Building/Community Resilience: identifying relationships that reduce disaster-related building downtime, improve functionality and build capacity

Original
Building/Community Resilience: identifying relationships that reduce disaster-related building downtime, improve functionality and build capacity / Iulo, Lisa D.; Hurtado Ortiz, Maria; MOHABAT DOOST, Danial; Pourabdollahtootkaboni, Mamak; Comfort, Louise. - ELETTRONICO. - 2:(2017), pp. 3070-3077. (Intervento presentato al convegno Passive Low Energy Architecture: Design to Thrive tenutosi a Edinburgh, Scotland nel 3rd to 5th -July 2017).

Availability:
This version is available at: 11583/2785712 since: 2020-01-27T17:06:13Z

Publisher:
NCEUB 2017 -Network for Comfort and Energy Use in Buildings http://nceub.org.uk

Published
DOI:

PLEA 2017 EDINBURGH
Design to Thrive

Building | Community Resilience: identifying relationships that reduce disaster-related building downtime, improve functionality and build capacity

Lisa D. Iulo[1], Maria Hurtado Ortiz[2], Danial Mohabat Doost[3], Mamak PourabdollahTootkaboni[3], Louise Comfort[4]

[1] Associate Professor of Architecture, Penn State, University Park, PA, USA , ldi1@psu.edu;
[2] Undergraduate Research Assistant, Department of Architecture, University Park, PA, USA, hurtado.maria94@gmail.com;
[3] Visiting Student of Civil Engineering, Penn State 3A Hammond Building, University Park, PA 16802;
[4] Professor of Public and International Affairs and Director, Center for Disaster Management, University of Pittsburgh, lkc@pitt.edu

Abstract: Buildings, including those of historic significance, are increasingly at risk due to climate change, manmade and natural disasters. Capacity of a building to recover and adapt is informed by both internal and external factors that must be holistically considered. This paper explores related concepts of building functionality and recovery in reducing downtime and postulates that the retrofit of a building with the integrated and redundant systems, often associated with sustainable design, can enhance a buildings overall resilience. The preliminary factors needed to establish the functionality/recovery model are examined for San Francisco, California (USA), a city exposed to recurring risk of earthquakes and recognized by the Rockefeller Foundation for its resilience planning (100resilientcities.org). Two established community programs, BORP and SPUR, are analysed. An objective is to identify factors affecting downtime with a particular focus on those external to the building. The capacity of organizational and technical systems is considered thereby allowing a building to be understood in the broader context of a community's resilience. An example for building recovery is proposed that accounts for both internal functions and externalities, such as utilities, in order to inform buildings that are better able to recover and adapt in the face of future events.

Keywords: Resilient sustainable building, community programs and organizations, capacity, downtime, functionality and recovery

Introduction

Existing, often historic, buildings are increasingly at risk due to climate change, man-made and naturally occurring disasters. Capacity of a building to recover and adapt is informed by internal and external factors that must be holistically considered. This paper explores the relationship between building functionality and recovery to reduce downtime and postulates that refurbishment of a building with integrated and redundant systems, often associated with sustainable design, can enhance a buildings overall resilience.

