CREATING DISASTER-RESILIENT BUILDINGS TO MINIMIZE DISASTER DEBRIS

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- *Top left*: Beach erosion caused by Hurricane Matthew in the St. Augustine, Florida, area (Paul Brennan, publicdomainpictures.net).
- *Top middle*: Infrastructure burning from the Caldor Fire in El Dorado County, California, on August 29, 2021 (California Department of Forestry and Fire Protection).
- *Top right*: Sinkhole affecting a structure and its supporting infrastructure, such as buried utilities lines, in the Dover area of Florida during a freeze event in January 2010 (Ann Tihansky, U.S. Geological Service).

- Bottom: The Federal Center South U.S. Army Corps of Engineers Seattle District Headquarters Building is a LEED Gold building completed by the U.S. General Services Administration in 2012 using nearly 200,000 board feet of structural and nonstructural lumber from an adjacent warehouse that was deconstructed (Theresa Blaine, U.S. Environmental Protection Agency).

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Executive Summary

Creating Disaster-Resilient Buildings to Minimize Disaster Debris provides practical actions for communities (e.g., cities, counties, states, territories, and tribes) on planning, designing, improving, and adapting new and existing buildings to withstand natural disasters today and in a changing climate. Community leaders and members, planners, designers, builders, and disaster response experts can use this information to increase the resiliency of homes, businesses, and other buildings to the impacts of natural disaster hazards, including flooding, fire, and high winds. This information can be applied in all communities, including communities with environmental justice concerns, where community involvement and investments in resilience are critically needed.

Natural disasters and extreme climate events pose significant risk to human health and the environment and burden communities, waste management facilities, and transporters. The generated debris is often disposed of in landfills, even when it could be safely reused, recycled, or composted – contributing to the circular economy. Designing the built environment, such as buildings and roadways, to be resilient to disasters helps minimize disaster debris and make reconstruction efforts less costly while using fewer resources. Resilient communities generate significantly less debris during and after a natural disaster, recover faster, encouraging residents and businesses to stay in the area as normal operations resume sooner, and save money and use fewer resources to rebuild and recover.

The first part of this document highlights proven, innovative strategies for disaster-resilient buildings. These best practices are inspired from nature and lived experience. They are organized by what can be done before a disaster, in anticipation of an imminent disaster, and after a disaster. Many of the practices apply to more than one phase. The second part presents lessons learned from two natural disasters, which illustrate the need for resilient buildings and strategies. The third and last part of the document provides resources on debris management, disaster planning, and resiliency that explore these topics in more depth.

Creating disaster-resilient buildings presents an opportunity to minimize disaster debris while advancing a circular economy, conserving resources, decreasing waste, and reducing health, social, environmental, and economic impacts.

Table of Contents

Introduction

Every year, natural disasters challenge the built environment for communities in the United States, destroying homes, businesses, and other infrastructure and costing billions of dollars in damages. As climate change increases, the frequency and severity of natural disasters, such as landslides, hurricanes, tornadoes, wildfires, and intense storms, the impacts associated with these disasters are growing and include loss of life, community disruptions, environmental impacts, property loss, and the burden of dealing with disaster debris. Natural disasters can also cause environmental justice impacts that should be addressed in all disaster phases.

What Is the Built Environment?

The built environment touches all aspects of people's lives, encompassing the buildings people live and work in, the distribution systems that provide communities with water and electricity, and the roads, bridges, and transportation systems people use to get from place to place.

Generally, the built environment encompasses the human-made or modified structures that provide people with living, working, and recreational spaces. Creating all these spaces and systems requires enormous quantities of materials.

Environmental Justice

Environmental justice[1] means the just treatment and meaningful involvement of all people, regardless of income, race, color, national origin, Tribal affiliation, or disability, in agency decision-making and other Federal activities that affect human health and the environment so that people:

- are fully protected from disproportionate and adverse human health and environmental effects (including risks) and hazards, including those related to climate change, the cumulative impacts of environmental and other burdens, and the legacy of racism or other structural or systemic barriers; and
- have equitable access to a healthy, sustainable, and resilient environment in which to live, play, work, learn, grow, worship, and engage in cultural and subsistence practices.

Due to factors such as historical discrimination, social marginalization, economic inequality, and environmental degradation, disasters and climate events often disproportionately affect communities with environmental justice concerns, worsening environmental, economic, and health injustices. For example, their proximity to industrial areas and hazardous waste sites make them more vulnerable to toxic leaks from storm damage and the mental and physical

[1] U.S. EPA (n.d.). Environmental Justice. https://www.epa.gov/environmentaljustice.

impacts of contaminated, unmanaged disaster debris.[2] Limited access to information, resources, and assistance can exacerbate the harm to these communities.

The Federal Emergency Management Agency's (FEMA's) *2022–2026 Strategic Plan*[3] recognizes that underserved communities and specific identity groups often suffer disproportionately from disasters. As a result, disasters can worsen existing inequities in society through, for example, the unequal siting of debris staging areas or the lack of local participation in debris management and recovery planning. This cycle compounds the challenges faced by these communities and increases their risk to future disasters.

Therefore, it is critical to advance human safety and environmental justice for all by providing resilient, affordable housing and effective, equitable disaster debris planning and management, which are key to the health, safety, and recovery of communities impacted by natural disasters.

To achieve this, marginalized and overburdened communities should be ensured access to the full range of disaster mitigation, response, and recovery resources (e.g., funding, equipment, personnel) and be involved as equal partners at every level of decision-making (e.g., planning, implementation, evaluation). As Administrator Regan in EPA's FY 2022-2026 Strategic Plan[4] statement shares, "We will employ the full array of policy and legal tools at our disposal to incorporate environmental and climate justice considerations in our analysis, rulemaking, permitting, enforcement, grantmaking, operations, **disaster response and recovery**, and other activities."

Disaster response and recovery also increase the demands on energy, natural resources, and community resources. By taking action to mitigate risks before a natural disaster occurs, communities can reduce community disruption and recovery costs after a disaster, supporting environmental justice, as well as advancing a circular economy. Some of the actions that can help mitigate risks are designing resilient and adaptable buildings and retrofitting existing buildings, securing the property against expected hazards, creating a disaster debris management plan, and contacting relevant agencies and organizations.

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[2] Brie Sherwin. (2019). *After the Storm: The Importance of Acknowledging Environmental Justice in Sustainable Development and Disaster Preparedness*. 29 Duke Environmental Law & Policy Forum 273-300. https://scholarship.law.duke.edu/delpf/vol29/iss2/2.

[3] FEMA. 2022-2026 *Strategic Plan.* https://www.fema.gov/sites/default/files/documents/fema_2022-2026-strategic-plan.pdf.

[4] EPA. (2022). *FY 2022-2026 EPA Strategic Plan.* https://www.epa.gov/planandbudget/strategicplan.

What is a Circular Economy?

A **circular economy** keeps materials and products in circulation for as long possible. The Save Our Seas 2.0 Act refers to an economy that uses a systems-focused approach and involves industrial processes and economic activities that are restorative or regenerative by design, enables resources used in such processes and activities to maintain their highest value for as long as possible, and aims for the elimination of waste through the superior design of materials, products, and systems.[5]

What is Embodied Carbon?

Also known as embodied greenhouse gas (GHG) emissions, **embodied carbon** refers to the amount of GHG emissions associated with upstream—extraction, production, transport, and manufacturing—stages of a product's life. Many initiatives to track, disclose, and reduce embodied carbon emissions also consider emissions associated with the use of a product and its disposal.[6]

Understanding and disclosing these emissions to better inform selection of lower-embodied carbon construction materials and products is rapidly advancing and is critical to reducing the carbon footprint of the built environment.

Decisions on design, construction, and materials within the built environment can have significant impacts on carbon emissions, human health, and resiliency.

This document focuses on actions community officials, leaders, and members (including those in cities, counties, states, territories, tribes, businesses, and community organizations) can take to plan, design, improve, and adapt homes and other buildings to withstand natural disasters today and in a changing climate. It advances a circular economy approach, shifting from the model in which resources are mined, made into products, and then become waste. A circular economy reduces material use, redesigns materials to be less resource and carbon intensive, and recaptures "waste" as a resource to manufacture new materials and products.

[5] U.S. EPA (n.d.). Circular Economy. https://www.epa.gov/circulareconomy.

[6] U.S. EPA (n.d.). What is Embodied Carbon? https://www.epa.gov/greenerproducts/what-embodied-carbon.

What Is Natural Disaster Debris and Why Should We Care[7]?

Natural disaster debris refers to the material and waste streams resulting from a natural disaster.

Disaster debris often includes building materials, sediments, vegetative debris, and personal property. Large quantities of debris can make response and recovery efforts difficult by hindering emergency personnel, damaging or blocking access to necessary infrastructure, and posing threats to human health and the environment.

The needs for disaster debris mitigation and sustainable management of generated debris are growing rapidly as the frequency and severity of natural disasters continues to increase. For many communities, more and stronger disasters means larger quantities of debris will be generated that may end up in landfills, thereby leaving the circular economy.

Considering the health, environmental, social, and economic costs and impacts to communities associated with debris generation, cleanup, and management, the development of effective strategies to plan for, mitigate, and respond to natural disaster debris is critical for resilience. **Resilience** means the capacity to plan for, withstand, adapt to, and recover from natural disasters with minimal damage in a timely, effective, and safe manner.

