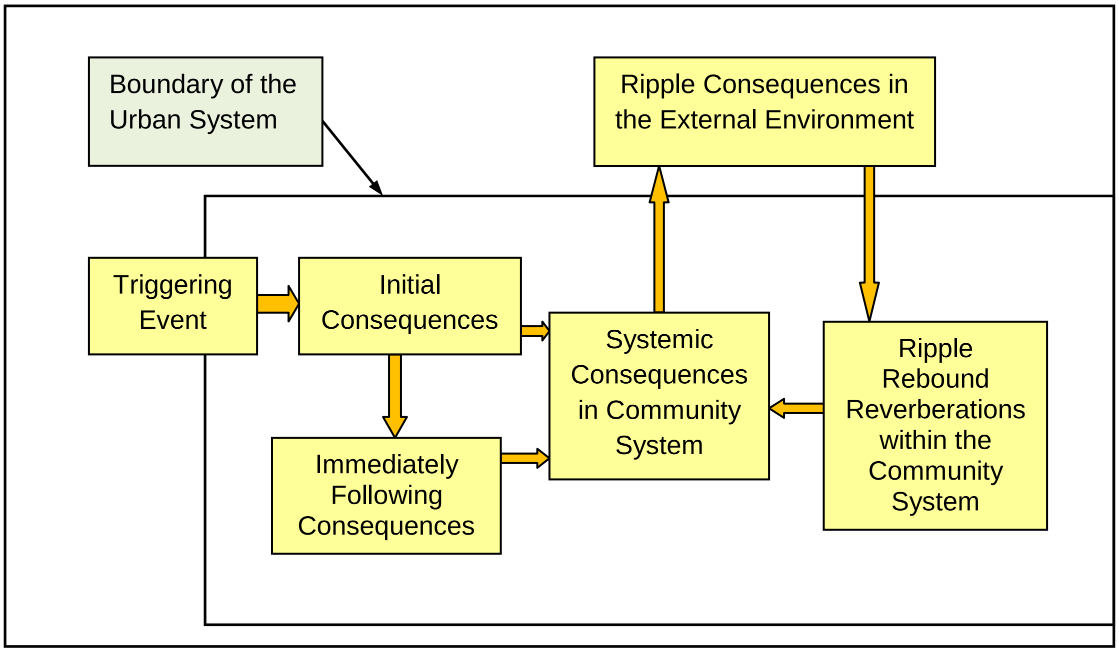
For us, a disaster occurs when an extreme event has exceptional consequences for a system by creating one or more significant discontinuities in critical elements of that system or in the relationships among the system elements so as to render the system or major elements of it unable to perform their systemic functions sufficiently to maintain system performance. Obviously, extreme events vary in terms of proximity, intensity, extensiveness, and duration. Similarly, disasters vary both in terms the extent to which they constitute discontinuities in systems and affect subsequent system performance. The discontinuities are of such a magnitude as to rise above the thresholds of the coping mechanisms of some elements within the system, causing instability.

To understand what it is from which the city is to recover, it is important to know what functions and interrelationships were damaged and must be re-established or developed anew to achieve recovery. This damage assessment can embrace simple counts of destroyed buildings as well as more complex assessments of social loss factors. Losses to social components and other complex network parts require their own assessment methods. Any theory of recovery must help to understand not only what parts of the system have to once again become functional for recovery to occur but, and here is the more difficult part, to enable us to understand how to facilitate creating or re-establishing the synergies essential to maintain an open system.

The March 11, 2011 9.0m earthquake and tsunami tragedy in Japan is a terrible and precise example of cascading consequences: a powerful earthquake generates a massive tsunami which generates failure of nuclear power plant backup systems and then the power plants themselves, exacerbating deaths and injuries, homelessness, economic collapse in the regions, supply chain disruptions and then more consequences that ripple out into other places and other lands.

Figure 1 is an attempt to identify consequences of extreme events into five distinct sets. Table 1 presents the set.

