KEY IMPLEMENTATION CHALLENGES AND CROSSCUTTING RESEARCH THEMES FOR DEVELOPING IMMEDIATE OCCUPANCY PERFORMANCE OBJECTIVES

Siamak Sattar, Christopher L. Segura Jr., Katherine J. Johnson, Therese P. McAllister, and Steven L. McCabe
National Institute of Standards and Technology (NIST)
Gaithersburg, MD USA

Abstract

New and existing buildings and supporting infrastructure may sustain extensive damage during natural hazard events such that building functions are degraded or lost. Widespread building damage across a community can have severe social and economic impacts. The U.S. Senate tasked NIST with identifying research needs and implementation activities to develop multi-hazard immediate occupancy (IO) performance objectives for commercial and residential buildings. With input from subject matter experts and stakeholders participating in a national workshop, NIST developed a report that describes research areas and implementation activities to fulfill the Congressional mandate. The content of the report is organized around four topic areas: enhancing building design, addressing community considerations, ascertaining social and economic issues, and identifying acceptance and adoption considerations that require further reflection in the process of developing the new IO performance objective. This paper discusses crosscutting themes that apply to all four topic areas and will need to be addressed to advance research and implementation activities for IO performance. These crosscutting themes define activities that are vital to the development of research tools, design standards, and educational tools needed to study the impacts of, and design for, IO performance. The paper also highlights key challenges in adoption and implementation of IO performance objectives; these challenges focus mainly on social, economic, and policy related issues that can support the successful adoption of IO objectives by the public.

Introduction

The U.S. Senate requested that the National Institute of Standards and Technology (NIST) create a report to plan for improvements to "the resiliency of buildings, homes, and infrastructure" for the American public (U.S. Senate, 2016). The congressional mandate was motivated by the reality that "current building codes often do not provide the necessary protection against natural hazards, particularly with regard to enabling immediate occupancy after a significant earthquake, hurricane, tornado, flood, or other natural disaster" (U.S. Senate, 2016). Communities, owners, and residents should benefit from buildings that are more resilient to natural hazard events to avoid lengthy and costly repairs or rebuilding, as well as minimizing the need for long-term evacuation of building occupants. Thus, the Senate directed NIST to identify engineering principles, research, and implementation activities needed for a new "safety building performance objective for commercial and residential properties" (U.S. Senate, 2016). In response to the congressional mandate, NIST developed a report identifying the research needs and implementation activities required to develop IO performance objectives (Sattar et al., 2018). This report was developed through a collaborative process with a steering committee of subject matter experts and a national expert stakeholder workshop hosted by NIST. In the NIST report, immediate occupancy (IO) performance is considered as the building's condition after a hazard event where damage to the building's structural system is controlled, limited, and repairable while the building remains safe to occupy. The building's ability to function at full or minimally reduced capacity is also affected by the functionality of the non-structural systems of the building (e.g., building envelope, equipment, interior utilities), as well as the infrastructure that connects the building to its surrounding community. The term IO is used for general reference to a potential range of functional levels for consistency with the congressional language. The role of lifelines in supporting the operation of functional buildings is acknowledged, but not addressed in detail in the NIST report. The NIST report covers improvements to building design, as well as community, economic and social, and adoption and acceptance considerations. This paper highlights crosscutting research needs and key implementation challenges to IO performance objective development identified in the NIST report.

Motivation

By ensuring continuing access to housing and resumption of local businesses following a hazard event, communities can use IO buildings to mitigate and recover from natural hazards and to reduce vulnerability and long-term negative consequences. Geographic regions in the United States face a unique combination of natural hazards. As shown in Fig. 1, significant weather and climate disasters in the continental U.S. in 2017 were widespread. These weather events cause extensive damage and disruption to buildings, loss of life, injury, property damage, displacement of residents and businesses, and have long-lasting economic and social effects that impact local communities and the spirit of the nation (NOAA, 2018). It is reported that 2017 was the costliest year for weather and climate events in the United States, with the U.S. incurring $306B in natural hazard damages (Mooney and Dennis, 2018). It is important to note that earthquakes are not included in NOAA's reports of weather and climate disasters (Fig. 1), and that the U.S. has not experienced a major damaging earthquake since 1994. However, the Federal Emergency Management Agency (FEMA) estimates the annualized cost of damage to U.S. building stock from earthquakes to be $6.1B per year (FEMA, 2017), and this should be included to more accurately assess risk.