From 2011 to 2022, 90 percent of U.S. counties – covering over 300 million people – experienced a flood, hurricane, wildfire, or other emergency serious enough to receive a federal disaster declaration, and more than 700 counties suffered 5 or more such disasters.[8]

When considering all the health, environmental, social, and economic costs of managing debris, including from damaged buildings, after a disaster, it is more sustainable and likely less costly to invest in resilient building siting and design before a disaster happens. A community that invests in debris mitigation actions before a natural disaster occurs can significantly reduce the generation of natural disaster debris after a disaster; protect neighborhoods; save energy, natural resources, and community resources; and, thereby, reduce response and recovery costs.

For example, the National Institute of Building Sciences' *Natural Hazard Mitigation Saves: 2019 Report* documents that rebuilding to the most recent building codes requirements saves on average $11 per $1 spent on mitigation, while exceeding building code minimum requirements saves $4 per $1 spent (Figure 1 below).[9] Additionally, FEMA's *Building Codes Save: A Nationwide Study* estimates $132 billon could be saved in property losses based on past and forecasted growth in the use of modern building codes from 2000–2040.[10]

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[7] U.S. EPA. (n.d.). https://www.epa.gov/homeland-security-waste.

[8] Rebuild by Design. (2022). *Atlas of Disaster.* https://rebuildbydesign.org/atlas-of-disaster/.

[9] National Institute of Building Sciences. (2019). National Institute of Building Sciences' Natural Hazard Mitigation Saves: 2019 Report. https://www.nibs.org/projects/natural-hazard-mitigation-saves-2019-report.

[10] FEMA. (2020). *Building Codes Save: A Nationwide Study.* https://www.fema.gov/sites/default/files/2020-11/fema_building-codes-save_study.pdf.

National Institute of BUILDING SCIENCES	ADOPT CODE	ABOVE CODE	BUILDING RETROFIT	LIFELINE RETROFIT	FEDERAL GRANTS
Overall Benefit-Cost Ratio	11:1	4:1	4:1	4:1	6:1
Cost ($ billion)	$1/year	$4/year	$520	$0.6	$27
Benefit ($ billion)	$13/year	$16/year	$2200	$2.5	$160
Riverine Flood	6:1	5:1	6:1	8:1	7:1
Hurricane Surge	not applicable	7:1	not applicable	not applicable	not applicable
Wind	10:1	5:1	6:1	7:1	5:1
Earthquake	12:1	4:1	13:1	3:1	3:1
Wildland-Urban Interface Fire	not applicable	4:1	2:1	not applicable	3:1

Figure 1. Benefit-Cost Ratio by Hazard and Mitigation Measure (Source: National Institute of Building Sciences' Natural Hazard Mitigation Saves: 2019 Report, *https://www.nibs.org/projects/natural-hazard-mitigation-saves-2019-report*).

To support the implementation of mitigation measures and practices that result in less disaster debris generation and, therefore, reduce the cost of response and recovery, this document provides an overview of:

1) Proven, innovative strategies for disaster-resilient buildings.

2) Lessons learned from natural disasters.

3) Resources on debris management and disaster planning.

Planners, designers, builders, disaster response experts, and community members can use this information to improve communities' adaptation and resilience to natural disasters. ***Climate adaptation*** strategies prepare a community for a changing climate, and resilience strategies increase the ability of the community to withstand and recover from natural disasters and related impacts. Incorporating these strategies together into building designs and improvements creates strong buildings and communities that can:

- **Generate significantly less debris** during and after a natural disaster.
- **Recover faster,** encouraging residents and businesses to stay in the area.
- **Save money and use fewer resources** to rebuild and recover.

Impacts of Natural Disaster Hazards on Buildings

Hazards from flooding, wind, fire, and other natural disasters vary widely and may cause a broad range of building-related damage and debris, especially if buildings have not been designed or retrofitted to withstand worsening hazards. Communities may be at risk for more than one type of natural disaster and may experience several disasters together. Their hazards can impact buildings and communities.

However, these impacts are not evenly distributed across society. Some communities, such as low-income, minority, or indigenous groups, often bear the brunt of natural disasters and their hazards, as noted above.

The following chart outlines common hazards created by natural disasters and associated building-related impacts and highlights some the issues that communities may face.

High Winds Caused by Hurricanes, Typhoons, Tornadoes, Derechos, and Other Phenomena

- Structural damage and failures caused by wind velocity, uplift, and/or pressure differentials, including damage to roofs, appliances, utilities, and heating, ventilation, and air conditioning (HVAC) equipment.
- Impacts from flying objects and falling objects like branches and trees.
- Moisture and mold issues in structures from wind-blown rain.
- Disruption of power through damaged and downed utility infrastructure like power lines, substations, and generators, which can delay response and recovery efforts and cause additional waste, such as spoiled food.

Figure 2. Tornado damage at a mobile home park in Ridgeway, South Carolina (FEMA).

Extreme Winter Weather and Temperature Variability from Winter, Ice, and Hail Storms

- Roof collapse and other structural failures from heavy snow and ice loads and falling branches and trees, as well as damage to appliances, utilities, and HVAC equipment.
- Roof, window, and other damage from hail.
- Freeze-thaw damage to building features.
- Mold from melting snow or ice.
- Water damage from plumbing failures associated with physical damage or extreme cold.

Figure 3. Partial roof collapse at an elementary school due to snow load (Building America Solution Center / U.S. Department of Education).

Coastal and Inland Flooding, Storm Surges, Tsunamis, Sea Level Rise, Extreme Rainfall Events, and Flash Floods

- Structural damage to foundations, floors, walls, roofs, doors, windows, interior elements, appliances, utilities, and HVAC equipment.
- Salt-related corrosion from coastal flooding and sea level rise.
- Damage from floating debris.
- Mold and impacts to indoor air quality from water.
- Biological and chemical contamination from contaminated water.
- Spread of disease from contaminated water.

Figure 4. Two residents of the village of Leone, American Samoa, walk through waist-high water while removing structure debris after a tsunami (Casey Deshong / FEMA).

Fire from Structure Fires, Earthquakes, Volcanoes, and Wildfires

- Structural damage and failure, including to interior elements, appliances, utilities, and HVAC equipment.
- Smoke damage from fire.
- Water damage and mold from fire suppression activities.

Figure 5. Residential structure during a wildfire (Jana Baldwin / FEMA).

Landslides and Erosion from Sinkholes, Mudslides, Avalanches, and Earthquakes

- Structural damage and failure for all building features, including to appliances, utilities, and HVAC equipment.
- Erosion damage.
- Ground failure (i.e., when the stability of the ground is impacted, including from landslides, liquefaction, and subsidence damage).

Figure 6. Home destroyed by a landslide following Hurricane Maria (Andrea Booher / FEMA).

Adaptation and resilience strategies are inherently place-based and should start with an understanding of which natural disasters a particular community is likely to experience and the impacts these hazards may have in the specific area. Historical information, geographical information, and climate change projections can help a community understand and prioritize planning for specific types of disasters and their hazards.

Also, the characteristics and features of the location and surrounding area may exacerbate hazards from natural disasters. For example, buildings in floodplains face a greater risk of flooding, and buildings located on slopes may face a greater risk of erosion or landslides. Existing structures can often be retrofitted to better address current and future hazards. New structures should be designed and built to withstand all expected hazards now and in the future. Communities should also keep in mind that reducing development in high-risk areas like coastal areas projected to be impacted by sea level rise and changing floodplain areas[11] may be the best strategy for avoiding additional damage from natural disasters.

[11] Sea level rise, changing precipitation patterns, and development have increased the flood risk across much of the U.S., changing traditional floodplain definitions. FEMA. (2023). Federal Flood Risk Management Standard. https://www.fema.gov/floodplain-management/intergovernmental/federal-flood-risk-management-standard.

Section 1. Best Practices for Creating Resilient and Adaptable Buildings

Resilient building adaptation and strategies range from simple and inexpensive to complex and costly. Some strategies can be implemented before any natural disaster occurs, in anticipation of an impending natural disaster, and after a natural disaster is experienced to build back a stronger and more resilient community.

This section describes some of the best practices that communities can take to protect the built environment from natural disasters. **Because the EPA encourages integrated, place-based planning and design appropriate for building function and local conditions, the following strategies and materials are not appropriate for all types of disasters, locations, and building types.**

1.1. Before Natural Disasters

When anticipating future natural disasters, using best practices in building design can support building and infrastructure resilience. Resilient building design can leverage natural systems and protections and incorporate biomimicry – the practice that learns from and mimics the strategies found in nature to solve human design challenges. In addition to designing for resiliency, other strategies to consider include designing buildings for disassembly and adaptation. Existing buildings can be retrofitted and upgraded to be resilient and adaptable to help limit damage from natural disasters and climate events, decrease the amount of debris generated by disasters, and speed up recovery. Current building codes and standards can help guide building design and retrofits.

Enhancing the resilience and adaptability of new and existing buildings can also help reduce the exposure of communities, including communities with environmental justice concerns, to disasters. For example, these best practices can advance affordable and accessible housing and infrastructure services, which can improve the living conditions and well-being of vulnerable communities, by reducing destruction and recovery costs.

Circular design principles can promote the use of renewable, biodegradable, and locally sourced materials, which can reduce greenhouse gas emissions, waste generation, and resource depletion. Also, by encouraging the reuse and recycling of building materials and components, the need for new extraction and production is reduced, which lowers the costs and environmental impacts of recovery. These best practices can also support the continuity and reliability of essential services, such as energy, water, and waste management, which can enhance the coping capacity and safety of communities with environmental justice concerns.