In the built environment, sustainable design refers to the methods employed to conserve capital, most often ecological in nature (Hassler & Kohler 2014). Ideally success is measured against all aspects of the "triple-bottom-line" of sustainability: environmental/ecological, economic and social. Sustainability is a goal put in place to achieve demonstrable outcomes (Anderies et al 2013; Hassler & Kohler 2014). Sustainability is often associated with defined performance metrics that show how decisions, or analytical frameworks are translated into previously defined goals (Anderies et al 2013; Redman 2014; Hassler & Kohler 2014). The concept of sustainability may be applied to systems of varying scales (Longstaff 2010; Hassler & Kohler 2014). Resilience typically does not set standards, but is instead a measure of the capacity of a system to both persist and adapt (Redman 2014; Hassler & Kohler 2014; Longstaff 2010, Comfort et al 2010). "It is important to point out that resilience is a system-level concept and is distinct from sustainability in that it is not normative, i.e., it does not include specific choices about performance measures" (Anderies et al 2013). Resilience in the built environment often refers to the innate ability of a system to retain and resume functionality in the face of the effects of both acute shocks and chronic stressors (Longstaff 2010, Comfort et al 2010). A system's measure of resilience is dependent on changes across both temporal and spatial scale, unlike sustainability, which may be a static measure of outcomes (Anderies et al 2013). Resilience is mainly considered at the community scale, and applying the concept to individual buildings is challenging (Longstaff 2010). Resilience has been referred to as the capacity of a system to absorb and adapt to change, while retaining the same essential functions and relationships (Vale 2014). This leads to a question posed by Comfort et al in *Designing Resilience* (2010): how quickly does a system or building have to recover and retain functionality after a crisis to truly be considered resilient, and which functions are essential during an emergency? In order to answer such questions, Different parameters - including downtime- must be studied.

Background: Building Downtime, Recovery and Resilience

> *Seismic resilience is conceptualized as the ability of both physical and social systems to withstand earthquake-generated forces and demands and to cope with earthquake impacts through situation assessment, rapid response, and effective recovery strategies… (Bruneau et al, 2003: 737)*

Factors affecting Downtime

Resilience mitigation, improved organizational communication, and intervention methods to reduce downtime is considered pre- (before), during, and after an event such as an earthquake. Porter and Ramer (2012) summarize downtime as estimated "using empirical, analytical, and expert-opinion approaches." They pose a method for the estimated time required to restore operability post-earthquake taking into account a building or facilities "unique combination of structural, non-structural and lifeline components" (Porter and Ramer, 2012). According to the previous studies, external factors affecting downtime include inspection, permit and regulatory uncertainty; utility disruption, transportation access, damage to neighbouring building and human fatalities; financing, relocation of building function, mobilization of contractors and equipment; component ordering, receiving and lead times and workforce availability (FEMA, 2004; Comerio, 2006; Ghorawat, 2011; Almufti and Willford, 2013; Terzic et al, 2014; Burton et al, 2015). Community organizations, community services, private organizations, and other community resources all have a role to play in addressing these external factors.

Frameworks for Recovery and Resilience

In the interest of establishing more quantitative measures to better understand factors contributing to resilience, Michel Bruneau and colleagues "developed a conceptual framework and a set of measures that make it possible to empirically determine the extent to which different units and analysis and systems are resilient." (Bruneau et al, 2003) These authors define resilience as "the ability of the system to reduce chances of shock, to absorb a shock if it occurs and to recover quickly after a shock. More specifically, a resilient system is one that:

- Reduces failure probabilities
- Reduces consequences from failures, in terms of lives lost, damage, and negative economic and social consequences
- Reduces time to recovery (restoration of a specific system or set of systems to their 'normal' level of performance)" (Bruneau et al, 2003: 736)

The authors established a conceptual curve illustrating loss of resilience by measuring expected degradation of quality of infrastructure (probability of failure) over time to recovery. Moreover, four fundamental properties for physical and social systems resilience are defined: "Robustness [an end], Redundancy [a means], Resourcefulness [a means], and Rapidity [an end]" Their conceptual definition recognizes interconnected "technical, organizational, social, and economic (TOSE)" dimensions of community resilience (Bruneau et al, 2003: 737-738). The framework described above mostly addresses the "two desired 'ends' of resilience – robustness and rapidity." Rapidity is essential to this framework in addressing recovery time. Retrofits of existing buildings, for example the addition of redundant systems, serve as means to these ends. Community organizations provide necessary resourcefulness.

