Designing for Natural Hazards: Resilience Guides for Builders and Developers

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Abstract

Home Innovation Research Labs (Home Innovation) proposed to the U.S. Department of Housing and Urban Development a research project to create a set of practical, actionable guidelines for builders and developers to follow in the design and construction of residential buildings, neighborhoods, and accessory structures in a manner that could improve residential resilience and integrate resiliency throughout an entire community. The Designing for Natural Hazards *guides accomplish that task by providing technical content in a straightforward manner that is easy for laypeople to understand. They also offer references so design professionals, builders, developers, and public officials can dive more deeply into the necessary details. The guides are segmented into five volumes, each focusing on a specific natural hazard type: wind, water, fire, earth, and auxiliary. The guides differ from other resiliency programs and resources because they do not constitute a prescriptive program or suggest lists of improvements. Instead, the resilience guides are designed to be flexible and thereby let a user focus on either a single resilient construction practice or multiple resilient construction practices, depending on the user's specific needs.*

This article introduces the idea of prioritizing resilient construction practices based on the frequency of occurrence for any given natural hazard event. The authors also analyzed damage recorded in post-disaster field reports and insurance industry data (such as predictive modeling results).

Introduction

According to Munich Re, one of the world's largest multinational reinsurance companies, in 2021, natural disasters caused overall losses of $280 billion in the United States, of which only $120 billion was insured (Munich Re, 2022). Moreover, on the basis of analyses of 50 years of historical data, Munich Re estimates that losses related to natural disasters have been trending upward. As the frequency and severity of natural disasters increase, many insurance companies are leaving high-risk markets in Florida (Rozsa and Werner, 2022) and California (Scism, 2022), where property losses have greatly increased.

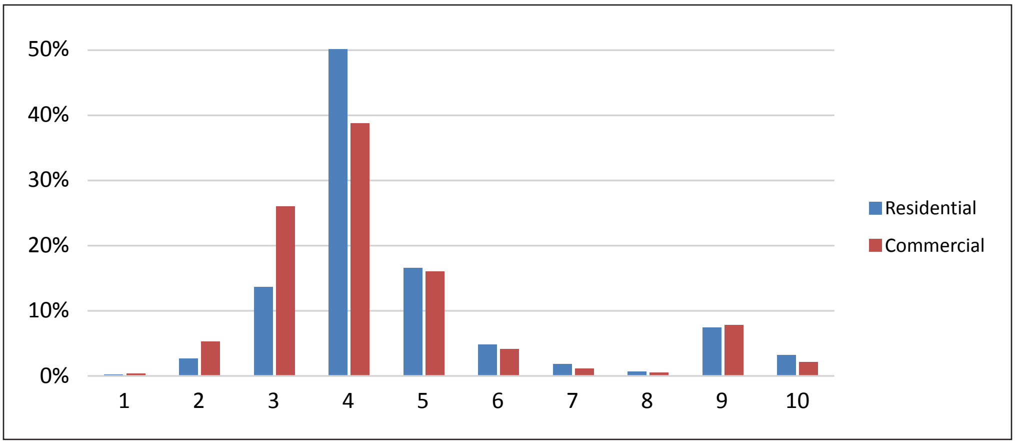
In 2021, the federal government declared 20 major natural disasters and allocated supplemental spending for disasters totaling approximately $145 billion (Smith, 2022). The U.S. Department of Housing and Urban Development (HUD) plays a major role in disaster recovery efforts through the Community Development Block Grant program (CDBG—Disaster Recovery Assistance). HUD's interest in minimizing property losses is reflected in the size of its Federal Housing Authority-insured portfolio, which consists of "76 million single-family insured loans, 11,213 multifamily insured loans [1,405,260 units], 3,825 residential healthcare facilities, and 88 hospitals with $1.2 trillion, $111 billion, $33 billion, and $6.3 billion, respectively, of mortgage balances [as of June 30, 2021]" (HUD, 2021).

As the frequency and severity of natural disasters increase, the Federal Emergency Management Agency (FEMA) and the U.S. insurance industry have emphasized the importance of hazard-resistant building codes. FEMA's 2020 *Building Codes Save: A Nationwide Study* estimated that adopting "hazard-resistant building codes" minimizes property losses (FEMA, 2020). Nonetheless, local jurisdictions must adopt current building codes with hazard-resistant provisions to achieve those avoided losses. Verisk, a property and casualty insurance company, rates building code adoption across the country by using its Building Code Effectiveness Grading Schedule (BCEGS) to assess "the community's building codes and their enforcement, with special emphasis on mitigation of losses from natural hazards. Municipalities with well-enforced, up-to-date codes should demonstrate better loss experience, which can be reflected in lower insurance rates. The prospect of lessening catastrophe-related damage and ultimately lowering insurance costs provide an incentive for communities to enforce their building codes rigorously—especially as they relate to windstorm and earthquake damage" (Thomure, 2022).