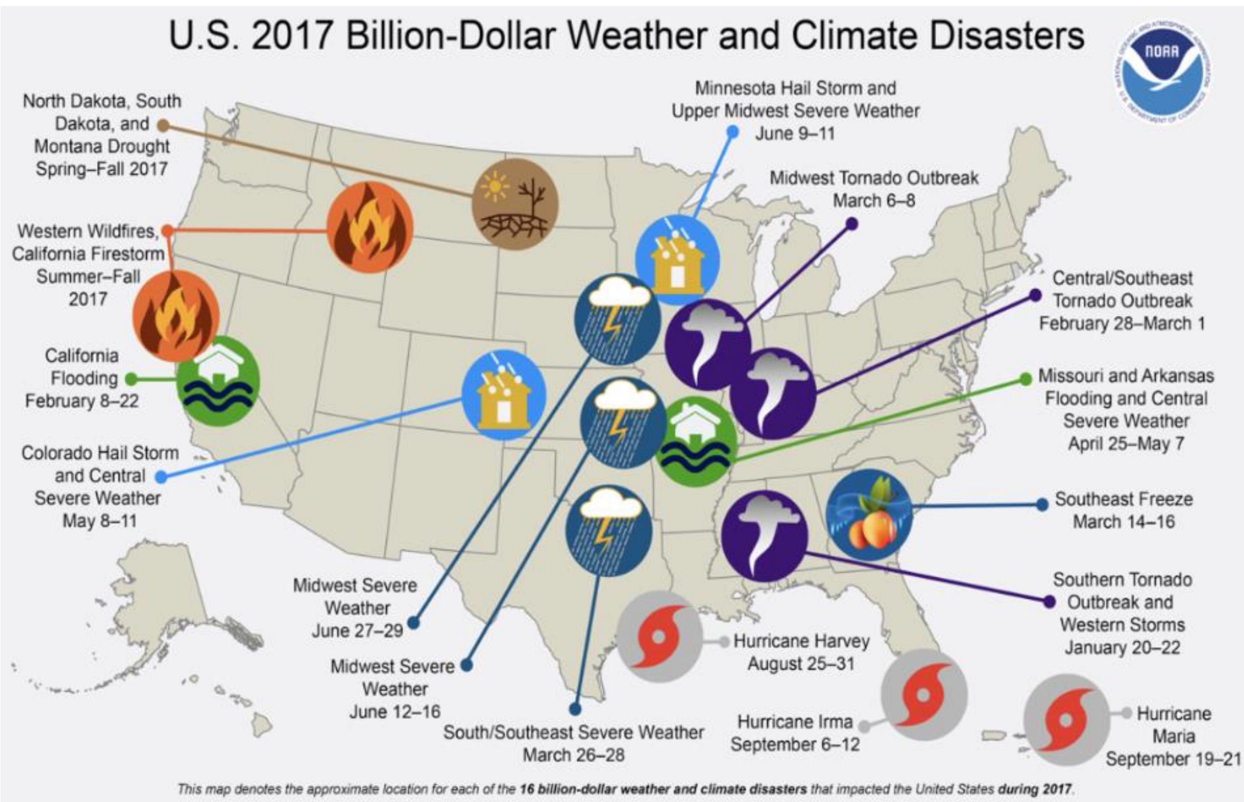

Figure 1. Regional variation of significant 2017 weather and climate disasters (source: NOAA, 2018)

The economic costs borne by individuals, governments, and insurance companies, as a result of natural hazard events, are substantial and provide an important measure of disaster impacts. Similar to reports for the U.S., 2017 was the costliest year for weather and climate disasters globally, with 710 recorded natural disasters (Munich Re, 2018). While 2017 may seem anomalous, it is representative of an increasing trend in occurrence of natural hazard events, with five of the past six years breaching the 600-event mark globally (Munich Re, 2018).

Development of new IO performance objectives to improve the resilience of buildings can help reduce damage and losses across all types of natural hazards, whether geologic or climatic and frequent or infrequent. In modern buildings, loss of life and structural collapse from natural hazard events are infrequent. The goal of building codes is to protect lives by reducing the likelihood of structural collapse for a design-level event (as defined in the codes), and to provide some level of property protection. However, societal needs are quickly outpacing this performance goal. A new performance objective in building codes would improve the performance of buildings and infrastructure, so that they are less likely to be negatively impacted and more likely to maintain functionality or regain it quickly. IO performance objectives could serve to reduce short- and long-term population displacement, adverse health effects, and disruption to communities caused by impairments to government, schools, and businesses.