Figure 1. Types of Consequences of Extreme Events that Cascade through the Urban Area and to and from the External Environment



Source: Adapted from Alesch et al. (2009)

Table 1 Discontinuity Consequence Set

Discontinuity Consequence Set
Initial
Immediate
Subsequent
Ripple effects
Ripple reverberation

The first set of consequences consists of *initial consequences* and the second set is *immediately following consequences* that cascade from the initial consequences. A familiar example stems from the 1906 San Francisco earthquake: the quake caused buildings to collapse and water mains to break, leading to an inability to control a great fire. The third set of consequences, *systemic consequences in the city system*, has to do with subsequent discontinuities that occur in other components of the city's systems in terms of their capacity to perform their functions; the discontinuities ripple through the urban system as various elements are damaged or destroyed and as relationships among them are impaired or severed. The fourth set of consequences, *ripple consequences in the external environment*, occur outside the city system as the relationships between elements of the city and external elements are disrupted with consequences for the elements in that external environment. Illustratively, other harbors on the Asian side of the Pacific benefited from the destruction of Kobe's harbor in January 1995 and Las Vegas flourished as Bourbon Street languished in the aftermath of Katrina. Alesch, et al. (2009) call the fifth and final set of consequences in this typology *ripple rebound reverberations within the city*. Elements outside the system that are affected by what happens to elements within the urban system typically engage in coping behaviors. These coping behaviors may have functional or dysfunctional consequences for systems within the damaged city. Kobe, for example, has yet to recapture its pre-earthquake pre-eminence as a shipping center. As of this writing, we have little comprehension of the ripple reverberation consequences for Sendai, the surrounding Miyagi Prefecture, and beyond.

Disruption of Functions Performed by the City

Lewis Mumford, in his 1938 classic, *The Culture of Cities*, described the contemporary city as having developed from the earliest roots of "the need for a common fortified spot for shelter against predatory attack [which] draws the inhabitants of the indigenous village into a hillside fortification" (p. 39). He goes on to say that "cities arise out of man's social needs" and "in the city remote forces and influences intermingle with the local: their conflicts are no less significant than their harmonies. And here, through the concentration of the means of intercourse in the market and the meeting place, alternative modes of living present themselves" (Mumford 1938: 41). In his writings, Mumford describes the development of the city through time, but always in terms of its symbolic and practical functions and how those functions are expressed in terms of its physical characteristics (See especially Mumford 1961).

James K. Mitchell added a more contemporary, although entirely compatible, view of the city defined in terms of the functions it performs. Mitchell identifies the following functions of what he refers to as communities (and which we refer to here as cities): material and economic functions, metabolic functions, learning functions, performance functions, creative expression functions, and regulatory functions. He says that "material and economic functions of communities involve the accumulation of resources and their conversion into products and services that sustain both the physical fabric of the built environments and the livelihoods of associated human populations." (Mitchell 2004: 8). He goes on to describe metabolic functions as those that "involve natural and human-modified life-support systems (i.e., ecosystems) including—among others—those that generate, nurture, circulate and absorb air, water, biota, and wastes."

Mitchell (2004: 10) describes each function he defines as being linked with "a characteristic kind of analytic model or metaphor." He identifies these models as: cities as machine, cities as organisms, cities as information exchange networks, cities as performances, cities as muses, and cities as power structures and regulated places. Cities are a complex settlement form and are not self-sufficient. They rely on external resources to function. They exchange with the external environment because they need those linkages, at times to adapt but always to survive.

Understanding Cities as Complex, Self-Organizing Systems

Alesch et al. (2009) describe cities as complex, self-organizing systems. They argue that we cannot develop a theory of city recovery from disasters without a basic understanding of how communities change through time and without understanding of the consequences of an extreme event for the city system. As early as 1962, Herbert Simon described a complex system as "one made up of a large number of parts that interact in a nonsimple way. In such systems, the whole is more than the sum of the parts … given the properties of the parts and the laws of their interaction, it is not a trivial matter to infer the properties of the whole" (Simon 1962: 468). Alesch et al. present a view of the city as a complex, open, dynamic, and self-organizing system. Viewing either a city or a city from that perspective enables one to think of it in terms of the functions it performs, how it changes through time, and the implications of a major perturbation to the city. It provides a means for identifying the consequences of extreme events for a city or community, for thinking about what constitutes recovery, and for thinking about how recovery occurs, in those instances in which it is believed to have occurred.