Plans should be made to identify any need for services to those with disabilities and limited English proficiency (LEP) to provide meaningful access to services.

Accessibility and Language Resources

- FEMA, Disaster Preparedness for People with Disabilities: Same But Different https://www.fema.gov/press-release/20230425/disaster-preparedness-people-disabilities-same-different.
- U.S. Department of Justice, Limited English Proficiency LEP.gov https://www.lep.gov/
- EPA, Assisting People with Limited English Proficiency https://www.epa.gov/external-civil-rights/assisting-people-limited-english-proficiency
- City of Baltimore, Language Access Toolkit https://ispeak.baltimorecity.gov/translating-vital-documents

1.1.1. Design for Resilience

Below are some strategies and resources to consider when designing buildings for resilience.

Passive Survivability

Resilient design can also include planning for ***passive survivability***, or designing a building to provide necessary shelter, thermal, and other life-support services during extended utility service disruptions. Designing for passive survivability can protect building occupants and help prevent additional damage and building-related disaster debris. For example, a tight building envelope and plumbing that will not freeze can reduce disaster debris from flooding. Passive survivability is especially important for critical infrastructure, such as fire and police stations, hospitals, schools, and emergency shelters.

Natural Systems

Considering natural systems and using natural materials during building design is a growing source of innovation used to generate more resilient buildings. Below are some examples of leveraging natural systems to help protect buildings and surrounding infrastructure from potential natural disasters.

Brock Regional Environmental Center, Virginia Beach, Virginia

This structure is raised 14 feet above sea level in anticipation of future sea level rise. The building uses the natural drainage features of the landscape, as well as water-permeable hardscape, to prevent paving and hardscaping from carrying water runoff. These features protect the building and surrounding structures.

Learn More

- *"Climate Change Ready," Chesapeake Bay Foundation,* https://www.cbf.org/about-cbf/locations/virginia/facilities/brock-environmental-center/climate-change-ready.html.

Figure 7. Brock Regional Environmental Center (Deanna Brusa / Chesapeake Bay Foundation staff).

Sustainable Adobe Safety Cottages, Santa Barbara, California

This proposed residential redevelopment in downtown Santa Barbara, California by Oasis Design envisions highly fire-resistant and earthquake-safe Adobe Safety Cottage micro-units designed to have minimal environmental impacts by using natural materials, maximizing water and energy conservation, having a long design life, and having low landfill volume for the full life of the project. The fiber composite adobe exterior is essentially a monolithic adobe "brick," fashioned in the shape of the whole house. The walls, floors, roof, and built-in ceiling are nonflammable, insulating, and heat absorbing. They are made of adobe, steel, thin shell cement, tile, granite, wrought iron, aluminum, and glass. Curves, built-in furniture, floors, and roofing are all part of a mutually reinforcing structure, which is held together by welded wire mesh and long straw.

Learn More

- The White House's *Nature-Based Solutions Resource Guide*. The guide contains 30 examples of ways that federal agencies have used nature-based solutions to achieve their goals. The diverse set of examples demonstrates that nature-based solutions can provide many different benefits. https://www.whitehouse.gov/wp-content/uploads/2022/11/Nature-Based-Solutions-Resource-Guide-2022.pdf.
- "Sustainable Affordable Adobe Safety Cottages," Oasis Design. https://oasisdesign.net/shelter/safetycottage/.

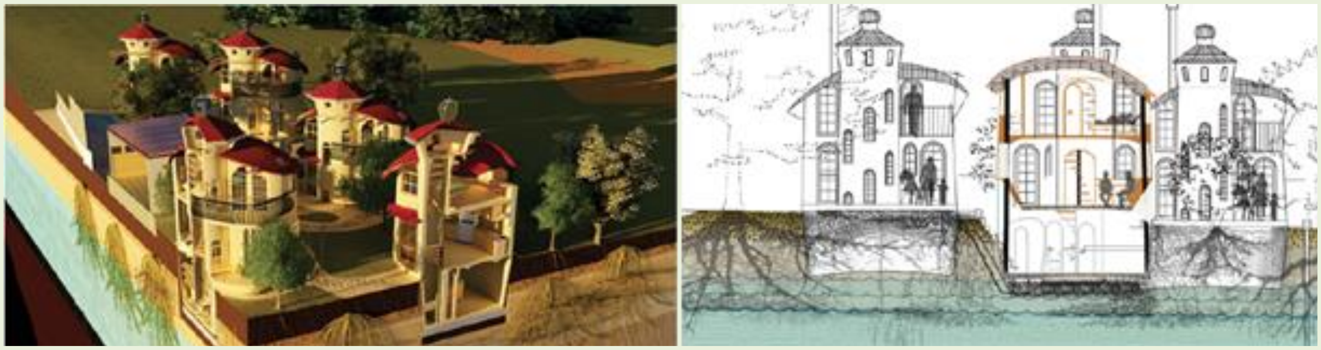

Figure 8. Models of highly fire-resistant and earthquake-safe Adobe Safety Cottage micro-units designed to have minimal environmental impacts by using natural materials and water and energy conservation (Art Ludwig / https://oasisdesign.net/).

Biomimicry

Biomimicry, an emerging set of practices that uses nature as both a pattern and an inspiration, can allow for more resilient and regenerative designs. This creative approach holds promise for reducing building-related disaster debris. Biomimicry can also inform the positioning and relationship of buildings to each other and to the local environment. EPA acknowledges the leadership of the Biomimicry Institute and Biomimicry 3.8 in developing and sharing this inspiring approach to designing buildings and building materials.[12]

Figure 9. Tree root systems may provide insights for building disaster resilient buildings (Francisco Ramos / Freeimages.com).

Increasing Building Resiliency: Root Systems

The oak trees that survived Hurricane Katrina could be used as a case study for surviving hurricanes. Underground, their roots are intertwined with neighboring trees, so when hurricane-force winds hit, the interconnected root systems mean the trees are more likely to remain standing than if their roots were not interconnected.

Research could be conducted to understand if building foundations could be connected with intertwined horizontal components to better withstand high wind speeds. Similarly, the intertwining of roots of mangroves on vulnerable coastal slopes and areas subject to erosion could inspire research tying building foundation systems together to increase strength and stability.

[12] Biomimicry Institute. (2016). https://biomimicry.org/ and: Biomimicry 3.8. (n.d.). https://biomimicry.net/.

Learn More

- *"Think Like a Tree: What We Can Learn from the Oaks That Survived Katrina," Wired Magazine, August 26, 2015,* https://www.wired.com/2015/08/think-like-tree-learning-oaks-survived-katrina/.
- *"Biomimicry of Mangroves Teaches How to Improve Coastal Barriers." Ansys, March 6, 2019,* https://www.ansys.com/blog/biomimicry-mangroves-improve-coastal-erosion-coastal-barriers.

Figure 10. A spider web provides a natural design model for resilient building materials (Christophe Libert / Freeimages.com).

Increasing Building Resiliency: Velcro and Webs

Velcro is another example of design informed by nature. It was invented by a Swiss engineer after he examined the tiny hooks of cockleburs stuck on his pants and in his dog's fur. Using a similar hook-and-loop fastening system, Velcro could be used to inform new construction of exterior building systems (e.g., panels) that could be reused, adjusted, and repositioned to adapt to changing environments.

The web silk of spiders is both lightweight and extremely strong – in some cases, stronger than steel. It is a remarkable example of biomaterial with superior mechanical characteristics. Engineers are looking into developing spider-silk-inspired materials, such as disaster retrofit connectors or other resilient building applications.

Learn More

- *"Spider silk is five times stronger than steel—now, scientists know why," Science, November 20, 2018.* https://www.science.org/content/article/spider-silk-five-times-stronger-steel-now-scientists-know-why.

Figure 11. SOM's entry in the Transbay Tower & Transit Center Competition for the City of San Francisco (Image copyright SOM, used with permission).

Figure 12. Dome house, California (Alfred Twu / Wikimedia Commons).

Increasing Building Resiliency: Natural Geometries

By combining structural system design and biology, engineers are investigating the growth patterns of bamboo, the fractal geometry of the chambered nautilus shell, and other natural systems for clues on how to design more resilient high-rise structures using fewer materials while increasing structural integrity.

Inspired by nature and the structural durability of natural forms like shells, some dome-shaped buildings can withstand high winds and debris impacts from hurricanes and tornadoes, as well as earthquakes. Efficient structural forms mimicking those found in nature can reduce the overall volume of materials required and eliminate large quantities of waste.

Learn More

- *"Nature | Structure: Structural Efficiency Through Natural Geometries." (White paper on developing sustainable structural solutions for buildings utilizing biomimicry.) Skidmore, Owings & Merrill, LLP (SOM), https://www.yumpu.com/en/document/read/26407050/nature-structure-skidmore-owings-merrill-llp.*

Resources on Resilience

Place-based pre-disaster preparation and disaster resilience planning that incorporates integrated hazard planning (e.g., source reduction; hazard mitigation; increased reuse, recycling, and composting), including mapping and assessment of both hazards and resources, can increase disaster resilience. Boosting community resiliency in anticipation and preparation for a natural disaster leads to a quicker and less costly recovery to the pre-incident state after a disaster occurs. The box below highlights some key disaster resiliency planning resources that can help communities develop strategies to decrease potential debris before a disaster occurs.