The average BCEGS rating countrywide is 4 out of 10 (with 1 being the best grade and 10 being the worst; see exhibit 1) (Verisk, n.d.). The data are available for most states but not all because some do not participate in the program.

Exhibit 1

BCEGS Rating Countrywide (USA)



Source: Verisk, n.d.

Building codes generally establish minimum construction requirements for reasonable levels of safety, public health, and general welfare for property and its occupants. Building codes get improved at various times on the basis of damage data from natural disasters or other building performance data, such as structural failures and fires. For example, after Hurricane Michael in 2018, the American Society of Civil Engineers (ASCE) updated its *ASCE/SEI 7-22 Minimum Design Loads and Associated Criteria for Buildings and Other Structures* (ASCE, 2021) to reflect new structural design requirements. The new minimum design requirements are typically referenced by the next version of the building code.

Two challenges remain with regard to building codes. First, rates of adoption of building codes vary across the country, with many states and local jurisdictions lagging behind the most current versions of model building codes. FEMA tracks building code adoption across the country and identifies through its interactive portal the versions of the building code that are in use (FEMA, 2022b). Verisk publishes its BCEGS rating, which captures code adoption, plan review, and inspection practices for a given jurisdiction. Both metrics show that certain areas of the country lag far behind in adopting the most current building codes. Second, many experts say that construction practices must be above minimum building code requirements to improve building resilience. The National Institute of Building Sciences and the Insurance Institute for Business & Home Safety have recommended using code-plus programs (IIBHS, 2016) for disaster resistance in buildings. HUD created the Disaster Recovery Tool Kit (HUD PD&R, n.d.), which is designed for property owners that are rebuilding after a disaster.

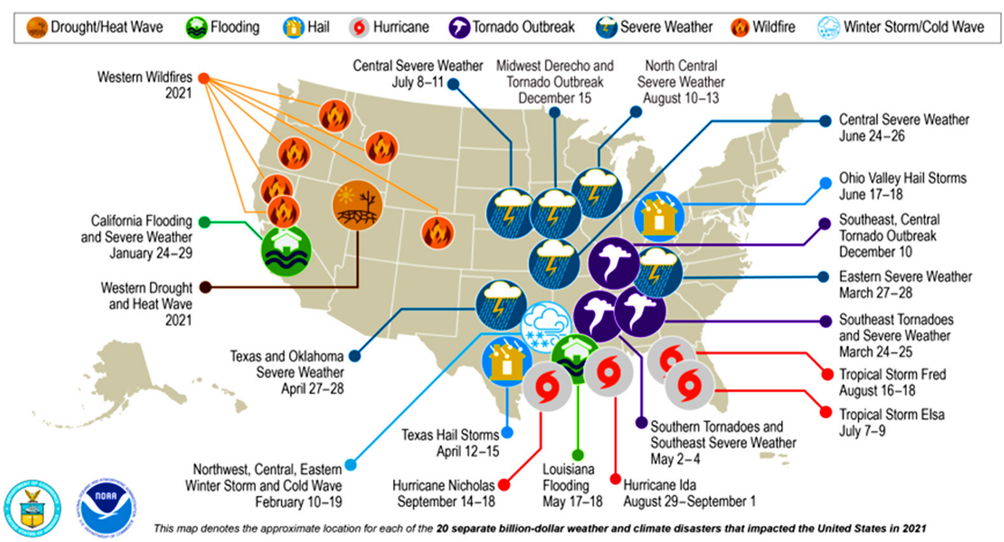
HUD has a Climate Action Plan, with increasing climate resilience as its first goal (HUD, 2021). The current Home Innovation research project contributes to that goal by developing design guides that builders and developers can consult before a natural disaster or in response to a major rebuilding effort after a natural disaster. The *Designing for Natural Hazards* guides focus on new construction and major reconstruction after natural disasters—especially reconstruction in areas where entire communities must be rebuilt after catastrophic events. The guides are not intended for minor repairs or renovations that are common after typical natural disaster events, and they do not cover commercial buildings, although many of the identified construction practices are also applicable to multifamily mixed-use buildings with wood framing.

To make the resilience guides as practical as possible, with as much input and buy-in as possible, Home Innovation assembled a Technical Advisory Group (TAG) by recruiting a balanced number of stakeholders—approximately the same numbers of users, producers, and public interest participants—to reach consensus on an approach to the development of content for the guides. The TAG was organized into five task groups based on the five natural hazard categories: wind, water, fire, earth, and auxiliary. The task groups met monthly to develop the content of the guides. In addition, all task group meetings were open to the public, and input was solicited beyond the members of the TAG and its task groups.