Areas for Research and Action

The research and implementation activities required to develop IO performance objectives are organized around four main topics:

1) *Building design*: includes advances related to designing or retrofitting an individual building to meet IO performance objectives and changes to building code provisions;

2) *Community considerations*: discusses the resilience context for the role of buildings in community physical, social, and economic systems before and after hazard events;

3) *Economic and social considerations*: addresses feasibility of implementing IO performance and the potential impacts that improved building performance may have on social and economic systems;

4) *Acceptance and adoption considerations*: addresses activities required for effective implementation of IO performance by stakeholder communities, including state and local government officials, engineers, architects, urban planners, developers, building owners, and building occupants.

These topics were developed through an iterative process that included a literature review and subject-matter expert input from the steering committee members and workshop participants. The research and implementation needs associated with each of these topics are discussed in Sattar et al. (2018).

Crosscutting Research Needs to Develop Immediate Occupancy

Several crosscutting issues were identified that address research needs and implementation activities pertinent to all four of the main topics. These issues include needs to develop research tools for studying the impacts of IO performance objectives, as well as to develop new guidelines, standards, and educational tools to support the implementation of IO. Crosscutting issues are organized according to the following six categories:

- *Data* – Datasets on building performance and community impacts to support the development of research and implementation tools for IO
- *Relationships and Dependencies* – Characterization of relationships that describe the factors that influence building functionality and the interaction of a building or building cluster with the surrounding community
- *Predictive Analytical Models* – Science-based models to study the impacts of IO performance objectives across multiple spatial and temporal scales
- *Metrics and Tools* – Mechanisms to evaluate the anticipated performance of buildings and to assess community functions in relation to IO performance desires
- *IO Guidance Documents and Design Standards* – Criteria used by architects, engineers, and community decision-makers to assess IO performance
- *Education, Outreach, and Training* - IO-specific competency and qualification programs

Data. To assist with the development of analytical tools, decision support tools, and stakeholder communication tools, broad datasets reflecting the performance of building systems, social systems, and economic systems in the pre-hazard, post-hazard, and recovery time periods are needed. Existing field reconnaissance data, laboratory data, and results of analytical studies should be consolidated so that they are readily available to researchers and to enable an assessment of data collection methods. Existing reconnaissance data and laboratory data should be evaluated against analytical modeling needs to identify shortcomings in data to support the development and validation of analytical models.

Standardized reconnaissance data collection protocols need to be established to ensure datasets are comprehensive and capture critical information needed to calibrate and validate analytical models. Data collection methods should emphasize the need for consistency in terms of the types, quantity, and timing of data collected. These standardized methods should also emphasize the need to collect data for buildings of various ages and construction types with a range of damage levels. Furthermore, prioritization should be placed on continued, periodic evaluation of the recovery of functionality for damaged buildings and the recovery process for impacted communities in the post-hazard time period. New data collection technologies are needed for monitoring and assessing the performance of IO buildings and to develop models expressing the relationship between building damage levels and functionality levels.

Relationships and Dependencies. A common theme across the four topic areas is the need to develop models that communicate the relationships and dependencies between functional levels, damage and recovery levels, and the effects thereof on populations, social and economic systems, and communities. In the context of an individual building, it is important to better understand how the functional level of a building is impacted by aging and periodic natural hazard events during the building's lifecycle. These relationships should express functional levels with respect to the entire building's structural and nonstructural systems, as well as infrastructure services. Such relationships should describe the short-term impacts of interruption to community infrastructure services (e.g., water and power) and reduced levels of building functionality when temporary backup services (e.g., generators and water tanks) are used. The impact of maintenance, repair, and retrofit technologies should also be considered.

On a community level, the relationships and dependencies between community infrastructure services, individual buildings, and building clusters need to be better understood. The relationships should incorporate redundancies within community systems to provide a broad description of the effects of damage on the functionality and recovery of the physical, social, and economic systems of the community.

Predictive Analytical Models. Analytical models are needed to better understand interactions between the complex systems of a community and to study the direct and indirect effects of interventions, including the introduction of IO buildings into a community. The models should enable the prediction of performance on multiple spatial scales ranging from the individual systems of a building, to clusters of buildings that support particular community functions (e.g., healthcare, education, business, or governance), to the community scale involving all building clusters within the community. The models should also address multiple temporal scales ranging from several days to multiple decades for the pre-hazard, post-hazard, and recovery time periods. The analytical models should incorporate the relationships, described above, that address the impacts of damage, maintenance, repair, and retrofit strategies on functional levels. These tools will allow for the assessment of the integrated performance of a community's physical, social, and economic systems, including the dependencies among these systems.