Key Disaster Resilience Planning Resources

- **U.S. Climate Resilience Toolkit.** A framework to help communities systematically consider and address their climate hazards. Communities can use this portal to document their past, present, and future exposure to climate-related hazards. https://toolkit.climate.gov/.
- **EPA Planning for Natural Disaster Debris.** Guide designed to help all communities (including cities, counties, territories, tribes, and more) create disaster debris management plans. https://www.epa.gov/homeland-security-waste/guidance-about-planning-natural-disaster-debris.
- **EPA Disaster Resilient Design Concepts.** This document showcases disaster-resilient designs, organized by hazard type, to help communities reduce the impact of disasters, recover more quickly, strengthen local economies, and create safer, more equitable places to live by reducing hazards especially for those most vulnerable. https://www.epa.gov/smartgrowth/disaster-resilient-design-concepts.
- **EPA Smart Growth Strategies for Disaster Resilience and Recovery.** Resources, such as the EPA-FEMA MOU and example projects on smart growth strategies. https://www.epa.gov/smartgrowth/smart-growth-strategies-disaster-resilience-and-recovery#EPA%20Resources.
- **FEMA Best Practices in Local Mitigation Planning.** Best practices for developing or updating a local hazard mitigation plan that will meet the requirements for approval by FEMA, based on FEMA's *Local Mitigation Planning Handbook (2013)*, as well as examples drawn from local hazard mitigation plans in the U.S. https://www.fema.gov/sites/default/files/2020-06/fema-local-mitigation-planning-handbook_03-2013.pdf and https://www.fema.gov/emergency-managers/risk/hazard-mitigation-planning/best-practices.
- **Resilient Design Institute.** Resilient design principles to achieve resilience at the building scale. https://www.resilientdesign.org/the-resilient-design-principles/.
- **RELi Resilient Design Guidelines + Certification.** Holistic project guide, rating system, and third party certification system that emphasizes resilience. https://c3livingdesign.org/reli/.
- **U.S. Resiliency Council Building Performance Ratings.** Rating metrics that describe the performance of buildings during earthquakes and other natural hazard events. https://www.usrc.org/usrc-rating-system/.
- **Insurance Institute for Business and Home Safety FORTIFIED Commercial Building Standard and FORTIFIED Home program.** Voluntary construction and re-roofing program designed to strengthen homes and commercial buildings against specific types of severe weather. https://fortifiedhome.org/ and https://fortifiedhome.org/technical-documents/#standards.

1.1.2. Design for Disassembly and Adaptation

Below are some strategies and resources to consider when designing buildings for disassembly and adaptation. This type of design is also sometimes called circular or reversible design.

Disassembly

Designing for disassembly—buildings with systems and materials that are easy and safe to take apart, repair, and reuse—is an important consideration of the complete life cycle of a structure. Disassembly supports the reuse and repair of buildings and building components. Designing buildings for easy disassembly can also reduce disaster-related building debris and support the repair, reuse, recycling, and even the relocation of structures and materials after disaster events. Items that can often be safely reused include:

- Lumber (structural and non-structural)
- Wood flooring
- Trim
- Cabinets & Vanities
- Brick
- Pavers
- Roofing Tiles
- Doors
- Fireplace mantels
- Countertops
- *Windows
- *Fixtures
- *Appliances

**Reuse if they meet code or recycle.*

Benefits of design for disassembly and building adaptation include reducing a building's life cycle environmental impacts, minimizing waste, reducing costs, and supporting the local economy and jobs.

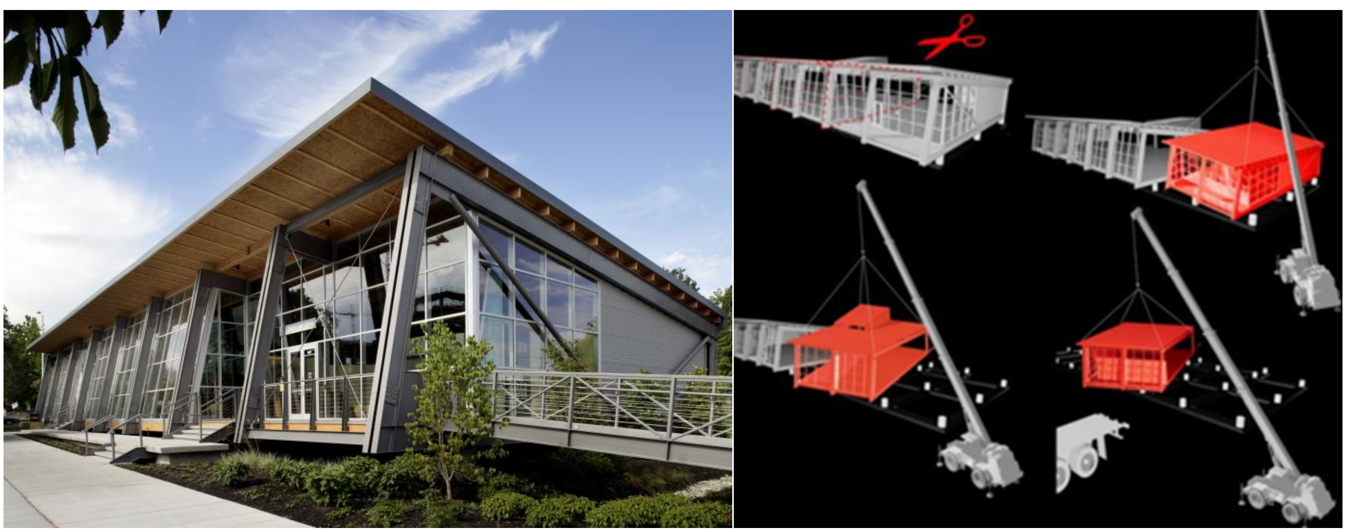

Figure 13. The South Lake Union Discovery Center in Seattle was designed for future transportation, reassembly, and reuse in a new location. The building separates at three integrated joints to break into four modules that can be moved on trucks by streets (not freeways). The building sits lightly on the land atop short concrete piers, allowing the grade and vegetation to run uninterrupted beneath. Gangway ramps with hinged joints can adapt to the topography of future locations (The Miller Hull Partnership).

Ten Key Principles for Design for Disassembly

1. Document materials and methods for deconstruction. As-built drawings, labeling of connections and materials, and a deconstruction plan in the design specifications all contribute to efficient disassembly and deconstruction.

2. Select materials using the precautionary principle. High-quality materials that are chosen with consideration for future impacts will retain value and/or be more feasible for reuse and recycling.

3. Design connections that are accessible. Visually, physically, and ergonomically accessible connections will increase efficiency and avoid requirements for expensive equipment or extensive environmental health and safety protections for workers.

4. Minimize or eliminate chemical connections. Binders, sealers, and glues on or in materials make them difficult to separate and recycle, as well as increase the potential for negative human and ecological health impacts from their use.

5. Use bolted, screwed, and nailed connections. Using standard and limited palettes of connectors will decrease tool needs, as well as time and effort to switch between tools.

6. Separate mechanical, electrical, and plumbing systems. Disentangling these systems from the assemblies that host them makes it easier to separate components and materials for repair, replacement, reuse, and recycling.

7. Design to the worker and labor of separation. Creating human-scale components or making components easy to remove by standard mechanical equipment will decrease labor intensity and increase the ability to incorporate a variety of skill levels.

8. Simplicity of structure and form. Simple open-span structural systems and forms, as well as standard dimensional grids, will allow for ease of construction and deconstruction in increments.

9. Interchangeability. Using materials and systems that exhibit principles of modularity, independence, and standardization will facilitate reuse.

10. Safe deconstruction. Allowing for movement and safety of workers, equipment and site access, and ease of materials flow will make renovation and disassembly more economical and reduce risk.

Source: City of Seattle, King County, Hamer Center for Community Design, Pennsylvania State University. *Design for Disassembly in the Built Environment: A Guide to Closed Loop Design and Building.* https://kingcounty.gov/~/media/depts/dnrp/solid-waste/green-building/documents/Design_for_Disassembly-guide.ashx?la=en.

Adaptation

Designing buildings to adapt to increasingly frequent and intense disasters can help reduce debris and their impacts post-disaster.

Indigenous Resilient Design

Examples of adaptable infrastructure can be found in Indigenous communities. The survival of many cultural traditions, including those practiced by Tribes and Indigenous nations, depend on safe access to raw materials found in nature. Because cultural traditions relied on the availability of natural resources, many tribal societies focused on developing building designs and practices that would endure for future generations. Traditionally, tribal nations built structures using local resources, without benefit of written codes or modern machinery. These structures were safe, strong, and energy and water efficient. Indigenous Resilient Design provides a framework for how communities can create infrastructure that is adaptable, ecofriendly, and enduring.

