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Assessment of Design Criteria and Best Practices for a Resilient Tomorrow

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Introduction
Buildings and infrastructure systems, also referred to as the "built environment," play critical roles in community resilience against natural hazards. Community resilience is the ability to prepare for anticipated hazards, adapt to changing conditions, and withstand and recover rapidly from disruptions (NIST 2021). Disaster resiliency means that a community can withstand an extreme natural event without suffering devastating losses, damage, diminished productivity, or quality of life without a large amount of assistance from outside the community (Mileti 1999). In that context, a resilient community is a sustainable network of physical systems and human components, both of which need to survive and function before, during, and after a disaster. Physical systems are the built and natural environmental components of the community, and may include public and private buildings, infrastructure, and flood control systems (the built environment), as well as topography, geology, and other ecological systems.

Activities, such as disaster preparedness—which includes prevention, protection, mitigation, response, and recovery—are key components of resilience.
In this report, "community" refers to a place designated by geographical boundaries that functions under the jurisdiction of a governance structure, such as a town, city, or county. It is within these places that most people live, work, play, and build their futures.
Communities are highly diverse in terms of geography and population. They are also subjected to different prevailing hazards with their own unique vulnerabilities leading to different degrees of risk tolerance (NIST 2016).

For communities to function and prosper, they need buildings and infrastructure systems that are operational. When buildings and infrastructure systems are damaged, social services are frequently interrupted, economic losses soar, and resources are re-allocated to repair and rebuild the systems. When damage is extensive, the recovery process can be a significant drain on local residents and their resources and may be drawn out over years (NIST 2016). Sometimes, full recovery is not possible, and the damage results in permanent changes. The consequences can be compounded as resources for maintenance and improvements are reallocated to repairs and reconstruction, exacerbating the recovery process, which, if it takes too long, can lead to economic decline and population relocation.
Effective implementation of community resilience planning requires that, at a minimum, communities adopt and implement applicable design and construction codes and their referenced standards (referred to hereafter as "codes and standards") to improve the performance of its built environment for natural hazards. However, while codes and standards for the built environment are a necessary aspect of resilience planning, additional criteria are needed to address resilience, such as recovery of the built environment within a specified timeframe. Best practices for design of the built environment that exceed the minimum requirements established in codes and standards may also address resilience concepts.

Each building and infrastructure system (e.g., , water and wastewater, transportation) generally has a set of "design practices" within the specific community to which they adhere. "Design practices" are meant to refer to building or infrastructure specific codes and standards, and any applicable regulations or ordinances that define their expected performance levels within that community. The community may also incorporate “best practices” into these design practices. Combining optional best practices with design practices for that component of the built environment defines the “design criteria”— criteria intended to meet performance expectations by the building or infrastructure when impacted by a natural hazard event. Design criteria include design hazard characterization, expected performance, recovery of function, interdependency issues, and emerging methods to address the impact of changing environmental conditions on infrastructure design and performance. However, this approach inherently leads to varying performance levels between buildings and infrastructure systems that are subjected to the same hazard types. This is because each component of the built environment may not be designed using a comparable design hazard level. Other differences arise due to each part of the built environment being required to withstand different types and levels of loading. Additionally, many infrastructure systems are interdependent, and are becoming increasingly so with developing technology. Changing environmental conditions are also affecting community infrastructure systems, though these events are not addressed in design practice.

Purpose and Scope

This report describes a high-level review that was conducted of design criteria in codes, standards, and best practice documents for major sectors of the built environment to improve understanding of current infrastructure design and anticipated performance from a community resilience perspective. The built environment includes buildings and infrastructure systems, such as water, transportation, and electric power systems. This report evaluates design criteria that support community resilience, including design hazard characterization, expected performance, recovery of function, interdependency issues, and emerging methods to address the impact of changing environmental conditions on infrastructure design and performance. A better understanding of how the built environment performs and recovers over a range of hazard levels along with technical gaps for resilient systems will help stakeholders (see Section 1.1.2) better understand needs for advancing community resilience in practice.