Conceptualizing the city as a system requires one to think in terms of both component parts of the city and of the relationships among those components and the relationships of the various components with components in the systems that comprise the city system's environment. Most commonly, components of open systems are referred to as elements of that system. It is the elements of the system, the relationships among them, and their relationship with their external environment that comprise the system. Allen (1997) in his work on the science of complex systems deepens this theory by arguing that the components themselves can to modify the properties of other components. In this way self-organizing can occur without extensive reliance on external resources or influences.

Highly developed systems (e.g., more complex urban settlements) have greater differentiation among the elements or classes of elements. This greater differentiation of function (reflected in who does what, where, how, and when) generates the need for more complex communication and interrelationships among the elements, some of which may be quite spatially distant from the immediate urban area. Unfortunately, the increased differentiation and complexity of communication makes the entire system both more susceptible and more vulnerable to disruptions in one or another set of interrelationships. For example, the loss of electrical power in the February 27, 2010 Chilean 8.8m earthquake and tsunami caused a loss of phone and cell phone services that cascaded into civil unrest, looting and arson in a few cities, resulting in the need for the army to be deployed to restore safety and security. This is an example of both “systemic consequences” and “ripple reverberation” in action.

In complex open systems, both the elements in the system and the relationships among them change and adapt through time as they adjust and adapt to eternal and internal stimuli. City systems rely on relatively stable and persistent relationships, but, like most advanced biological systems, the system changes virtually continually and at the margin. This occurs because elements of the system (agents, city members) from time to time must be replaced or because they change what they do, how they do it, where they do it, and when they do it. Of course, except in rare circumstances, the individuals and organizations comprising the city do not make drastic changes all at once. If that were to happen, the system would become highly unstable. Changes typically occur at the margin. The relationships among elements change in response to stimuli from both within the system and in its environment. Complex, open, dynamic systems are not static; they have a tendency toward dynamic homeostasis, but they may also decline in functionality (approach a state of entropy) or “morph” into more highly developed systems (experience negentropy).

Conceptualizing cities and communities as dynamic systems changing through time, often in unexpected ways, also requires us to view them as never being “finished”, i.e., never in the final form, except when they have become completely entropic. At any given time, the city is simply a snapshot of a dynamic entity undergoing change. Until it dies, the city never stops changing, if not in physical terms, at least in social terms. The system continues to change through time in response to changes in the actions of actors and actions within it and from its external environment. Technology plays a special role here as its application may be used to strengthen the resistance to damage and the adaptive capacity of sub-components. On the other hand, increased complexity offers the potential for increased susceptibility to system malfunctions. As technology continuously evolves in a modern world its influence on systems needed to be taken into account.

From this perspective, then, and at the simplest level, city systems may be conceptualized in terms of cellular automata or fractals and best characterized in terms of agent-based models. In *Cities and Complexity*, Michael Batty provides an extensive exploration of conceptualizing and modeling urban areas in those terms, except that his focus is on urban spatial morphology rather than social and economic change (Batty 2005: 294). In a more recent work, Batty and colleagues suggest that “Agent-based modeling (ABM) is fast becoming the dominant paradigm in social simulation due primarily to a worldview that suggests that complex systems emerge from the bottom-up, are highly decentralized, and are composed of a multitude of heterogeneous objects called agents. These agents act with some purpose and their interaction, usually through time and space, generates emergent order, often at higher levels than those at which such agents operate” (Crooks, Castle, and Batty 2007: 1). In the same publication, though, Batty and colleagues say that people as agents can have different behavior from routine to strategic. Consequently, he thinks that agent based models work better with routine rather than strategic attributes. Agents can be assigned roles, learn and adapt. This is an important advantage for agent-based models over equilibrium models that do not possess these characteristics. Since disasters, by definition, are not routine, further exploration and analysis is required to ascertain the extent to which cellular automata and fractals are useful analogies for conceptualizing recovery and the extent to which agent-based models might be used to simulate recovery.