"The Smartest Cities are Resilient Ones." (Rockefeller Foundation)

The Rockefeller foundation established 100 Resilient Cities in 2013 to "help cities around the world in order to be more resilient to the physical, social and economic challenges (Rockefeller Foundation)." The program aims to tackle the chronic stresses and acute shocks that weaken the city fabric. These stresses can range from high unemployment and crime rates to inefficient public transportation systems. Natural disasters, terrorist attacks and/or outbreak diseases are considered acute shocks. Selected 100 Resilient Cities represent regions across the globe, addressing "all challenges." The framework posed by Rockefeller Foundation's 100 Resilient expands the dimensions of resilience posed by Bruneau et al. 100 Resilient Cities demonstrate seven (7) qualities that can help them overcome the stresses and shocks, demonstrating qualities of being reflective, resourceful, robust, redundant, flexible, inclusive and integrated. The added attributes – flexible, inclusive and integrated - can be directly related to design and system considerations in architecture and urban design. Rockefeller Foundation also claims *reflective* (rather than *rapidity* defined in the framework established by Bruneau et al). The term reflective is indicative of the planning necessary for holistically considered solutions.

In 2014, San Francisco, Oakland and Berkeley – in the San Francisco Bay Area of the west coast of the United States, were three of the first 32 cities recognized by the Rockefeller Foundation 100 Resilient Cities initiative. The resilience plans for these three cities are complimentary, but each focuses on a different 'acute shock' affecting the Bay Area. Oakland and Berkeley focus on shocks that are consequences of climate change such as droughts, flooding and fires. San Francisco established comprehensive earthquake resiliency plans with initiatives that inform responses in Berkeley and Oakland. Herein two of San Francisco's progressive resilience planning programs area further explored.

Programs that Enhance Building Recovery and Resilience

> *Unlike hurricanes and some other natural hazards, earthquakes strike suddenly and without warning….preparedness requires the participation of owners, managers, and workers, as well as those who design, build, regulate and maintain buildings used as workplaces* (FEMA, 2015).

In 1997 the U.S. Federal Emergency Management Agency established *Project Impact* to initiate local level community-based programs to "foster public-private partnerships [building partnerships between businesses, agencies, churches, neighbourhoods and others to work together on locally based hazard-mitigation activities] that would undertake hazard and risk assessments, community education programs and mitigation projects to reduce future earthquake losses" (Bruneau, 2003, pp. 734). Although short-lived, discontinued as a national program in 2001, it is credited with saving lives and providing a guide for future adaptation (Holdeman and Patton, 2008). Subsequent programs are managed by organizations that are national or city specific; many of the national organizations have programs that are specific to the local chapters of the organization. Some programs are also established by response groups, such as first responders and other community "life-lines" or planning organizations - clusters of informed opinion leaders that shape resilience understanding. Figure 1 maps the relationship between two San Francisco programs and the related factors that affect building recovery and resilience.

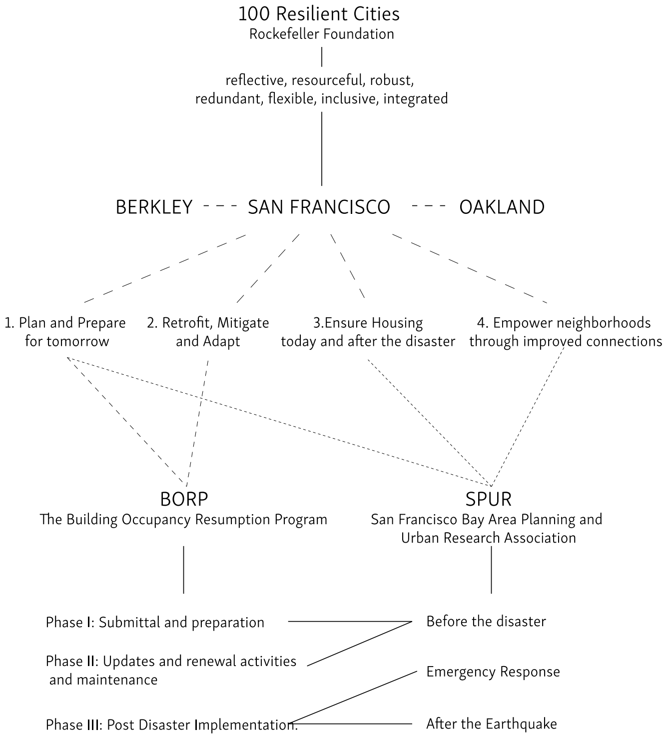


Figure 1. San Francisco Resilience Programs analysed according to the 100 Resilient Cities Framework and the three phases of building recovery.