The *Designing for Natural Hazards* guides provide comprehensive information on a broad range of natural hazard types. Exhibit 2 shows the diversity of natural hazard events in the United States in 2021 (Smith, 2022) below. Note that each guide within the *Designing for Natural Hazards* series provides specific construction details to minimize property loss.

Exhibit 2

U.S. 2021 Billion-Dollar Weather and Climate Disasters



Source: National Oceanic and Atmospheric Administration, National Centers for Environmental Information. NOAA National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters (2022). https://www.ncei.noaa.gov/access/billions/, DOI: 10.25921/stkw-7w73

For local jurisdictions that have not adopted the most current building codes, the guides are valuable because they can be used to improve construction practices beyond what older building codes require. For builders and developers seeking above-code guidance, the *Designing for Natural*

Hazards guides identify ways to design above requirements even for current building codes—similar to a code-plus approach.

The TAG used damage data from natural hazard reports and risk assessment data from companies that compile such information for the insurance industry so it could prioritize construction practices within the *Designing for Natural Hazards* guides. The TAG understood that funding to improve construction resilience may be limited, so the group prioritized construction practices on the basis of high-frequency damage observed after events. Such an approach encourages users of the guides to select and implement construction practices that minimize the kinds of damage that are most common and costly to repair.

The resilience guides are not intended to substitute for engineering or architectural project design work; instead, the technical guidance within them identifies the kinds of components that builders can enhance or improve to achieve above-code performance. When those enhancements and improvements get implemented, the resiliency of residential buildings and other community assets, such as utilities and defensible spaces, should also improve.

How to Use the Resilience Guides

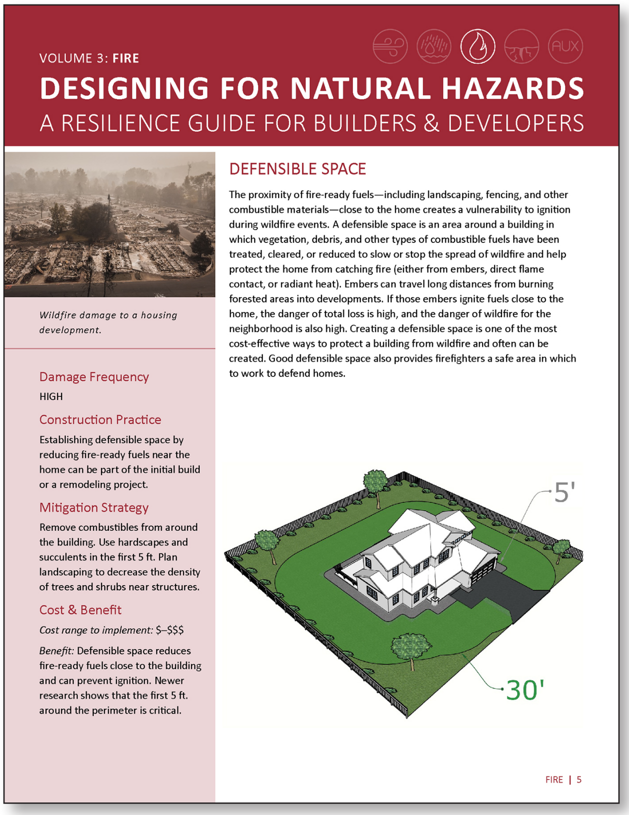
At the start of the project, Home Innovation asked builders that wanted to participate in the Technical Advisory Group whether they were familiar with existing resilience resources and whether they used those resources. Builders familiar with resilience resources—such as technical reports, resilient-building programs, and resilience tool kits for residential buildings—said that the resources were difficult to use because they lacked construction details and descriptions of the kinds of damage they would minimize. Those missing components then became a primary objective of the project: to deliver technical guidance in an easy-to-use manner that is accessible to a wide range of stakeholders.

The *Designing for Natural Hazards* guides are meant to be used by that wide range of stakeholders: design professionals, builders, developers, realtors, and even prospective homebuyers. The *Designing for Natural Hazards* guides differ from other resiliency programs and resources because they are not prescriptive programs and do not contain lists of improvements. Instead, the resilience guides are designed to be flexible and to let a user focus on either a single resilient-construction practice or multiple resilient-construction practices depending on the user's specific needs.

Each one-pager contains key information about the specific natural hazard and resilient construction practices that would minimize or eliminate potential damage. The front of each document (1) identifies the damage expected by the hazard, as shown in a photo; (2) gives the frequency with which a specific type of damage occurs; (3) shows a description of the resilient-construction practice that can minimize damage; (4) describes the mitigation strategy; and (5) offers a summary of the costs and benefits of implementing the resilient-construction practice (exhibit 3).