Metrics and Tools. Performance metrics and analysis tools are needed to evaluate the anticipated performance of buildings designed for IO objectives. Performance metrics should describe the desired goals for building damage and functionality, community recovery, and social and economic well-being. Analysis tools should provide the means to analytically evaluate the ability of a building's systems to meet desired IO performance objectives and to assess existing community functions in relation to IO building performance desires.

IO Guidance Documents and Design Standards. Guidance documents and design standards are needed to support the implementation of IO performance objectives. These tools will articulate the technical evaluation criteria for a building and its systems relative to desired levels of building functionality and design level hazards. The design tools should contain guidance on identifying buildings for IO objectives, by considering their role in the community and their impact on social and economic systems.

Education, Outreach, and Training. Recruiting and maintaining a workforce knowledgeable about IO performance objectives and implementation methods will be crucial to ensure a common understanding across professions. For the engineering and architectural fields, designing buildings to IO performance objectives would be a notable shift from current practice. It may require an IO-specific set of competencies, and a licensure or accreditation program for designers, contractors, and code officials. This could have widespread implications on undergraduate and graduate curricula and future workforce recruitment and retention. In addition to the technical workforce necessary to design and construct IO buildings, code officials will need to be trained to enforce the design standards and ensure buildings are constructed to code and can meet IO performance objectives.

Building owners and community leaders need education on hazard risks, costs and benefits, and best practices. Additionally, opportunities for diverse sets of stakeholders to interact and communicate in a group setting, such as community workshops, should also be explored. Examples of these stakeholders include financial institutions, insurance companies, foundations, federal and state governments, business, utilities, commercial building owners, and homeowners.

Key Implementation Challenges to Develop Immediate Occupancy Performance Objectives

Research and implementation needs for developing IO building performance objectives is more than a technical problem of how to design and construct buildings that are more resilient to natural hazards. In addition to the four technical research topics discussed earlier, there are multiple complex social, economic, and policy challenges that should also be addressed to ensure successful adoption of IO performance objectives. The challenge of achieving IO performance is just as much a social and economic matter as it is a technical one. The key implementation challenges described below are outside the scope of the crosscutting research topics or implementation activities discussed earlier and would require coordinated and cooperative work over time and across sectors.

Motivating Action. While communities often reflect on desired building performance in the wake of a natural hazard event, a key barrier to adoption and acceptance of an IO performance objectives is motivating the community to invest in improved building performance in advance of hazard events. There is a general expectation that current building codes and regulations protect against damage or loss of functionality from hazard events. In reality, building codes are primarily designed to safeguard lives and only provide some degree of property protection. Shifting public expectations to IO performance and functionality, and ensuring those objectives are reflected in revised engineering and code design, will require coordinated actions over time. Education and outreach activities are needed to ensure stakeholders, including community officials, engineers and architects, building owners and the public at large, have the necessary tools to make effective decisions about the value of enhanced performance by designing to IO performance objectives.

Managing the Distribution of Costs and Benefits. One of the core challenges in constructing for enhanced building performance for both new and existing buildings is that owners and developers who invest in IO performance measures may not be the primary beneficiaries of the investment. Research is needed to help clarify costs and benefits and to support development of innovative and feasible adoption mechanisms, such as financial incentives to offset investment costs, that can help balance costs and benefits for stakeholders including occupants, building owners and communities.

Influencing Private Owners. While the performance of individual buildings during a hazard event cumulatively affects the ability of a community to respond to and recover from the event, the majority of buildings are privately owned. Research is needed to identify the considerations associated with how private owners may be influenced or incentivized to participate in improving the performance of their buildings.

Influencing Public Sector. Buildings that are owned by local, state, or federal agencies (hospitals, nursing homes, housing, etc.) may affect community recovery, especially in economically disadvantaged regions. Public buildings may not be subject to local codes; thus, research is needed to identify appropriate implementation and adoption mechanisms for the public sector.

Protecting Vulnerable Populations. Vulnerable populations are more likely to live in older structures and often in more hazard-prone areas such as flood plains. It is important that adoption measures ensure all populations, including those who are socioeconomically disadvantaged, the elderly, and those requiring medical or caregiving attention, have opportunities to benefit from enhanced building performance and hazard resilience.

Addressing Liability for Building Performance. A building's systems may not perform as anticipated during a hazard event. While in some circumstances this may be due to error in design, construction, or maintenance of the structure, building system performance can be affected by factors beyond the control of the designer. For example, performance might be impacted by an extreme hazard level that is not considered in the design, the availability of infrastructure services, or other factors outside of the building envelope and beyond building code requirements. Additional research and stakeholder input is needed to address legal issues surrounding liability for the actual hazard performance of buildings and the influence these considerations will have on IO performance objective adoption.