Building Occupancy Resumption Program (BORP)

BORP (Building Occupancy Resumption Program) is an award-winning program first established by the City and County of San Francisco, CA, USA in 2009 after the Loma Prieta earthquake and has since been adopted in many Northern California jurisdictions. This program was created and developed by the San Francisco Department of Building Inspection (DBI), in cooperation with SEAONC (Structural Engineers Association of Northern California), BOMA (Building Owners and Managers Association of San Francisco) & AIA (American Institute of Architects). BORP allows building owners to enter an agreement with qualified engineers and specialty contractors to expedite building inspection following a hazard event with assurance of inspection within 72 hours of an earthquake event. The Program consists of three basic phases including 1) Building-specific post-earthquake inspection plan, 2) Annual update and renewal activities and the maintenance portion of the work, 3) the post-disaster implementation of the program. In addition, estimated hours needed to conduct the detailed inspection are specified and guarantee in the contracts (San Francisco Department of Building Inspection). BORP has two major advantages over the state government's post disaster inspection (see fig. 2):

- Pre-inspections provide deputized inspectors to have an intimate knowledge of the building in order to make more accurate and timely judgements;
- BORP minimizes business interruption after the disaster by accelerating the structural inspection process and allowing building owners/tenants to safely reoccupy their building or initiate necessary repairs. (SEA)

Related to resilience, table 1, ("adaptability") and sustainability, "BORP can be easily adapted for use in other cities that have the cooperation of the local structural engineers… Maintenance of the program requires annual renewal to address any changes made to the building or to the inspection team and to maintain current contact information.” (EERI Northern California Chapter)

Table 1. BORP initiatives in relationship to Rockefeller Foundation 100 Resilient Cities resilience framework. Key: darker the hatch, the more present the association between the resilience concept and the program goals.

	Reflective	Resourceful	Robust	Redundant	Flexible	Inclusive	Integrated
BORP	░		▓	░		▓	░

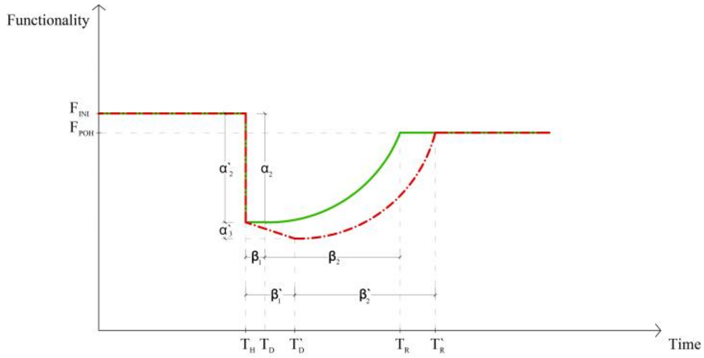
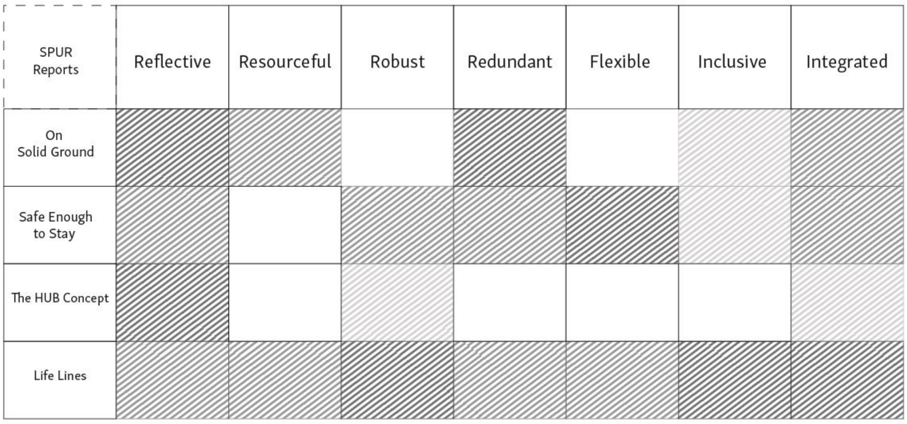