Exhibit 3

Sample Front Page


VOLUME 3: **FIRE**

DESIGNING FOR NATURAL HAZARDS

A RESILIENCE GUIDE FOR BUILDERS & DEVELOPERS

Wildfire damage to a housing development.

Damage Frequency

HIGH

Construction Practice

Establishing defensible space by reducing fire-ready fuels near the home can be part of the initial build or a remodeling project.

Mitigation Strategy

Remove combustibles from around the building. Use hardscapes and succulents in the first 5 ft. Plan landscaping to decrease the density of trees and shrubs near structures.

Cost & Benefit

Cost range to implement: $–$$$

Benefit: Defensible space reduces fire-ready fuels close to the building and can prevent ignition. Newer research shows that the first 5 ft. around the perimeter is critical.

DEFENSIBLE SPACE

The proximity of fire-ready fuels—including landscaping, fencing, and other combustible materials—close to the home creates a vulnerability to ignition during wildfire events. A defensible space is an area around a building in which vegetation, debris, and other types of combustible fuels have been treated, cleared, or reduced to slow or stop the spread of wildfire and help protect the home from catching fire (either from embers, direct flame contact, or radiant heat). Embers can travel long distances from burning forested areas into developments. If those embers ignite fuels close to the home, the danger of total loss is high, and the danger of wildfire for the neighborhood is also high. Creating a defensible space is one of the most cost-effective ways to protect a building from wildfire and often can be created. Good defensible space also provides firefighters a safe area in which to work to defend homes.

FIRE | 5

Source: Home Innovation Research Labs, forthcoming

The document provides additional design guidance details: (1) multiple design variations and supplemental resilient-construction practices, (2) the corresponding level of difficulty associated with the implementation of alternative resilient-construction practices, (3) the relative costs of implementation of the various options, and (4) technical references that have more information for each design option.

Exhibit 4

Sample Back Page

GUIDANCE	DIFFICULTY	COST
Use hardscapes and succulents for the landscaping within the first 5 ft. of the building. [1,2]	Easy	$
For forested areas, when developing a community: thin trees and shrubbery within the community to provide 30 ft. of defensible space for each structure. [1,2]	Moderate	$$
Establish a means of annual landscaping maintenance within the neighborhood association to refresh defensible space. [1,2]	Complex	$$$
Use noncombustible fencing within the first 30 ft. of the building, and include provisions in the neighborhood association covenants stating this requirement for future fencing installations. [3,4]	Easy	$
Ensure that accessory buildings are more than 30 ft. away from the main structure, and incorporate separation distance provisions in the neighborhood association covenants. [5,6]	Easy	$
Zoning can be used to cluster development into defensible areas and keep development away from fire hazards, such as steep slopes, where fires are difficult to contain. Develop green zones, parks, water retention, or roadway infrastructure as fire breaks. Incorporate multiple ingress and egress planning as part of evacuation planning. [7]	Complex	$$$

RESOURCES

1. Chapter 7A, 701A.5 Materials and Construction Methods for Exterior Wildfire Exposure. *2019 California Building Code*.
2. Section 603, Defensible Space. *2021 International Wildland-Urban Interface Code* (IWUIC).
3. *Preparing Homes for Wildfire* (NFPA.org). National Fire Protection Association.
4. *How to Prepare Your Home for Wildfires*. National Fire Protection Association.
5. *Wildfire Ready* (Disaster.org).
6. *Wildfire Ready: Home Preparedness Guide* (Disaster.org).
7. *Protect Your Home & Property from Wildfire* (csfs.colostate.edu). Colorado State Forest Service.

6 | FIRE HUD.GOV

Source: Home Innovation Research Labs, forthcoming

Because the resilient-construction practices summarized in the guides are intended to be implemented in areas where building codes do not specify such practices, builders cannot rely on a building code official to verify that the practices have been followed. Therefore, builders that undertake those resilient-construction practices will have to either incorporate the practices into their internal quality assurance processes or hire third-party organizations to confirm that the resilient-construction practices were appropriately included in the design and constructed per their specifications, which requires additional detail beyond the one-pagers.

Identifying Resilient Construction Based on Natural Hazard Types

Each task group was assigned to develop a specific volume of the *Designing for Natural Hazards* series. The task group's first undertaking was to identify typical damage that results when natural hazard events occur. To that end, each task group reviewed technical reports related to major natural disaster events so it could identify the most relevant resilient construction content to be included in its one-pager.

Wind

The Wind Task Group identified damage that occurs from various windstorms, including the most common types: thunderstorms, microbursts, tornadoes, hurricanes, cyclones, haboobs, and derechos. The National Oceanic and Atmospheric Administration (NOAA) defines damaging winds as those that exceed 50 to 60 miles per hour, which includes thunderstorm, straight-line, and tornado winds. The Wind Task Group did not distinguish the cause of wind damage because wind damage can occur from a wide range of weather phenomena, and insurance companies generally handle claims the same way.