If one is to examine the relationship between the built environment and long-term city recovery, then one must consider the characteristics of the land on which the built environment is located and the space within which it develops. The physical and locational characteristics and the space on which the city's physical artifacts are located are important because they constrain and, to a considerable extent, influence the spatial distribution of activities on the land, the characteristics of the built environment, and the city's relative susceptibility to extreme events. Batty has integrated various urban physical morphology constraints into his models, including, specifically, the spatial characteristics of the land and spatial configuration within which his models are applied. Geographers and urban planners have long worked to understand the relationships between characteristics of land areas and how cities develop in terms of the spatial distribution of activities and functional performance.

What, Then, Constitutes Recovery?

Too often, recovery efforts appear to be based on an implicit perception of cities as machines. That is, "if we simply repair the machine, it will begin to work again." The city as machine metaphor is inappropriate because the city system is more than the sum of its parts and, for the most part, the parts that comprise it act on their own volition. The city as machine analogy negates the effect of culture on cities and people's choices. Anthony Oliver-Smith makes the case for culture in the continued rejection of relocation choices by traditional communities (Oliver-Smith and Hoffman 1999). Culture itself is a system component as we have seen in the 2005 Katrina event in New Orleans and in the 1995 Kobe event. Communities exist because they perform many functions for the inhabitants and, usually, for other communities as well. We usually view communities as providing places to live and work, but one can extend the line of thinking in Mitchell (2004) by saying that they are representations of cities as places of consumption and production of material, intellectual, social, service, and interactive (places to meet people) goods.

If recovery were simply a matter of restoring utilities and repairing or rebuilding damaged structures, it would be a relatively easy matter to have things back in good order within a relatively short period of time, provided that enough money is provided and security of place issues agreed upon. If that were the case, then Homestead, Florida, would not have been nearly insolvent a decade after Hurricane Andrew; Montezuma, Georgia, would have a thriving central business district; Princeville, North Carolina, would be a model city; and the Mississippi Coast and communities in Louisiana hard-hit by Katrina would be "recovered" as soon as someone found the wherewithal to rebuild the structures that were swept away or flooded and consequently demolished. But cities are more than their buildings and utilities. Buildings and utilities are only a means to an end, not ends in themselves.

The discussion of what constitutes recovery is confounded by the failure to specify for whom or for what we are contemplating recovery. Recovery may or may not take place for individuals or families, for the municipal corporation, for individual neighborhoods or socio-economic communities, or for aggregate urban systems. Recovery for each of these is measured with different indicators of functionality. Here, the focus is on recovery of the aggregate urban system rather than on the recovery of individual persons, households, or firms. As the urban system is in continuous change, recovery is best thought of as a process with various stages that may be viewed at various times.

The challenge of recovery for urban systems is defined by the nature and extent of the problems generated by the collision between the pre-event city and the extreme event. We have come to understand that recovery is relative; there is no fixed point at which recovery can be said to have taken place. Following a disaster, aggregate urban system recovery occurs as that system is capable becoming a generally viable entity. It can cope with internal and external challenges within the generally accepted social, economic, and political standards of its regional and national context. A measure of viability is the level of stability within the city functions or its system elements. Examples of this are: in the built environment being able to provide electric power on a regular basis; in the economic environment providing employment or income flows required; and in the social environment ensuring people's aggregate sense of trust, security, and connection. Recovery is happening when the city repairs or develops social, political, and economic processes, institutions, and relationships that enable it to operate and cope in the new context within which it finds itself. The recovered city may closely resemble the pre-event city in physical terms or other characteristics, but it need not. The extent of recovery cannot be measured by how closely the post-event city resembles the pre-event city. It needs other dimensions such as how the social networks function and what levels adaptation has occurred. Here the use of scale analysis might be employed to estimate the large parts of what we call aggregate recovery. Scale analysis is a bridge between the complex and simple. The two questions asked, according to Boccaletti (2011) are: what quantities matter most to the problem at hand, and what are the expected dimensions (magnitudes) of the quantities?

In a sentence, we believe that recovery of a city system means becoming a viable, adaptable system with a new normality in the post-event context. The establishment of viability in the present and for the future is the critical variable that defines recovery. It means that the system has a capacity projected to result in continued self-sufficiency and that its key institutions are coping with and adapting to changing aggregate needs of the functions. At a recent workshop on recovery theory, the assemblage concluded that "Following perturbation by an extreme event, recovery is a complex and urgent process to achieve functioning of socio-ecological systems and adapt to new conditions" (Public Entity Risk Institute 2010).