Figure 2. Schematic representation of improved building recovery (green curve) as a result of BORP programs. Adapted from the resilience framework proposed by Bruneau et al (2003)

San Francisco Bay Area Planning and Urban Research Association (SPUR)

After a hazard, the “ripple effect” spreads through the community and disrupts it functionality (McAllister, 2013). Critical facilities and infrastructure systems (life lines such as power, emergency response, hospitals, etc.) need to be operational during and after a hazard event. To minimize disruption, additional buildings and infrastructure systems need to be recovered within a specific period. Performance depends on the codes and standards adopted and enforced. Community policies and private organizations play a key role in community resilience by affecting these codes and standards (fig. 3). SPUR is a member supported non-profit organization and policy think-tank with offices in San Francisco, Oakland and San Jose. Its mission is to promote good urban planning and government in Bay Area cities. SPUR includes a ‘Resilience+ Sustainability’ policy agenda focused on reducing the global footprint and increasing the resilience of its cities. Initiatives fall into three categories: before the disaster (planning for preparedness), emergency response (during an event), and organizational support to improve earthquake and disaster response and community infrastructure after the disaster. The policies and initiatives that SPUR advocates align with the City of San Francisco’s 100 Resilient Cities agenda (Table 2).

Table 2. SPUR initiatives in relationship to the Rockefeller Foundation 100 Resilient Cities resilience framework.



SPUR Reports	Reflective	Resourceful	Robust	Redundant	Flexible	Inclusive	Integrated
On Solid Ground	▨	▨		▨		▨	▨
Safe Enough to Stay	▨		▨	▨	▨	▨	▨
The HUB Concept	▨		▨				▨
Life Lines	▨	▨	▨	▨	▨	▨	▨

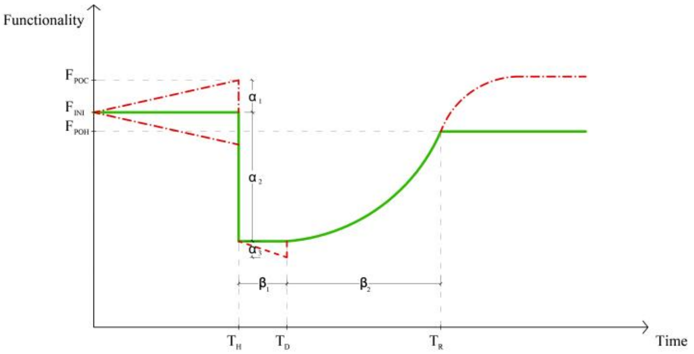


Figure 3. Schematic representation of the possible overall improvement in functionality and resilience as a result of SPUR. Diagram adapted from the resilience framework proposed by Bruneau et al (2003)

Conclusion: Retrofitting for Resilience

A system-of-systems approach that considers the building in the context of its community is necessary to the realization of sustainable, resilient buildings. The total functionality of a building is the union of the functionalities of the systems (Internal or external) that are required to fulfil its intended use. Internal systems (Fig. 4) are those within the building, such as structural, HVAC and fire suppression systems. External systems (Fig. 5) are related to community life-lines (communication, first responders, hospitals/schools/churches, transportation, utility systems). Through integration between building and community, capacity - defined as the reserve of functionality - can be mobilized to recover and improve a building or system after an event.