Water

The Water Task Group considered the damage that occurs from flooding or wind-driven rain. FEMA defines flooding as "a temporary overflow of water onto land that is normally dry. It is the most common natural disaster in the United States. [Floods] result from rain, snow, coastal storms, storm surge, and overflows of dams and other water systems." FEMA defines wind-driven rain as "rain [that] is propelled into a covered structure by wind, that is considered wind-driven rain and is not covered under your flood insurance policy." The group focused on both flooding and wind-driven rain as natural hazards. The practices in the water-resilient construction guide improve construction in moderate- to low-risk flood zones and can be implemented incrementally by adding one or more flood-resilient features to a building. Because hurricanes and other major storms may lead to damage caused by wind-driven rain, the Water Task Group identified construction practices that improve the performance of roofs, windows, and doors.

Fire

The Fire Task Group studied damage that occurs from wildfires, defined by FEMA as "an unplanned, unwanted fire burning in a natural area, such as a forest, grassland, or prairie. Wildfires can start from natural causes, such as lightning, but most are caused by humans, either accidentally or intentionally." The Fire Task Group focused on wildfires that occur as natural hazards, not accidental fires—such as from cooking, equipment, and smoking—and not on arson inside a residential building. Wildfires generally burn the exterior of a building due to direct contact with flames, wind-blown embers landing on the building, or extreme radiant heat that causes flammable chemicals or materials to combust. Resilient-construction practices that minimize damage from wildfires focus primarily on removing fuel around a building using fire-resistant landscape design and using fire-resistant building materials for both the building envelope and outdoor living features, such as decks and fencing.

Earth

The Earth Task Group analyzed typical damage that happens when earthquakes or other ground disturbances occur. Such disasters can occur from various events, including the most common types: earthquakes, landslides, mudslides, soil dynamics, sinkholes, and freeze and thaw heaving. FEMA defines an earthquake as "a sudden release of energy that creates a movement in the Earth's crust." The group reviewed case studies and field reports of earthquake events, such as the Alaska Earthquake of November 30, 2018, published by FEMA, and the Northridge, California, Earthquake of January 17, 1994, published by HUD. The group discussed the damage described in the reports and then reviewed a wide range of technical resources to identify resilient-construction methods that could minimize earth-related damage. Per FEMA, "Most earthquake-related property damage and deaths are caused by the failure and collapse of structures due to ground shaking. The level of damage depends upon the extent and duration of the shaking. Other damaging earthquake effects include landslides, the down-slope movement of soil and rock (in mountain regions and along hillsides), and liquefaction." The Earth Task Group focused primarily on damage caused by earthquakes and considered other earth-related hazards secondary because many are driven by other natural hazards. For example, a mudslide can occur after an extended drought followed by a period of heavy rain or after an earthquake.

Auxiliary

The Auxiliary Task Group focused on hazards that do not fit within the wind-, water-, fire-, or earth-related categories. The major auxiliary hazard covered in the guide is volcano-related damage, but extreme cold, extreme heat, and hail are also included because they were not covered in the wind or water guides. The United States Geological Survey (USGS) says, "[Volcanic] eruptions often force people living near volcanoes to abandon their land and homes, sometimes forever. Those living farther away are likely to avoid complete destruction, but their cities and towns, crops, industrial plants, transportation systems, and electrical grids can still be damaged by tephra, ash, lahars, and flooding." FEMA has provided mitigation and prevention guidance for damage from cold waves in the form of freezing pipes and snow loads; heat waves in the form of pressure on the power grid and loss of power; and hail, which damages roofs and sidings. The Auxiliary Task Group identified the typical damage that results when volcanoes, cold waves, heat waves, and hail occur. The task group reviewed case studies of volcano hazard events, such as the recent eruption of Kilauea in Hawaii on May 3, 2018, published by FEMA. The task group then discussed the damage described in the report and reviewed a wide range of technical resources to identify the most relevant resilient-construction content.

Identifying the Frequency of Damage Types

After familiarizing themselves with the specific kinds of damage caused by various natural hazards, each task group was asked to determine the type of damage most likely to occur when one considers all possible kinds of damage. That task proved challenging because damage data are difficult to collect for three reasons: (1) Insurance-related claims data are proprietary, and a portion of the damage is covered by the building owner's insurance. (2) Forensic field reports are generally available only for major natural hazard events; they are not compiled for every natural hazard event that occurs. (3) Only limited data are available for natural hazard events that rarely occur.