We can conceive of a simple continuum based on pre-event trajectories: positive and negative (and, of course, the gray areas in between). Based on past events, negative trajectories tend to reinforce themselves where positive ones tend to provide some level of resilience for the recovery process. Our existing common measures for trajectory include level of economic well being, education levels, age profiles, and migration rates. These are used because of access to data sets, and the lack of any cultural or institutional indicators. For communities with downward trajectories, the disaster may simply accelerate a downward spiral despite heroic attempts to use the disaster as a springboard into viability. Montezuma, Georgia is an excellent example of a smaller, rural city that, through time, lost its historic economic *raison d'être* and, following a major flood, was unable, despite heroic efforts, to reverse its longer term trends of gradual decline.

If communities are, in fact, largely self-organizing, that has major implications for recovery theory. First, it implies that recovery must come from within the disrupted city system; it cannot be accomplished by outside actors: outside actors can only facilitate recovery activities such as infrastructure replacement. Since agents in self-organizing systems are thought to respond to relatively simple rules and cues, then agents from both inside and outside the system can provide cues to members of the city and to other generally independent agents outside the city system, encouraging them to take actions likely to contribute to reorganizing the system in ways viewed as desirable. Internal self-organizing capacity has been reported in Mexico City after the 2005 earthquake where neighborhoods that took control over their own recovery process reached viability quickly (Inam 2005), and in Central America where communities in Nicaragua and El Salvador who made their own recovery policies and implemented them became established viability with limited external resources (Siembieda 2005). Certainly the US experience with Greenburg, Kansas after the May 4, 2007 tornado destroyed 90% of all the town's buildings is an example in internal self-organizing. The positive recovery of the Nada neighborhood in Kobe, Japan after the 1995 earthquake and fire is attributed to the prior existence of an active neighborhood organization that spoke with one-voice.

A second implication of cities as self-organizing systems is that recovery would seem to imply the need for a critical mass of agents within the disrupted city to act in ways that contribute to generating or regenerating a viable city system. Behavioral cues come from many sources; one cannot assume that the only cues the agents respond to are the ones from those attempting to create a positive city. If self-organizing systems bring order from chaos, we should not assume that the order that is generated would necessarily result in an optimal or even a desirable city system. Agents in a system they perceive as functioning poorly either before or after a major discontinuity may well choose, entirely rationally, to do what they do somewhere else. Those agents remaining in the city may be unable or unwilling to take actions either independently or collectively to create a functional city capable of interacting successfully within the environment within which it finds itself. The longer, in time, the discontinuity and its cascading effects are in place, the less the probability that the city will return to a state closely resembling the pre-event city. It is the risk of worsening negative effects that prompts the external environment to push for rapid replacement or repair of system functions or elements. This leads us to believe that once a system component threshold has been breached there is limited time available to repair the components capacity to play its role in the necessary overall organization of functions. Recovery is never guaranteed and, should it occur, does not proceed along pre-determined paths or on a pre-determined schedule. This is because components of the self-adjusting system may not converge at the same time or with the same impact.

The Roles of the Built Environment in Long Term Urban Recovery

Given our views of cities and communities as complex self-organizing systems and of disasters as significant disruptions in the ability of the city to perform critical functions at an acceptable level, we are in a position to contemplate the roles of the built environment in long-term urban recovery. We see three critical roles: prevention, facilitation, and performance of critical city functions.

Prevention

The old adage is “an ounce of prevention is worth a pound of cure” and that makes sense in terms of extreme events, cities, and disasters. A modern version of this adage is provided by Beniya (personal communication) as “what we believe is safe is not necessarily safe”. In our conceptualization of how an extreme event becomes a disaster, the initial consequences of the event (e.g., earthquake) and of the consequences that follow immediately (e.g., tsunami) on the built environment and human life are critical determinants of the extent to which systemic consequences cascade through the urban system, into its environment, and back into the urban system. Thus, to the extent that the built environment is able to resist the forces imposed by the extreme event, the less damaging will be the systemic consequences for the city, the village, or the city. In the February 27, 2010 M8.8 Maule earthquake in Chile, buildings constructed under modern seismic codes performed well, while those made of older design and materials contributed to most of the residential loss. Those homes and businesses located beyond the tsunami impact zones also suffered less loss.