The National Institute of Health's *Environmental Health Perspectives* article entitled, "Healthier Tribal Housing: Combining the Best of Old and New," provides an overview of the environmental and health benefits of modern adaptations of indigenous building materials and designs. The article explains the use and reuse of locally sourced materials and green design elements to build homes that can adapt and respond to local climates.[13]

For example, earth lodges were a common form of shelter built by American Indians, particularly by the Great Plains and Eastern Woodlands tribes. These underground or semi-underground shelters, partially or completely covered with earth, were usually circular or elongated round structures with a dome-like roof. They provided excellent shelter from high winds and extreme temperatures.[14]

Other Examples of American Indian Resilient Design

The Sustainable Native Communities Collaborative, with funding from the U.S. Department of Housing and Urban Development (HUD), produced case studies of traditional and local materials used in tribal building projects:

- Navajo Nation Elder Hogan Homes combined traditional design with low-tech, tribally sourced materials, including straw bales from the Navajo Agricultural Products Industry, FlexCrete (Navajo-owned, lightweight, energy-efficient aerated concrete panels), and other high-performance materials for durable, low-impact, culturally accurate housing.[15]

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[13] NIH. (2012). *Healthier Tribal Housing: Combining the Best of Old and New.* https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3548302/.

[14] New World Encyclopedia. (2017). *Earth Lodge*. https://www.newworldencyclopedia.org/p/index.php?title=Earth_lodge&oldid=1006962.

[15] Sustainable Native Communities Collaborative. (n.d.). *Elder Hogan Homes.* https://roadmap.sustainablenativecommunities.org/wp-content/uploads/2015/09/17_cs_hud_elder_hogan_homes.pdf.

Figure 14. Left: Interior of a finished Elder Hogan home (Photo: Harry Connolly). Right: Construction of straw bale exterior walls (Photo: Nathaniel Corum). Photos used with permission from Sustainable Native Communities Collaborative.

- Apsaalooke (Crow) Tribe Good Earth Lodges use insulated and compressed earth block walls, other energy-efficient materials, and passive solar design to create durable, healthy homes in Montana's harsh climate.[16]
- The Ohkay Owingeh Owe'neh Bupingeh project in the northern New Mexico pueblo of Ohkay Owingeh was a culturally accurate housing rehabilitation program that included research into traditional materials and techniques, education and training, sourcing of local materials, and restoration of adobe housing in the village that has been occupied for at least 700 years. The work included using earthen plasters, restoring traditional roof *vigas* (round wood beams), and reusing the materials from unstable adobe walls that were torn down and replaced in the earthen plaster. The project also included energy upgrades, such as insulation and better windows.[17]
- The Pinoleville Pomo Nation Homes project near Ukiah, California built two earthen-plastered straw bale homes designed through a collaborative community design-build process with technical assistance from the University of California, Berkeley. The homes incorporate culturally accurate design features, natural finishes, locally harvested timbers, and energy and water efficient design.[18]

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[16] Sustainable Native Communities Collaborative. (n.d.). *Good Earth Lodges.* https://roadmap.sustainablenativecommunities.org/wp-content/uploads/2015/09/13_cs_hud_good_earth_lodges.pdf.

[17] Sustainable Native Communities Collaborative. (n.d.). *Owe'Neh Bupingeh.* https://roadmap.sustainablenativecommunities.org/wp-content/uploads/2015/09/16_cs_hud_owe_neh_bupingeh.pdf.

[18] Sustainable Native Communities Collaborative. (n.d.). *Pinoleville Pomo Nation Homes*. https://roadmap.sustainablenativecommunities.org/wp-content/uploads/2015/09/07_cs_hud_pinoleville_pomo_nation_homes.pdf.

Figure 15. Left: Homes constructed for the Pinoleville Pomo Nation Homes project. Right: Applying earth plaster on an interior wall. Photos used with permission from Sustainable Native Communities Collaborative.

1.1.3. Retrofit and Upgrade Buildings

Below are some example strategies and techniques for retrofitting existing houses and buildings to improve their resilience to different natural hazards and disasters, as well as example funding strategies and incentives.

Storm and High Wind Event Preparedness

Doors and Windows

- **Install temporary or permanent storm doors and impact resistant windows and shutters** ahead of a high-wind event.
- **Ensure external doors and windows open outward** to resist being blown open in high winds. When doors or windows blow open and allow rain into buildings, increased interior pressure can contribute to roof and wall failures and cause mold issues.

Walls, Roofs, Garage Doors, and Gutters

- **Install lateral bracing to reinforce gable end walls** (i.e., the triangular portion of a wall between the edges of intersecting roof pitches). Gable end wall failure is one of the most common types of damage caused by hurricanes (Figure 16).
- **Strengthen roof-to-wall connections** by using a combination of straps to transfer uplift from the trusses or rafters through the double top plate and into the wall studs. This technique can help tie the roof to the foundation and support high-wind structural integrity.
- **Install secondary water barriers** with a water-resistant layer or a roof underlayment layer or product on the roof deck under the roofing to protect against water intrusion and associated moisture or mold damage.
- **Install additional bracing systems** (e.g., heavy-duty hinges and bars) on the inside of a garage door to reinforce it from high winds.
- **Design gutters to resist wind upload** by ensuring the roof edge flashing does not extend into the gutter, lift up due to high winds, or peel off the roofing and roofing membrane.
- **Use appropriate fastener size, spacing, and type** for wall cladding, roofing, vents, HVAC equipment, windows, and doors. Decisions should be governed by code requirements, design wind speeds, and wind pressure variation considerations.

Figure 16. Top: Gable end wall failure occurs when walls lose support along the top edge; as a result, sheathing is blown off, causing the walls to fall inward or outward (South Carolina Department of Insurance). Middle: Integral gutters on a roof will not be torn away from the structure during a high-wind event (FEMA). Bottom: Storm shutters installed over doors and windows on a residence (Photo by Dave Gatley / FEMA).

Flood Preparedness

Design for Water

- **Build with materials that can get wet and easily dry,** like concrete, brick, and ceramic tile.
- **Design basement or lowest floor walls in flood hazard areas with breakaway walls, openings, or automatic vents.** These features allow equalization of water levels and pressures on walls and foundations, preventing structural damage from floodwater flowing under the building.

Protect Utilities

- **Raise HVAC and electrical systems above anticipated flood levels** or protect them from floodwater. Elevating equipment can decrease equipment damage, the time and cost needed to re-start the systems, and building damage caused by extreme temperatures or a lack of ventilation after an event.
- **Install backflow prevention valves** for sanitary sewer lines and floor drains.

Flood Barriers

- **Add flood barriers,** such as bottom tracks or floor barriers to door and window frames and other vulnerable openings, to ensure a weathertight seal. Residential flood barriers include systems to seal entry and garage doors, crawlspace vents, basement windows, and exterior stairs.

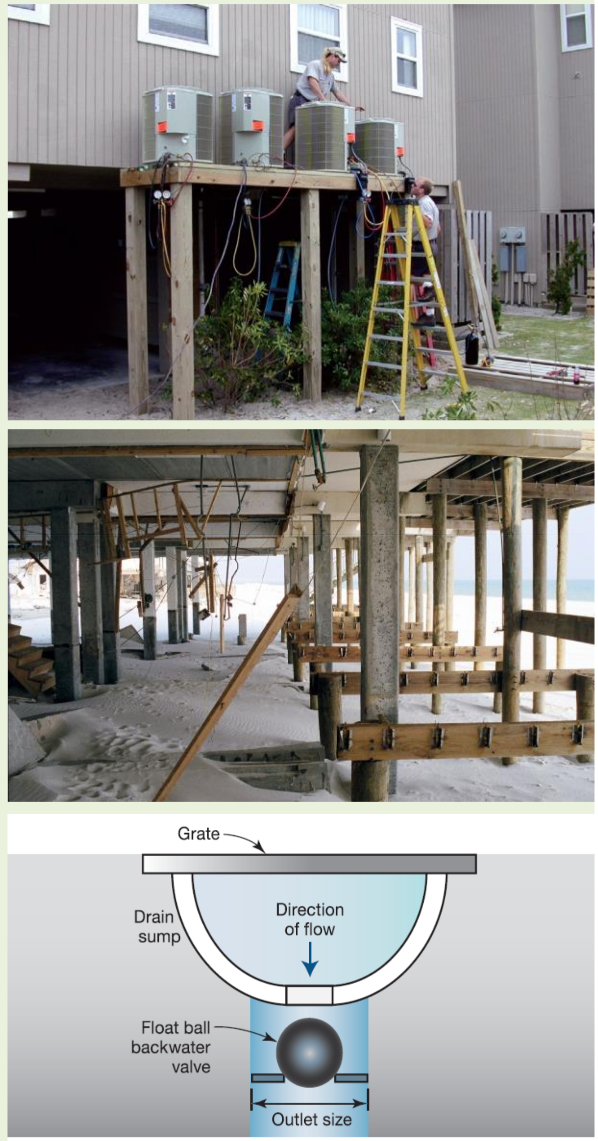

Figure 17. Top: Elevated air conditioning compressors (FEMA's Home Builder's Guide to Coastal Construction). Middle: The underside of an elevated V Zone building after Hurricane Ivan. The breakaway walls underneath the building broke away as intended during the hurricane, and the structure remained standing. (FEMA's Design and Construction Guidance for Breakaway Walls). Bottom: Floor drain with ball float check valve (FEMA's Protecting Building Utility Systems from Flood Damage).

Fire Preparedness

Roofing and Attic Vents

- **Install Class A roofing** (i.e., highest resistance to fire) and fire-resistant building materials. Plug gaps, such as gaps that occur in some clay or cement tile roofs at the ridge and at the lower roof edge, with a non-combustible material.
- **Avoid or retrofit roof vents and gutters to reduce fire risk**. Vents can allow embers and high heat to enter roofs and eaves. All external vents should be screened with 1/8-inch or 1/16-inch metal mesh.