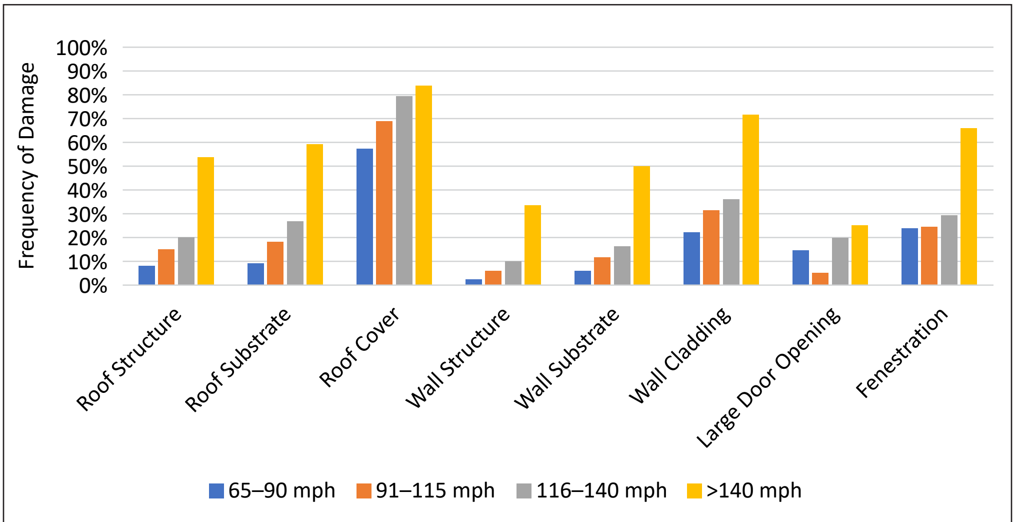
Wind

The Wind Task Group was fortunate to have several sources of data, such as information from Auburn University's Structural Extreme Events Reconnaissance (StEER) program. StEER focuses on collecting representative datasets for each hazard event by sampling from clusters of similar structure types—such as single-family residential and commercial—across the hazard gradient and by sampling at regularly spaced intervals within the clusters, such as every other or every third structure. StEER provided the damage frequency data in exhibit 5, which focuses on the primary building components with visible exterior damage, stratified by hazard intensity and structure occupancy. Damage to large door openings was calculated using only structures that contained large door openings; as a result, the sample size was smaller.

StEER evaluates structural damage caused by hurricanes, tornadoes, other wind events, earthquakes, and tsunamis. StEER does not investigate wildfires or flood-related damage.

Exhibit 5

Sample Frequency of Wind Damage Data to Single-Family Homes



Source: Structural Extreme Events Reconnaissance (StEER) program for compiled for Home Innovation

Water

The Water Task Group did not have access to damage data, but the group reviewed various tools provided by FEMA that estimate the costs of water damage caused by flooding. The risk of flooding is generally based on flood zones and maps, but predicting where a flooding event will occur is impossible. FEMA states, “Flood hazards change over time. Updated flood maps provide a more accurate picture of a property’s flood risk. To better reflect your current flood risk, the National Flood Insurance Program (NFIP) and the Federal Emergency Management Agency (FEMA) use the latest technology and data to update flood maps nationwide.” USGS “provides information about the magnitude and frequency of floods based on records of annual maximum instantaneous peak discharges. The information is in the form of a list of current USGS flood frequency reports published by state” (USGS, 2021). The Water Task Group gathered reports and discussed the water damage described therein; then, it reviewed a wide range of technical resources—for example, resources from FEMA, HUD, ASCE, the International Code Council, and the Insurance Institute for Business & Home Safety. Using that information, the task group identified damage types and estimated frequencies of occurrence.

Fire

The Fire Task Group considered wildfire hazards limited to low-density developments. Areas with medium- and high-density developments—which typically add fuel once a wildfire spreads—were not considered. Neither did the group consider how firefighting can mitigate the spread of wildfire. Instead, the guidance focuses strictly on methods of improving the fire resistance of individual homes.

Determining the frequency and type of fire damage is difficult because, unlike other natural hazards, when fire damage occurs due to wildfires, the structure is generally a total loss. The dynamics of wildfires are complex because they depend on many factors, such as wind, terrain, fuel ignition potential, the density of vegetation, building structures, the size and intensity of the fire, and firefighting. Historically, insurance companies have modeled risk for many natural hazards, including wildfires, but they have found that many historical models no longer capture the current risks of wildfires or the resulting damage or losses. That realization has led risk management companies such as Risk Management Solutions, Verisk Analytics, and Zesty.ai to develop new predictive wildfire-modeling tools. In some cases, insurance companies are partnering with those companies to develop improved models.