The scope of this report is limited to national codes and standards, regulations, and best practices (where best practices are published guidelines, manuals of practice, etc.) in the United States. Resilience is an emerging area of focus in the international community as well. Although this report is limited to assessment of codes, standards, and best practice documents used in the design of the built environment in the U.S., it is acknowledged that international literature and guidelines do inform new guidance in the U.S. in many cases. The review is focused on design criteria related to natural hazards, specifically, flood, wind, and seismic hazards, and the nationally recognized codes and standards, regulations, and best practices that typically govern the design of buildings and infrastructure systems. It is not intended to be a comprehensive review of all design documents that exist. The potential prevailing hazards for a community go beyond the natural hazards discussed in this report. Hazards can include earthquakes, wind-related hazards (hurricanes, tornadoes, windstorms), fire-related hazards (community-scale fires in the wildland-urban interface, building fires), water-related hazards (storm surge, flood, tsunami) and human-made hazards (accidental, criminal, or terrorist in nature).

Buildings and Infrastructure Systems

This report addresses both building and infrastructure systems commonly referred to as the "built environment." The term "building" includes all systems necessary for its functional operation, including architectural, structural, building envelope, life safety, mechanical, electrical, plumbing, security, communication, and information technology (IT) systems. The review of buildings primarily focuses on the structural and building envelope systems. The term "infrastructure" refers to physical components such as plants, transmission, and distribution networks for transportation, water/wastewater, and electricity.

For the purposes of this report, the built environment is characterized into the general categories and subcategories of infrastructure systems listed in Table 1-1. For national infrastructure security, they are referred to as sectors and represent 7 of the 16 Critical Infrastructure Sectors plus the inclusion of buildings in all of the sectors (CISA 2020). They are organized in support of Presidential Policy Directive-21 (PPD-21 2013), wherein the federal government has a responsibility to strengthen and maintain secure, functioning, and resilient critical infrastructure against both physical and cyber threats.

Table 1-1: Buildings and Infrastructure Systems Addressed in This Report

Built Environment	Main Systems and Subsystems
Buildings	Residential Commercial Critical Facilities
Water	Potable Water Wastewater Stormwater Dams and Levees
	Substations Microgrids
Transportation	Roads and Highways Rail Air Maritime (Ports, Harbors, and Waterways)
Electric	Generation Transmission Distribution

Audience
This report is intended to help stakeholders (industry associations, design professionals, community building code officials, community and city planners, and researchers) better understand needs for advancing community resilience in practice. The target audience is code and standard development organizations, industry associations, design professionals, community building code officials, community and city planners, and researchers.

Community and Infrastructure Resilience
Resilience is an "umbrella" concept that integrates pre- and post-event activities to minimize physical damage and social consequences and to improve the rate of recovery for hazard events. Resilience activities include planning, prevention, protection, mitigation, response, and recovery, as well as consideration of climate change and social equity and impacts, which together enable resilient infrastructure systems.

Resilience can be broadly defined as "the ability to prepare for and adapt to changing conditions and to withstand and recover rapidly from disruptions" (PPD-21 2013). This resilience definition, which is used by the *Community Resilience Planning Guide for Buildings and Infrastructure Systems* (Guide, NIST 2016), is based on Presidential Policy Directives (PPD) 8 (2011) and 21 (2013). PPD 8 addressed the need for National Preparedness for all disruptive events and defined resilience as "the ability to adapt to changing conditions and withstand and rapidly recover from disruption due to emergencies". PPD 21 addressed the need to improve the security and resilience of critical infrastructure and extended the definition to: "the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions. Resilience includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents."

Resilience is addressed at multiple scales through varying combinations of planning, preparation, design, mitigation, response, and recovery activities. It can address hazard events, climate change effects, and physical conditions that change over time. Resilience can be assessed at national, regional, community/local, project, and individual scales. For the built environment, the focus is primarily at regional, community, and project scales, with buildings at the community and project scales and geographically distributed infrastructure at regional or community and project scales.

Depending on location, adaptation may include planning for future sea level rise in coastal areas or improving design and performance requirements for hazard events that may be expected to change in intensity or frequency over time, such as flooding or wind events. For existing infrastructure, changing conditions may also prompt alterations in its intended use.