Gutters

- **Cover roof gutters** with screens or other devices to keep debris, including flammable debris and embers, from accumulating. Remove debris that does accumulate.
- **Install flashing** (i.e., thin, impervious sheets of material placed in construction to prevent water penetration or direct the flow of water) that fully covers the edge of the roof sheathing (i.e., sheet or board material, such as plywood or particle board, connected to the roof rafters to act as a base for shingles or other roof coverings) and flammable fascia (i.e., board or band at the outside vertical surface of a building) near gutters.

Windows

- **Install fire-resistant windows and shutters.** Dual-pane windows, with at least one pane of tempered glass, offer greater fire protection. Shutters or window covers of plywood can be installed when needed and can also protect windows from external fire heat.

External surfaces

- **Choose non-combustible exterior walls.** Masonry, cement stucco, and fiber-cement siding are examples of good exterior wall finishes in fire-prone areas.
- **Ensure deck surfaces adjacent to or connected to buildings are ignition-resistant,** such as lightweight concrete.
- **Choose non-combustible fencing products** in wildfire prone areas.

Figure 18. Top: Ceramic tile roofing is a best practice to mitigate embers from igniting the roof structure. This home was protected by its ceramic roof during the Valley Fire in Middletown, California (Adam Dubrowa / FEMA). Middle: FEMA graphic on the importance of clearing gutters (FEMA). Bottom: Home in New Mexico that incorporates fire safety measures, such as metal roofs and exterior doors, adobe and stucco exteriors, and defensible space (FEMA).

Earthquake Preparedness

Note: Seismic structural upgrades typically require engineering assessment and vary greatly between sites and buildings.

Structural and Nonstructural Features

- **Strengthen unreinforced masonry** and loadbearing walls, such as by using galvanized steel wire ladder or truss laid in the mortar between courses of brick or block.
- **Strengthen foundation-to-wall and wall-to-roof connections** (more information in the section above on *Storm and High-Wind Event Preparedness*).
- **Strengthen cripple walls,** which enclose the crawl space under the first floor in older wood-framed buildings. Anchor plywood to the interior face of the cripple wall, as well as to the sill plate below the foundation, to increase wall strength.
- **Add shear walls** (i.e., braced panels) or steel frames to strengthen multistory buildings.
- **Install engineered tie-down systems** for manufactured housing.
- **Add seismic restraints** to heavy mechanical equipment, water heaters, and appliances.

Additional resources to help with earthquake preparedness are below:

- **The California Seismic Safety Commission's *Homeowner's Guide to Earthquake Safety*** provides guidance on residential building earthquake safety. For more information, visit https://ssc.ca.gov/wp-content/uploads/sites/9/2020/08/20-01_hog.pdf.
- **FEMA's *Best Practices Stories: South Napa Earthquake*** documents best practices from the August 2014 earthquake in Napa, California, such as documenting the investment value of code-related seismic retrofits, National Flood Insurance Program Community Rating System flood insurance discounts, successful retrofits that saved historic buildings, and creative funding for repairs and upgrades.
For more information, visit https://cupdf.com/document/best-practices-stories-south-napa-earthquake-dr-1493-best-24-8-2014-best.html?page=2.

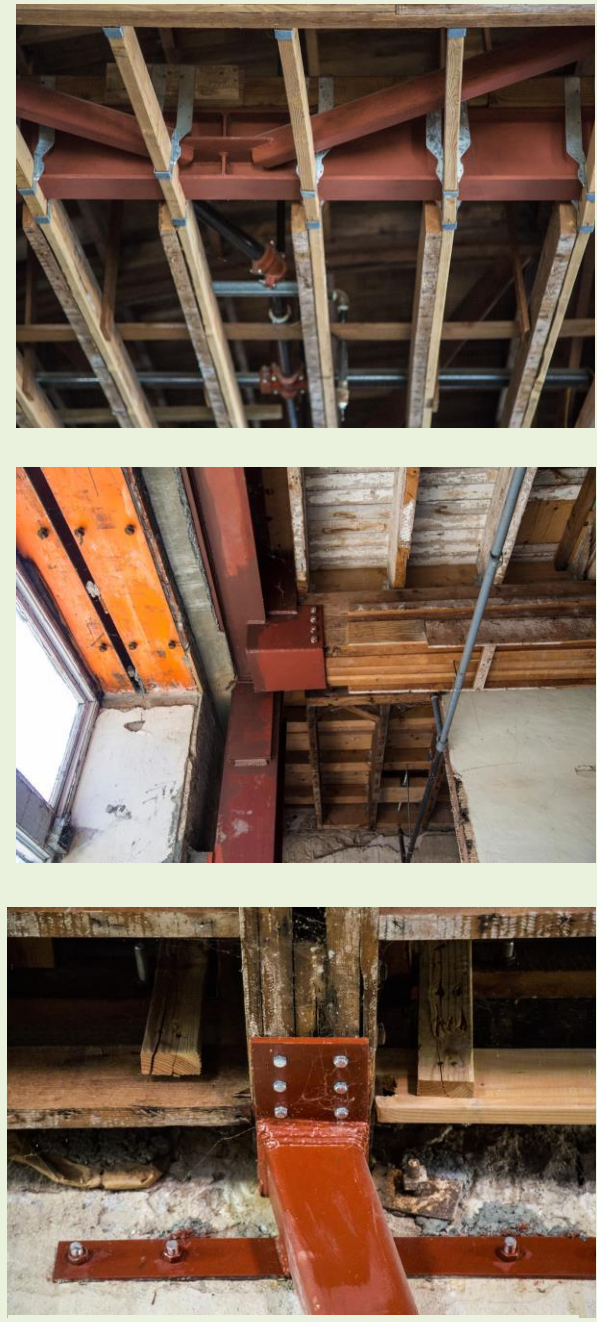

Figure 19. Photos of a secondary steel structural support inside the historic Borreo Building on Third Street in the city of Napa, California, which survived a magnitude 6.0 earthquake on August 24, 2014, with minor damage (Christopher Mardorf / FEMA).

Example Funding Strategies and Incentives

Communities have used a wide range of funding strategies and incentives to promote resilient and adaptable building retrofits, including:

Strategies and Incentives	Examples
Tax Credits, Transfer Taxes, and Property-Assessed Financing	• *South Carolina Department of Insurance SC Safe Home Program* uses a multifaceted approach with tax credits for fortification retrofits to increase structural resilience (e.g., roof-to-wall connections, brace gable ends, secondary water barriers) and education.[19] • *City of Berkeley Real Property Transfer Tax to Seismic Retrofit Refund* imposes a 1.5 percent property transfer tax on all sales or transfers of property, one-third of which is available as a refund for use within one year for voluntary eligible seismic upgrades. • *City of San Francisco Property Assessed Clean Energy* financing program helps property owners finance seismic upgrades and environmentally conscious building improvements through a property tax assessment backed by municipal bonds paid through an addition to the regular property tax bill. The program provides 100 percent financing, including permits, design, and inspections, for seismic improvements complying with the Soft Story Mandatory Retrofit Program.
Historic Building Restoration	• *Restore Oregon's Resilient Masonry Buildings: Saving Lives, Livelihoods, and the Livability of Oregon's Historic Buildings* documents the risks, obstacles, and planning for resilient historic restorations.[20]
Insurance Incentive Program	• *FEMA's Community Rating System* is a voluntary incentive program encouraging communities to exceed the National Flood Insurance Program's (NFIP's) minimum requirements, resulting in a communitywide discount in flood insurance premiums. Solano County, California, provides a case study of the benefits from updating their multi-hazard mitigation plan, including communities reaching a higher rating on NFIP's Community Rating System and a lower premium rate for homeowners. [21]

[19] South Carolina Department of Insurance. (n.d.). *Brochures & Tools*. https://doi.sc.gov/620/Brochures-Tools.

[20] Restore Oregon. (2012). *Resilient Masonry Buildings*. http://restoreoregon.org/wp-content/uploads/2016/03/UPDATED-RO-Special-Report-Masonry-Bldgs-Final_web.pdf.

[21] FEMA. (n.d.). *Best Practices Stories: South Napa Earthquake, DR-1493-CA*. https://cupdf.com/document/best-practices-stories-south-napa-earthquake-dr-1493-best-24-8-2014-best.html?page=2.

1.1.4. Building Codes and Standards

Building codes and standards establish a basic set of minimum requirements for performance and safety of buildings and facilities. Although codes generally address specific types of hazards, their focus has historically been on life safety, rather than sustainability or resilience. In some cases, and especially due to climate change, resilience planning is essential to ensure safety and protect life.

In 2022, FEMA launched a Building Codes Strategy to advance the adoption and enforcement of hazard-resistant building codes and standards for FEMA programs. The strategy promotes integrating building codes and standards across FEMA, strengthening nationwide capability and expertise, and driving public action.[22] In addition, the White House announced a National Initiative to Advance Building Codes to help communities adopt the latest building codes and standards to help them increase their resilience to extreme weather events that are intensifying due to climate change.[23]

The International Code Council (ICC) develops the most widely used model building codes throughout the United States. Chapter 3 of the *ICC Performance Code for Buildings and Facilities* provides "a framework to establish minimum levels to which buildings or facilities should perform when subjected to events such as fires and natural hazards." The minimum levels established by this chapter are based on the risks associated with "the use of the building or facility, the intended function of the building or facility and the importance of the building or facility to a community."