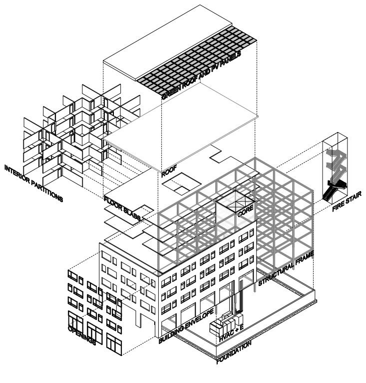


Fig. 4: Internal systems diagram

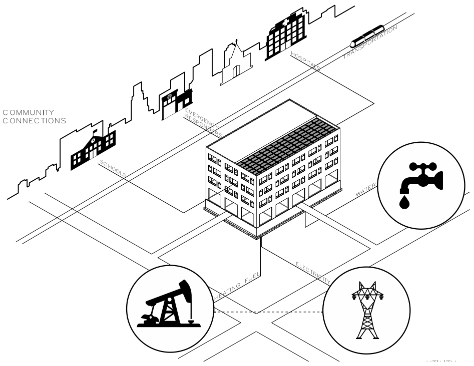
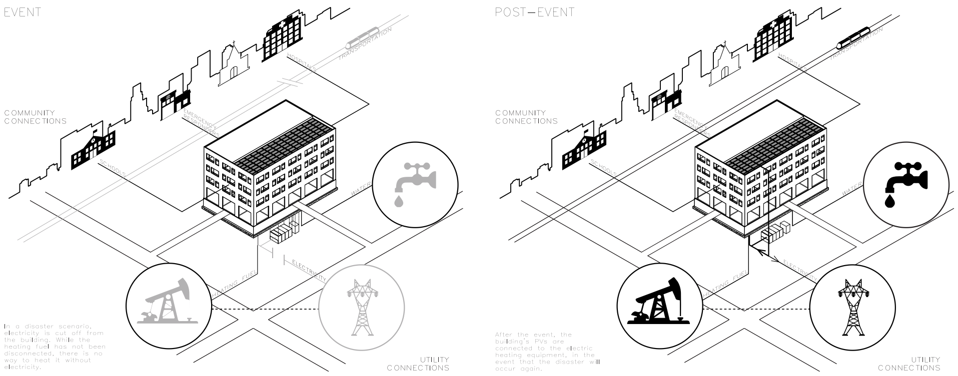


Fig. 5: External systems and basic services diagram

Bruneau et al (2003) discuss addressing seismic resilience by "enhancing the ability of a community's infrastructure (e.g., lifelines, structures) to perform during and after an earthquake, as well as through emergence response strategies that effectively cope with and contain losses and recovery strategies that enable communities to return to levels of pre-disaster functioning (or other acceptable levels) as rapidly as possible." The retrofit of buildings, holistically integrated with the communities, provides a buffer during an event and contributes to long-term resilience. Existing historic buildings are likely to have been constructed to incorporate regionally appropriate passive design strategies. Recognition and enhancement of these strategies, coupled with improvements to the building envelope and systems can significantly reduce the energy use required. Associated with passive survivability, a building can maintain a higher level of function during a disaster-associated event. Coupled with redundant systems, such as a building-integrated and interconnected photovoltaic array, capacity is enhanced (fig. 6). Organizational support can facilitate improvement and foster effective communication between a building and its community necessary for resilience.



In a disaster scenario, electricity is cut off from the building. While the heating fuel has not been disconnected, there is no way to heat it without electricity.

After the event, the building's PVs are connected to the electric heating equipment, in the event that the disaster will occur again.

Fig. 6: Diagram of limited functional relationships in a building during an event (left); (right) a scenario where function is enhanced by retrofitted with interconnected redundant, sustainable systems.

Acknowledgements

This research is supported by NSF CMMI-1455424 and CMMI-1455444 Collaborative Research RSB and an associated NSF-REU Research Experiences for Undergraduate Students grant. Kaitlyn Troutman's preliminary literature review, evaluation and graphic representations and Vina Rahimian's on-the-ground work in San Francisco were essential to this study. The authors are grateful for the input of our research collaborators, especially Gordon Warn.

References

Almufti, I. and Willford, M. (2013). REDi^{TM} Rating Systems: Resilience-based Earthquake Design Initiative for the Next Generation of Buildings. ARUP.