Community Resilience

The Guide (NIST 2016) provides a method for communities to develop resilience goals and plans by linking social functions and the performance of community infrastructure. The Guide addresses community resilience in terms of the collective resilience of its buildings and infrastructure—performance during and recovery of function after a disruptive event—and their role in supporting community social and economic functions.

At the community level, functionality is based on the collective functionality of the building stock. Individual building owner and community plans for temporary measures to rapidly restore functionality and services is a key component of community resilience.

Community resilience includes consideration of social, cultural, economic, and human functions and their dependence on the built environment. Such functions include services provided by housing, businesses, education, healthcare, finance, and governance, and the supporting infrastructure, people, and supplies that are required. A community refers to a "place designated by geographical boundaries that functions under the jurisdiction of a governance structure, such as a town, city, or county" (NIST 2016).

Figure 1-1 illustrates the concept of community resilience for the built environment, in terms of functionality versus the performance goal for recovery time, where:

Functionality is a measure of how well a building or infrastructure system operates and delivers its service or meets its intended purpose relative to a pre-event or other baseline level. (NIST 2016*).*

Time to recovery of function is a measure of how long it takes before a building or infrastructure system is functioning (providing intended services) following a disruptive event (NIST 2016).

As depicted in Figure 1-1, the condition of the built environment prior to a hazard event affects the level of damage and time to recovery of function. Improvements include infrastructure updates and retrofits that reduce the level of damage and time to recovery of function. The green scenario represents a more resilient system relative to the blue scenario based on pre-event condition of the built environment. Given that codes and standards for buildings and infrastructure provide minimum design criteria and requirements, additional performance objectives may be required for individual buildings and systems to meet community resilience objectives.

The Guide further refines the recovery timeline into three phases, based on FEMA *National Disaster Recovery Framework* (FEMA, 2016): short-term (days to weeks), intermediate (weeks to months), and long-term (months to years). These recovery phases inform planning for stages of infrastructure recovery at the community level (e.g., 30%, 60%, and 90% of all buildings within specified time frames), so that infrastructure recovery can be prioritized to meet community needs. For instance, critical facilities would be in the first priority group, and housing, schools, and businesses might be in the second priority group.

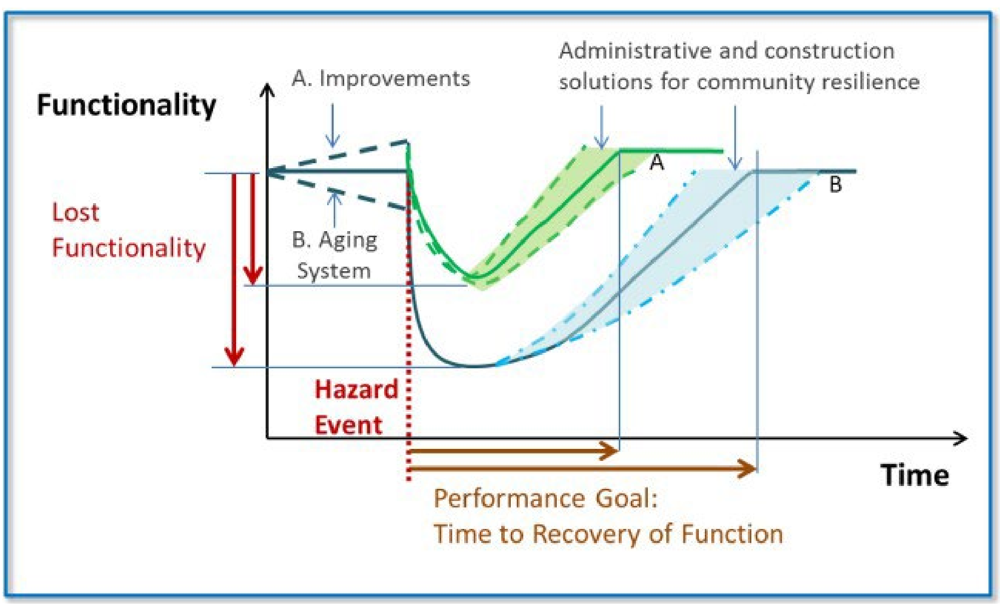

Figure 1-1: Resilience Concept of Functionality Versus Recovery Time for the Performance of the Built Environment During a Disruptive Event (Source: McAllister 2013)