ICC recommends higher building standards for buildings with potentially large occupancies, such as schools; power, water, and wastewater facilities; buildings containing significant quantities of hazardous materials; and hospitals, health care, and emergency care facilities. These codes can be applied to other types of buildings, including residential buildings, to provide more resilient performance in disasters.[24] Other code resources include:

- The *International Green Construction Code*, which contains provisions for more sustainable and resilient commercial buildings.[25]
- *State of Georgia's Construction Codes* include two "permissive" code appendices ("R" and "N") for residential and commercial disaster resilient construction, respectively.

[22] FEMA. (2022). *Building Codes Strategy.* https://www.fema.gov/emergency-managers/risk-management/building-science/building-codes-strategy.

[23] The White House (2022), *National Initiative to Advance Building Codes*. https://www.whitehouse.gov/briefing-room/statements-releases/2022/06/01/fact-sheet-biden-harris-administration-launches-initiative-to-modernize-building-codes-improve-climate-resilience-and-reduce-energy-costs/.

[24] International Code Council (ICC). (2018). *2018 ICC Performance Code for Buildings and Facilities.* https://codes.iccsafe.org/content/ICCPC2018/effective-use-of-the-international-code-council-performance-code-for-buildings-and-facilities.

[25] ICC. (2018). *International Green Construction Code.* https://www.iccsafe.org/products-and-services/i-codes/2018-i-codes/igcc/.

These *Disaster Resilient Building Code* Appendices are optional regulations relating to hurricane, flood, and tornado damage and disasters.[26]

- Oregon's 2017 *Residential Specialty Code* allows the reuse of residential framing lumber that is not damaged or cracked, which can reduce waste and support post-disaster rebuilding efforts.[27]

Building codes and guidelines can advance disaster resilient building practices. State and local governments in regions with more severe and/or more frequent hazard events sometimes enact stricter requirements than model building codes. One example is more stringent earthquake requirements in California.

Other disaster-specific examples include:

- **Flooding and High Winds.** The state of Georgia has a Permissive Disaster Resilient Building Code. Provisions, which local jurisdictions must adopt to enforce them, promote enhanced public health, safety, and general welfare in order to reduce public and private property losses due to hazards and natural disasters associated with flooding, high winds, and windborne debris.

- **High Winds.** The city of Moore, Oklahoma, has building codes for wind resistance.[28] Following a devastating tornado outbreak in 2013, the city of Moore modified their building codes to incorporate more stringent building practices for homes to be built to withstand winds of 135 miles per hour (mph). The new research-based code provisions address roof sheathing and nailing, maximum 16-inch spacing for roof and exterior wall framing, hurricane clips or framing anchors on all roof framing connections, structural sheathing and bracing for gable end walls, continuous plywood bracing, wind-resistant garage doors, and other requirements.

- **Tsunamis.** The 2015 and 2018 editions of the International Building Code (IBC) Appendix M Tsunami-Generated Flood Hazard provisions[29] make tsunamis a required consideration in planning, siting, and design of coastal structures in the five western states subject to tsunamis.

- **Hurricanes.** After the devastating impacts from Hurricane Andrew in 1992, the state of Florida established some of the most stringent storm-specific building codes in the United States. Miami-Dade County adopted the new building codes, which includes

[26] State of Georgia. (n.d.). Construction Codes. https://www.dca.ga.gov/local-government-assistance/construction-codes-industrialized-buildings/construction-codes.

[27] State of Oregon. (2021). *Oregon Residential Specialty Code*. https://codes.iccsafe.org/content/ORRSC2021P1/copyright.

[28] City of Moore, OK. (2014). *Ordinance No. 768 (14)*. https://s3-us-west-2.amazonaws.com/municipalcodeonline.com-new/moore/ordinances/documents/1601324422_Ordinance%20No.%20768%20(14).pdf.

[29] ICC. (2018). 2018 *IBC Appendix M, Tsunami-Generated Flood Hazard*. https://codes.iccsafe.org/content/IBC2018/appendix-m-tsunami-generated-flood-hazard?site_type=public.

product approvals for construction materials, an updated safety inspection program, and trainings. [30]

- **Performance-Based Codes.** Innovative performance-based codes, such as those referenced in the National Institute of Building Sciences High Performance Building Council's *National Performance Based Design Guide*, can support resilient design and construction of new facilities and major repairs and alterations of existing buildings.[31]

Wildfire Protection Activities

A 2015 survey, conducted by the University of Oregon, looked at specific actions to improve wildfire preparation across the western United States. The 116 community respondents, across 70 communities (including 52 counties), answered questions regarding specific wildlife protection activities that have been or were being conducted in their county. The chart below depicts county survey results on the rates of community adoption of wildfire planning and preparation activities and shows wildfire-related building codes or design standards were the top wildfire planning and preparation activities, used by 55 percent of counties surveyed.

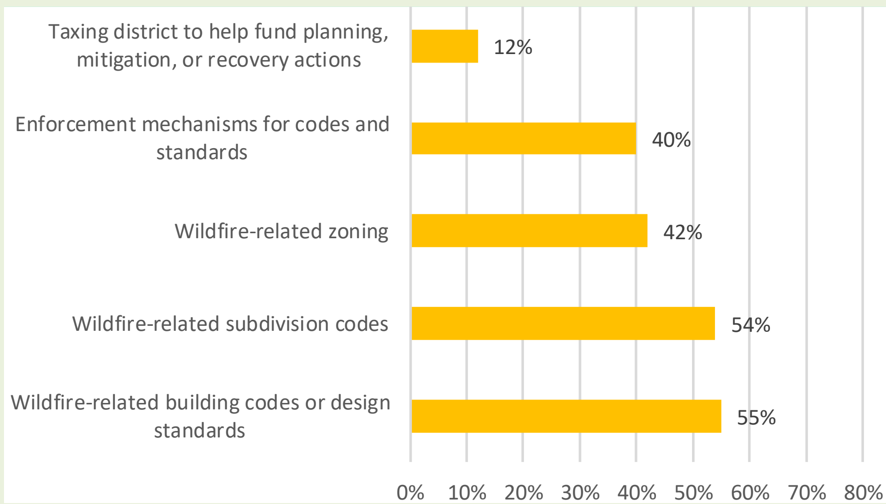

Figure 20. Examples of wildfire planning and preparation activities performed by counties in the western United States.[32]

1.2. In Anticipation of Impending Natural Disasters

Preparing for disasters, even on short notice, can reduce the disaster's impacts on people and communities, reduce disaster debris, and support faster and less costly recovery. The tips below on disaster preparedness – both imminent and longer term – are excerpted from the

[30] *Overview of the Florida Building Code* (n.d.). https://www.floridahousing.org/docs/default-source/aboutflorida/august2017/august2017/tab4.pdf. City of Miami, FL. (2024). About the Building Department. https://www.miami.gov/Building-3/About-the-Building-Department?transfer=abd7e227-6f2f-4406-81ed-05875a2840f1.

[31] National Institute of Building Sciences. (2014). *National Performance Based Design Guide*. https://www.wbdg.org/pbdg/.

[32] University of Oregon. (2015). *Community Experiences with Wildfire: Actions, Effectiveness, Impacts, and Trends*. https://scholarsbank.uoregon.edu/xmlui/bitstream/handle/1794/19162/WP_56.pdf?sequence=1&isAllowed=y.

following guides developed by FEMA: *Protect Your Property from High Winds,*[33] *Be Prepared for a Flood,*[34] *Avoiding Wildfire Damage: A Checklist for Homeowners,*[35] and *Earthquake Safety at Home.*[36]

Disaster	Actions That Can Be Taken
High Wind Events	• Inspect roofing for loose shingles or flashing (thin metal material that directs water away from certain roof areas). • Trim dead branches, remove dead trees, and properly manage the removed material. • Remove or tie down objects, furniture, toys, and materials stored outdoors that could become windblown. • Cover and secure windows and doors (e.g., with protective shutters). • Properly anchor small outbuildings (e.g., sheds, playhouses) with straps or ground anchors.
Floods	• Keep storm drains on and around property clear of debris and vegetation. • Clean gutters and roof drains. • In flood-prone areas, keep sandbags and other flood protection materials on-hand to put around buildings. • Remove or tie down outdoor objects like furniture and propane tanks. • Install sump pumps with battery backup in basements or belowground rooms. • If floodwater is imminent, turn off gas, water, and electricity, if this can be done safely.
Fires	• Remove dead or diseased trees and trim limbs, grass, and vegetation away from buildings. • Replace highly flammable vegetation, such as pine, evergreen, eucalyptus, junipers, and fir trees, with low-growing ground cover and less flammable species. • Clear roof and gutters of leaves. • Use fire-safe landscaping and fire-resistant building materials (e.g., metal roofs and stucco).

[33] FEMA. (2011). *Protect Your Property from Severe Winds*. https://www.fema.gov/sites/default/files/2020-11/fema_protect-your-property_severe-wind.pdf.

[34] FEMA. (2014). *Be Prepared for a Flood*. https://www.ready.gov/sites/default/files/2020-03/flood_information-sheet.pdf.

[35] FEMA. (n.d.). *Avoiding Wildfire Damage: A Checklist for Homeowners*. https://www.fema.gov/pdf/hazard/wildfire/wdfrdam.pdf.