Building resistance into the built environment is the foundation to building city resiliency. Resiliency can be incorporated into the built environment by locating the built environment in places relatively secure from extreme events (e.g., outside flood plains, away from known fault lines, not on slopes of active volcanoes, not on barrier islands, not on land that is sinking into the sea, etc.). We must remember though that in the March 11, 2011 Japan earthquake and tsunami even the world's largest man-made sea wall failed to protect life and property. Given the propensity of people to build in inherently dangerous places, the next best thing, perhaps, is to build resilient structures. A Gulf Coast city, following the Katrina-Rita events, chose to replace its seaside sewage treatment plant that was destroyed by the storm surge with a treatment facility built at a higher level away from the shore. It pumps its sewage from the lower levels of the city to the new facility with force mains, thus reducing the likelihood of a large spill and long periods without treating discharges to the sea. That assumes, of course, that the pumps at the shoreline are built to prevent failure from storm surges. In Chile, the reconstruction of the major port city of Talcahuano will be done with new building designs to lessen tsunami impact on houses and commerce that remain in a dangerous location. These are examples of self-adjusting systems.

Facilitating and Performing Urban Functions

The built environment, particularly infrastructure, has become increasingly important in what we call advanced societies: human settlements characterized by highly differentiated economies and large concentrations of people. Damage to the built environment from an extreme event in those societies is very likely to generate major consequences for and discontinuities in the city's behavioral subsystems and in other communities as well. Urban recovery requires re-establishing those parts of the urban system that enable organizations to perform the metabolic functions as essential to the operation of the city: recovery begins with creating shelter and with creating the structures necessary to provide food, water, sanitation, power, healthcare, and public safety. When cascading events occur, such as seen in the March 11, 2011 Japan disaster, opportunity arises for major system adaptation in terms of land use for human settlement and land use for human settlement protection.

Metabolic functions extend beyond ensuring access to those things required for physical well-being. Familial and social linkages are critical metabolic functions of the city. These are facilitated by electronic, broadcast, and print media—each of which requires infrastructure support from the built environment. In the aftermath of disaster, in the first steps toward recovery, these elements of the built environment facilitate familial and social reconnection and provide the means for communication among survivors of the disaster and with the outside world.

The built environment is essential to performance of what Mitchell (2004) refers to as material and economic functions. Where people live, take care of their families, and obtain their basic services are all location bound and links to systems of infrastructure-serviced land-use. These include establishing a working transportation network and other infrastructure needed to facilitate the development or redevelopment of an economic base, employment, and sustained economic activity. These functions are performed by or facilitated by the built environment. Initial steps toward system recovery require that those functions can be performed, at least with external help and at minimally acceptable levels.

The built environment itself performs symbolic functions. Creating or recreating city landmarks provides a means for connecting or reconnecting with the city as a symbolic artifact and helps to establish a sense of continuity and place. Building or rebuilding structures used for religious and other social uses helps to provide a sense of connectedness and reassurance.

Necessary but Not Sufficient

As the world's population is more urban than rural, we rely on the urban built environment as a central element in our daily lives. It protects us from the elements, helps us perform our jobs, provides places for us to engage in social activities, and provides the settings within which we carry on most of the aspects of our lives. Reestablishing the built environment is necessary for recovery, but not sufficient. People must want to choose to remain in a place, or want to relocate into an impacted area, in order for the built environment to support recovery as it emerges from the interaction of systems components. Again the function of culture and also the social contract between the people and their government plays a part in self-adjustment.

Where to from Here?

The theory beginning to emerge from this discussion states that recovery is a resultant of internal self-adjustment within the city. The scope of self-adjustment is a function of the impact of the discontinuity and the extent of cascading events within and outside of the spatial impact area. Recovery viability is influenced by the form and substance of the transactions between the external and internal sectors. We have also said that viewing the city as a set of functions that require attention (based on damage to the networks) rather than a list of repair sites allows recovery actions to be formulated through the interaction of system actors. A positive example of this is real and documented improvement in the New Orleans public school system after Katrina, as internal agents rejected the previous downward trajectory and worked to recreate the education function in a new image. We argue that functions are starting points for framing recovery analysis.