Coordinating Interdisciplinary Collaboration. Due to the interdisciplinary nature of developing and implementing actions and measures for IO performance objectives, collaboration is needed across the array of stakeholders that have an interest in enhanced building performance. This includes collaboration across disciplines, professions, and across public and private sectors within a community. This collaborative approach is often challenging due to the traditional roles and responsibilities of individuals involved in building design. Harnessing the diverse set of relevant expertise is essential to ensure IO performance objectives are adopted in an effective, successful manner.

Garnering Public Support. Stakeholder support is critical to the success of achieving IO performance. Eliciting buy-in and support across individuals, public and private sectors, and communities, is essential to garnering community trust, participation, and influence in developing IO building performance initiatives. By collaborating with existing community networks and leveraging the role of community leaders, local knowledge, skills, resources, and priorities can more effectively be integrated to achieve IO goals.

Conclusion

This paper articulates crosscutting issues as well as key policy challenges to support the development and implementation of IO performance objectives. The crosscutting issues are critical steps toward IO development as they cover multiple technical fields and also consider the interaction between building design, community resilience, social and economic impacts, and implementation activities. The key implementation challenges in successful adoption of IO performance objectives includes complex social, economic, and policy challenges. The challenge of achieving IO performance is just as much a social and economic matter as it is a technical one. The adoption of IO performance objectives will require holistic consideration of the impact of IO building performance on private owners, public sectors, and vulnerable populations. In addition, garnering support for, and shifting public expectations to, IO performance is important for successful implementation of IO objectives.

The diverse research needs and challenges discussed in the paper demand multidisciplinary perspectives and engagement from all levels of society. They will require reallocation of existing effort, time, resources, and financial investment. Moreover, substantial changes would be required for education, training, and practice within the engineering, architectural, and building professions. The involvement and enthusiasm of professional societies and other key stakeholders would be necessary to produce change within standards developing organizations and in building codes. While these activities are necessary for achieving IO performance objectives, additional research and implementation activities concerning the performance of infrastructure and interaction of infrastructure with the functionality of IO buildings would be needed to improve the resilience of buildings to the benefit of the public.

Acknowledgements

This project was completed with assistance from personnel at the Science and Technology Policy Institute (STPI) of the Institute for Defense Analyses (IDA), located in Alexandria, VA. The authors also gratefully acknowledge contributions from a number of groups: the steering committee members Mary Comerio, Gregory Deierlein, Susan Dowty, John Gillengerton, James Harris, William Hirano, Laurie Johnson, Timothy Reinhold, and James Rossberg; workshop participants; and reviewers of the NIST report.

References

FEMA, 2017, *Hazus Estimated Annualized Earthquake Losses for the United States*, FEMA P-366, Federal Emergency Management Agency, Washington, DC, U.S.A., 75 pages.

Mooney, C., Dennis, B., 2018, "Extreme hurricanes and wildfires made 2017 the most costly U.S. disaster year on record," Washington Post, Energy and Environment, Washington, DC, U.S.A., https://www.washingtonpost.com/news/energy-environment/wp/2018/01/08/hurricanes-wildfires-made-2017-the-most-costly-u-s-disaster-year-on-record/?utm_term=.89276e56808a, Accessed January, 2018.

Munich Re, 2018, "Natural catastrophe review: Series of hurricanes makes 2017 year of highest insured losses ever," Munich, Germany, https://www.munichre.com/en/media-relations/publications/press-releases/2018/2018-01-04-press-release/index.html, Accessed January, 2018.

NOAA National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters, 2018, Washington, DC, https://www.ncdc.noaa.gov/billions/.

Sattar, S., McAllister, T., Johnson, K., Clavin, C., Segura, C., McCabe, S., Fung, J., Abrahams, L., Sylak-Glassman, E., Levitan, M., Harrison, K., Harris, J., 2018, *Research Needs to Support Immediate Occupancy Building Performance Following Natural Hazards*, NIST SP-1224, National Institute of Standards and Technology, Gaithersburg, MD, U.S.A., 80 pages.

U.S. Senate; S. Rep. No. 114-239, at Disaster Resilient Buildings, 2016, Retrieved from GPO's Federal Digital System: https://www.gpo.gov/fdsys/pkg/CRPT-114srpt239/html/CRPT-114srpt239.htm.