During the project, the Fire Task Group received fire-modeling data from Zesty.ai, a company specializing in data analytics for natural hazards that has developed new, predictive fire-modeling tools for the insurance industry, including its Z-FIRE modeling and scoring tool (Zesty.ai, 2022). Zesty.ai collects satellite data for determining the defensible space, vegetation types, and roofing types for buildings in an area that may be at risk of wildfires. Such metrics can help insurers build better predictive fire models and better assess the risk of houses being damaged or lost during a wildfire. Modeling based on post-event fire data may not fully capture structural-fire behavior because the models lack the influence of defensive firefighting activities. Fire propagation is further confounded by the fact that buildings themselves add to the fuel, and such a consideration is not captured in the predictive models.

With those limitations in mind, the Fire Task Group reviewed the data provided by Zesty.ai along with other guidance from FEMA, the California Department of Forestry and Fire Protection, and the U.S. Department of Agriculture's Forest Service to determine that defensive space and fuel management was well correlated with better outcomes for low-density developments. From the data available, the Fire Task Group could not determine which elements of the building envelope—roof, gutters, decking, and the like—were more vulnerable to embers than other elements. However, the Insurance Institute for Business & Home Safety research has shown that vented roofs and soffits can be improved with ember-resistant features. On the basis of a review of available post-wildfire damage data and judgment by the Fire Task Group, those data were used to identify the frequency of each specific type of damage from wildfires. More detailed wildfire forensics could lead to the use of better metrics to identify which house components are more likely to contribute to the loss of a building structure.

Earth

The Earth Task Group had to infer the frequency of damage from technical reports, FEMA's *Homebuilder's Guide to Earthquake-Resistant Design and Construction*, and mitigation programs.

Although the StEER network investigates and publishes technical reports after earthquake events, the damage data available are not as extensive as the network's wind hazard data because earthquakes do not often occur in the United States.

After the Ridgecrest, California, earthquakes of July 4 to 5, 2019, StEER published a preliminary virtual reconnaissance report documenting the damage observed. The executive summary of the report states, "The impact of the two earthquakes on the city of Ridgecrest demonstrated its resiliency as it recovered rapidly where many restaurants and gas stations are back up and running. There was very little structural damage, even from the second, stronger (M 7.1) earthquake, except for the typically vulnerable buildings (e.g., unreinforced masonry structures and mobile homes). However, there were substantial non-structural and content losses. The other city that was impacted the most is Trona, which did not perform as resiliently as Ridgecrest, where the city remained dysfunctional up to the time of writing this report. There were more damaged structures, mostly from the effects of ground failure and possibly strong site response related to soft sediments. The town suffered from significant loss of water where its main water pipes fractured due to fault rupture and lateral spreads." The complexity of damage, as illustrated in the StEER report, varied on the basis of soil type, age of the building, type of construction, and magnitude of the earthquake.

Auxiliary

The Auxiliary Task Group had to infer from technical reports, FEMA's disaster preparedness documents, and other mitigation programs to establish the frequency-of-damage metric for volcanoes. The United States has five observatories—in Alaska, California, the Cascades, Hawaii, and Yellowstone—that monitor volcanic activities. USGS says that "scientists [at the observatories] also assess volcano hazards and work with communities to prepare for volcanic eruptions."

The areas in the United States with active volcanoes include California, Oregon, Washington, Alaska, Hawaii, American Samoa, and the Mariana Islands. Notable recent eruptions have threatened the health and safety of residents and have damaged property and infrastructure, according to USGS. For instance, in 2018, more than 700 structures were destroyed when swift-flowing lava erupted from fissures in Kilauea's lower East Rift Zone. Lava covered 35.5 square kilometers (13.7 square miles), which included houses, farms, wild spaces, roads, highways, and critical infrastructure. Kilauea is ranked the U.S. volcano with the highest threat score in the very-high-threat category.

In 2009, more than 300 airline flights were canceled and Anchorage International Airport shut down when Redoubt Volcano in southern Alaska erupted clouds of volcanic rock and ash. Redoubt ranks in the very-high-threat category.

Observatories can usually give surrounding areas notice before major volcanic eruptions occur. The damage would be catastrophic to buildings in the immediate vicinity of a volcanic eruption.

Prioritizing High-Frequency Damage for Resilience

The Technical Advisory Group recommended prioritizing high-frequency-damage areas of a building as the most practical mitigation strategy for resilience. Many worried that if hazard mitigation funding for above-code practices and strategies were limited or if a builder wanted to invest in one specific resilient-construction practice instead of others, knowing what was most important to do would be difficult without some level of prioritization.

Data about the frequency of damage type are necessary for builders and developers so they can prioritize the resilient-construction practices that would yield the greatest benefit—or the least amount of damage—to buildings. Damage-frequency metrics on the one-pagers are intended to provide builders and developers with a general idea of the frequency and severity of possible damage so that cost alone does not drive the mitigation strategy.

Assessment or reconnaissance reports provide some guidance, but given the complexity of the damage observed after different types of natural hazards, additional, detailed forensics data after events are needed to develop a more accurate method of prioritizing damage types. During the project, task groups relied on their collective judgment and expertise when determining how to classify high-, moderate-, and low-frequency damage.