We have suggested that disasters be accepted as discontinuities in the overall dynamic homeostasis that characterizes the urban setting at any point in time. Work is required to understand the effect of discontinuities in urban systems from discontinuities triggered by a broad range of extreme events, including both those characterized by sudden-onset and slow-onset. We need, then, to learn much more about why various classes of agents in the system employ different methods of attempting to cope with the resulting adversity. This requires more understanding of the social contract between society and its people in terms of how much self-adjustment will be permitted and under what conditions. Finally, we would hope to learn which kinds of interventions in damaged communities have greater effectiveness under various circumstances to facilitate communities achieving positive trajectories following major discontinuities. We certainly have not given enough attention to culture as a system element.

Time and scale make a difference in understanding discontinuity from a theory and a policy perspective. It would help to understand how Western Europe, with virtually no infrastructure intact following World War II, emerged within a decade of the end of the war as a fairly well functioning economy that continued to grow and develop. We know that the Marshall Plan helped, but we have put similar levels of resources into other places without similar results. The experiences in Wenchuan China (2008) and now in the Tohoku region of Japan (2011) also will inform us. To do this will probably require collaboration with others who are not particularly interested in urban disasters, but whose skills and knowledge are critical to understanding city systems.

Agent-based models of dynamic urban systems hold some promise for those looking for recovery theory. While we recognize that cascading events can enlarge the damage from a discontinuity we have done little research in to modeling event linkages and then using this information to strengthen the resilience of the built environment. This is a rich area for future research.

References

Alesch, D. J., L. A. Arendt, and J. N. Holly. 2009. *Managing for Long-Term Community Recovery in the Aftermath of Disaster.* Fairfax, VA: Public Entity Risk Institute. See especially pages 15-50.

Allen, P. M. 1997. *Cities and Regions as Self-organizing Systems: Models and Complexities.* Amsterdam: Gordon and Breach Publishers.

Batty, M. 2005. *Cities and Complexity: Understanding Cities with Cellular Automata, Agent-Based Models, and Fractals*. Cambridge, MA: MIT Press.

Beniya, S. 2011. "Taking Leadership Roles in Prevention and Disaster Mitigation." Lecture at The Great Hanshin-Awaji Earthquake Memorial Disaster Reduction and

Human Renovation Institution. November 17.

Boccaleti, G. 2011. *Scale Analysis.* Accessed April 1, 2011, from http://edge.org/q2011/q11_7.html#boccaltetti.

Crooks, C., C. Castle, and M. Batty. 2007. *Key Challenges in Agent-Based Modeling for Geo-Spatial Simulation*. London: University College London, Centre for Advanced Spatial Analysis (CASA).

Inam, A. 2005. *Planning for the Unplanned: Recovering from Crises in Megacities*. New York: Routledge.

Oliver-Smith, A. and S. M. Hoffman. 1999. *The Angry Earth: Disaster in Anthropological Perspective*. New York: Routledge.

Miles, S. B. and S. E. Chang. 2006. "Modeling Community Recovery for Earthquakes." *Earthquake Spectra* 22(2): 439-458.

Mitchell, J. K. 2004. "Re-conceiving Recovery." Keynote address to the Recovery Symposium, Napier, New Zealand, July 12-13.

Mumford, L. 1938. "Introduction." In *The Culture of Cities*. Reprinted in 1970. New York: Harcourt, Brace, Jovanovich.

Mumford, L. 1961. *The City in History: Its Origins, Its Transformations, and Its Prospects*. Orlando, FL: Harcourt, Inc.

Public Entity Risk Institute. 2010. *Theory of Recovery Workshop.* Held at the University of North Carolina, Chapel Hill, November.

Siembieda, W. J. 2005. "Recovery from Disasters: Challenges for Low Income Communities in the Americas." In *The Network Society*, edited by L. Albrechs and S.J. Mandelbaum. London: Routledge.

Simon, H. A. 1962. "The Architecture of Complexity." *Proceedings of the American Philosophical Society* 106(6): 467-482.