Anderies, J. M. (2014). Embedding built environments in social–ecological systems: resilience-based design principles, *Building Research & Information* 42/2, pp. 130-142.

Bruneau, M., Chang, S. E., Eguchi, R. T., Lee, G.C., O'Rourke, T. D., Reinhorn, A.M., Shinozuka, M., Tierney, K., Wallace, W. A. and von Winterfeldt, D. (2003). A Framework to Quantitatively Assess and Enhance the Seismic Resilience of Communities, *Earthquake Spectra*, Vol. 19, No. 4, pp. 733-752, November 2003, Earthquake Engineering Research Institute.

Burton, H. V., Deierlein, G., Lallemant, D., and Ting, L. (2015). Framework for Incorporating Probabilistic Building Performance in the Assessment of Community Seismic Resilience. *Journal of Structural Engineering,* Vol. 142 (8), August 2016: C4015007

Comerio, M. C. (2006). Estimating Downtime in Loss Modeling. Earthquake Spectra22 (2), pp. 349-365.

Comfort, L. K., Boin, A., and Demchak, C. C. (2010). The Rise of Resilience in *Designing Resilience*. Pittsburgh Press, Pittsburgh, PA, USA.

EERI Northern California Chapter of the Earthquake Engineering Research Institute. Building Occupancy Resumption Program (BORP). Available: www.eerinc.org/?page_id=222, accessed 03 April 2017.

FEMA (2004). Using HAZUS_MH for Risk Assessment How-To Guide, HAZUS®-MH Risk Assessment and User Group Series. FEMA 433/ August 2004.

FEMA (Federal Emergency Management Agency, 2015) "Earthquake Safety at Work," online report, U.S. Department of Homeland Security, updated 18 December 2015. Available at: https://www.fema.gov/earthquake-safety-work. Accessed: 31 March 2017.

Ghorawat, S. (2011). Rapid loss modelling of death and downtime caused by earthquake induced damage to structures. Thesis, Texas A&M University, 2011.

Hassler, U. and Kohler, N., (2014). Resilience in the built environment, *Building Research & Information*, 42/2, pp. 119-129.

Eric Holdeman and Ann Patton (2008). "Project Impact Initiative to Create Disaster-Resistant Communities Demonstrates Worth in Kansas Years Later." In *Emergency Management, Preparedness and Recovery*, published December 12, 2008. Available at: http://www.govtech.com/em/disaster/Project-Impact-Initiative-to.html. Accessed 3 April 17

Huang, Yinghui. Building Damage, Death and Downtime Risk Attenuation in Earthquakes. Diss. Texas A&M University, 2012.

Porter, K.A and Ramer, K. (2012). A Performance-Based Earthquake Engineering Method to Estimate Downtime in Critical Facilities. In: The 15th World Conference on Earthquake Engineering. Lisbon, Portugal, 24-28 September 2012, Lisbon: 15WCEE.

Longstaff, P. H. (2010). Building Resilient Communities: A Preliminary Framework for Assessment. *Homeland Security Affairs* (September), Vol. 6/3.

McAllister, T. (2013). Developing guidelines and standards for disaster resilience of the built environment: A research needs assessment. US Department of Commerce, National Institute of Standards and Technology.

Rockefeller Foundation, 100 Resilient Cities. Available at: www.100resilientcities.org, Accessed 02 April 2017.

San Francisco Department of Building Inspection. BORP Guidelines for Engineers. Available at: http://sfdbi.org/borp-guidelines-engineers, Accessed 03 April 2017.

SEA (Structural Engineers Association of Northern California). Building Occupancy Resumption Program. Available at: http://www.seaonc.org/building-occupancy-resumption-program, accessed 3 April 2017.

Terzic, V., Mahin, S. A., and Comerio, M. C. (2014). Comparative life-cycle cost and performance analysis of structural systems for buildings. In: *Frontiers of Earthquake Engineering* 10th US National Conference on Earthquake Engineering, 21-25 July 2014, Anchorage, Alaska, USA: Curran Associates, Inc. Red Hook, NY.