Implementing Resilient-Construction Practices

The task groups believed that licensed design professionals and subject matter experts would be able to prioritize resilient-construction practices without much guidance. However, given the myriad options and design alternatives on the one-pagers, they recommended that bundling multiple one-pagers would be valuable so that a builder or developer could offer a prepackaged system of resilient-construction practices, similar to other resiliency programs.

The most basic prepackaged system of resilient-construction practices could be as simple as selecting all the high-frequency one-pagers to improve the areas where damage is most likely to occur. Each task group explored a good-better-best approach to grouping the one-pagers, whereby basic levels of resilience would be branded as good; more advanced practices could be combined with those basics to offer a better option; and the most comprehensively resilient practices could be considered the best level of resilience.

A builder or developer could also focus on implementing just one or two resilient-construction practices and could provide customers with the one-pager. Certain resilient-construction practices may be considered alternatives, whereas others may be additional practices to be implemented. By emphasizing the unique possibility of customization, the *Designing for Natural Hazards* resilience guides offer a wide range of solutions—from the good-better-best approach to a single area of improvement that a builder or developer could consider.

Next Steps: The Future of Resilience

As resilient-construction practices evolve, the one-pagers in the series' various guides should be updated to reflect improvements or modifications. For damage-frequency metrics to improve, additional data are needed from post-disaster forensic reports, FEMA's National Flood Insurance Program, and the insurance industry's proprietary claims data. The aggregation and anonymization of insurance claims data could help improve building codes and identify where damage occurs the most. Moreover, organizations like the StEER network should expand their work in post-disaster field assessment and consider including other disaster events in the areas of investigation. For instance, StEER network wind damage data should serve as a model for ways to capture and catalog damage-frequency information.

Damage data should be shared widely with the building products industry to spur improvements in building materials and construction methods. The authors did not study new products and whether they improved resilience because such a study was beyond the scope of work, but new and better products are potential resilience solutions. For example, paying a premium up front for a better wall-sheathing product could avoid the added cost of major renovation and replacement of water-damaged building materials in the future.

Better predictive-modeling tools are essential for estimating the locations and risks of flooding and wildfire hazards. FEMA maintains flood maps and related cost modeling to estimate the costs of repairing flood damage (FEMA, 2022a). The Wildland Urban Interface (WUI) maps are important for determining areas at risk of wildfire damage (U.S. Fire Administration, n.d.). The maps and risk areas can change over time with regard to both flooding and wildfire hazards. Therefore, builders and developers should consider resilience as above-code construction practices that minimize damage from natural hazards in areas where the risk is low or moderate.

The Fire Task Group discussed methods of preventing smoke damage and improving indoor air quality during a wildfire by employing a special clean room designated within a building, but those methods were not included in the resilient guide because they require further research or field validation. Although the techniques discussed seemed technically sound, the group was reluctant to recommend one-pagers on resilient-construction practices that have not yet proven effective. However, most buildings that have survived wildfires with little fire damage have suffered major smoke damage.

Although this research project focused on new construction, the existing housing stock is at greater risk of damage than new buildings because of greater numbers and more inventory. In a few reconnaissance reports, StEER has discussed correlating damage data and year of construction to illustrate whether a building code has improved house performance over time. The data for earthquake events are not as comprehensive as for wind events, and the data do not identify specifically whether an existing building was retrofitted to improve earthquake performance before an earthquake event occurred. Such data should be collected and analyzed to demonstrate the efficacy of retrofit programs and to learn whether the above-code construction practices improve building outcomes after natural hazard events occur.

The Auxiliary Task Group recommended that the definition of resilience be expanded to include the health and safety of the building occupants—beyond the structure of the building itself. Because the research project was conducted during the COVID-19 pandemic, the task group felt compelled to consider safety in terms of biohazards, such as airborne viruses, and how they can be circulated through a heating, ventilation, and air-conditioning system. Although the scope of this research project did not allow an opportunity to address biohazards, biohazard is a valid area for future research. Either the topic could be included within the auxiliary guide, or a new biohazard guide could be created for occupant resilience in buildings.

Conclusion

As climate change drives more extreme weather events and the severity of damage to housing increases, many communities will want to rebuild using the above-code construction practices that are resilient and easy to implement. The *Designing for Natural Hazards* series offers solutions that residential designers, builders, and developers can readily incorporate into their business practices, focusing on minimizing high-frequency damage while providing a wide range of solutions. The guide can also be integrated into existing sustainability programs by offering new resilience options to complement green building practices. *Designing for Natural Hazards* can be a precursor to developing a new resilience standard focused on residential buildings. The standard would be an above-code program shaped by insurance data, damage assessments, and better modeling of natural hazards.

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