[36] FEMA. (2020). *Earthquake Safety at Home*. https://www.fema.gov/sites/default/files/2020-08/fema_earthquakes_fema-p-530-earthquake-safety-at-home-march-2020.pdf.

Disaster	Actions That Can Be Taken
Earthquakes	• Replace rigid gas line connections with flexible ones where they enter the building or connect to appliances. • Install seismic gas shutoff valves. • Identify and secure potentially dangerous objects (e.g., heavy furniture, office equipment, filing cabinets, shelving) by strapping or attaching them to walls to prevent them from falling. • Secure (e.g., install restraining wires, strips, or other mechanisms) hazardous chemicals to prevent them from falling and spilling. • Replace magnetic latches on cabinet doors with mechanical latches designed to assure they remain closed during severe shaking.

1.3. After Natural Disasters

After a natural disaster, communities may need to manage disaster debris from any damaged buildings and repair and rebuild. Planning can facilitate the management of debris and post-disaster rebuilding and should begin as soon as possible, even before a natural disaster occurs, if possible.[37] EPA developed an online All Hazards Waste Management Planning Tool, available at https://wasteplan.epa.gov/welcome, to help communities create or update a comprehensive disaster debris management plan for managing materials and wastes generated from disasters. Rebuilding in the recovery phase after a disaster is an opportunity to make the community more resilient for the next disaster.

To further support a circular economy, rebuilding efforts can potentially incorporate building materials recovered following the disaster to repair or rebuild structures. Coordinating and collaborating with interested parties ahead of disasters is essential to support planning and the safe reuse and recycling of building materials during response and recovery. In addition to the communities themselves, these interested parties include disaster planners, emergency responders, recovery experts, community organization members, builders, building officials, and solid and hazardous waste professionals, such as deconstruction, reuse, recycling, composting, and state and local solid waste departments and environmental agencies.

Planning for disaster debris and rebuilding can also help foster the empowerment and participation of communities with environmental justice concerns by creating opportunities for social and economic inclusion and innovation, as communities with environmental justice concerns are often left behind or left out of these conversations. Including them in decision-making processes can ensure the alignment of circular economy solutions with local needs and preferences. Communities should also consider the potential trade-offs and environmental justice challenges, such as the displacement, exclusion, or exploitation of overburdened communities, and unintended consequences or rebound effects of circular solutions. Education and training programs can also equip communities with environmental justice concerns with

[37] EPA. (2019). *Planning for Natural Disaster Debris*. https://www.epa.gov/homeland-security-waste/guidance-about-planning-natural-disaster-debris.

the skills and knowledge to access and benefit from the circular economy and contribute to its development.

1.3.1. Planning for Resilience and Waste Reduction

Through planning, communities can determine how they can rebuild more resiliently and sustainably after a disaster. Planning efforts should include the best practices and strategies discussed in Section 1.1. for new and existing buildings and should incorporate lessons learned in past events. Planning efforts should also include plans to implement resilient building codes and standards in order to generate less debris from natural disasters in the future.

Waste Reduction at Disaster Response Camps

Planning for waste reduction is critical when anticipating natural disasters. An example where post-disaster recovery planning occurs is at disaster response camps, which are temporary command posts where emergency responders and firefighters coordinate initial emergency response and firefighting activities, spend their off time, eat, and sleep. They are typically self-contained mini-cities that are set up in less than a day.

Figure 21. Aerial view of a Forest Service fire camp (Alan Dyck / U.S. Forest Service, https://www.nrel.gov/news/features/2016/forest-service-turns-to-nrel-for-help-fighting-fires-more-sustainably-1.html).

The U.S. Department of Agriculture (USDA) Forest Service National Greening Fire Team (GFT), winner of an EPA Federal Green Challenge Innovation award, established a vision of achieving net zero waste, water, and energy at all large fire incidents by 2030 and a mission of integrating sustainable operations best management practices into the fire community. USDA has also issued guidance to reduce overall use of financial and natural resources without compromising safety or impeding incident operations.

The GFT team researched, recommended, and assisted with implementing sustainability best management practices in incident operations in addition to:

- Releasing a “Sustainable Operations in Incident Management—Preparing for the 2019 Fire Season” memo for senior leadership.
- Establishing a public-facing website, quarterly bulletin, webinar series, and Ambassador Program to increase awareness of GFT’s mission and to advance application of its deliverables.
- Executing an **Onsite Incident Recycling Blanket Purchase Agreement (BPA)** - or contract -spanning four Geographic Area Coordination Centers covering Arizona, New Mexico, California, Oregon, and Washington.

Figure 22. Recycling station at a U.S. Forest Service fire camp.

The three-year BPA was ordered on nine fires in 2019 to:

- Standardize recycling equipment, signs, processes, and expectations so fire camp personnel have a similar recycling experience on each camp, increasing efficacy and engagement.
- Assure incident management teams that waste diversion services at fire camps would improve waste management practices with less strain on in-house personnel.
- Standardize waste diversion reporting to capture and communicate waste reduction and recycling results to achieve compliance with waste reduction directives, executive orders, and laws.

The BPA has cut waste hauling costs by 50 to 80 percent, with a cost savings of up to $18,000 per week, while conserving resources and reducing local community landfill impacts.

Specific fire camp zero waste recommendations included:

- Use bulk water whenever possible. Bottled water costs more money and depletes resources.
- Recycle as much as possible while at fire camp.
- Reduce food waste. When food goes to landfills, it rots and produces methane, a greenhouse gas with 25 times the global warming potential compared to carbon dioxide over a 100-year period.
- Avoid unnecessary vehicle idling in fire camps, which creates unnecessary pollution. Firefighters take precautions to protect their lungs on the fire line; the same should be done where they sleep and eat.

Forest Service Greening Fire Team Website
https://www.fs.usda.gov/managing-land/fire/sustainable-ops

Contract/Blanket Purchase Agreement Information:
https://www.fs.usda.gov/managing-land/fire/sustainable-ops/incident-recycling

For debris that is generated, debris management plans should document how debris will be safely and sustainably managed and waste will be reduced. These plans should also cover activities, such as:

- **Collection, temporary storage, and safe management of household and other hazardous waste** and waste with hazardous or harmful components, potentially including electronics.
- **Segregation of materials for safe reuse and recycling**, including concrete and asphalt recycling, and mulching or composting of clean unpainted lumber and vegetative debris.
- **Tracking and the documentation of debris managed in different ways, including through reuse, recycling, mulching, composting and disposal,** as well as quantities, revenues, and costs.
- **Planning and contracting with local or regional haulers, equipment operators, recyclers, and other contractors** capable of storing, collecting, transporting, and processing disaster debris.
- **Collection of information on key contacts and established networks** of disaster experts, training professionals, and community organizations.
- **Certification procedures and documentation** for qualified disaster recovery personnel.

To effectively adapt strategies over time, a disaster recovery phase review and assessment should be included in the planning process. This will support continuous learning and communicating lessons learned with other communities and interested parties.

1.3.2. Using Salvaged Materials

A circular economy is supported by buildings that are not only designed for disassembly and adaptation, but also by buildings that can be converted into stocks of materials or “material banks” of resources for rebuilding, repairs, and upgrades. Using building materials recovered following a disaster to repair or rebuild structures or to build disaster response sheds to securely store response workers’ belongings and supplies can reduce both environmental impacts and costs of rebuilding. For example, clean, undamaged lumber can be reused, and damaged concrete can be used as base, such as crushed aggregate material, in accordance with all applicable codes and regulations. This reduces the environmental impacts of building material production, transportation, and disposal, as well as the need to buy new lumber or base material. This approach reduces waste and the embodied carbon emissions to manufacture and transport building materials, which has been recognized by the U.S. General

Services Administration (GSA) and building industry leaders as the next big sustainability opportunity.[38]

The U.S. Environmental Protection Agency (EPA) is working to advance the data quality, standardization, and disclosure of embodied carbon emissions associated with construction materials and products. EPA is supporting material manufacturers and coordinating with other federal agencies to develop robust data, tools, standards, and policies that facilitate procurement of substantially lower embodied carbon materials and drive market change. In addition to grants that support development of Environmental Product Declarations (EPDs) that disclose the environmental impacts of materials, EPA is also developing a Carbon Labeling Program that will include only materials that meet stringent requirements in demonstrating they are lower in embodied carbon compared to industry averages.

EPA is initially focusing efforts on traditionally carbon intensive materials, such as steel, concrete, glass, and asphalt, that are common in the built environment and a large percentage of federal construction expenditures. EPA is also prioritizing salvage and reuse of construction materials to support a more circular economy. Since reusing materials largely avoids the production impacts associated with virgin materials, reuse has the potential to drastically reduce embodied carbon.

When entire structures cannot be rebuilt, opportunities to deconstruct and salvage building materials exist. For example, in Alachua County, Florida, a home located in a floodplain was deconstructed as part of a FEMA-funded buyout and the lumber was used to rebuild HUD Section 8 affordable housing inland using current building codes.[39]

Figure 23. Panelized deconstruction was used to deconstruct a home in a floodplain buyout in Alachua County, Florida, and the lumber was used to build new Section 8 affordable housing inland (Brad Guy).

[38] Memorandum for Heads of Executive Departments and Agencies. (2023). Advancing Climate Resilience through Climate-Smart Infrastructure Investments and Implementation Guidance for the Disaster Resiliency Planning Act. https://www.whitehouse.gov/wp-content/uploads/2023/11/M-24-03-Advancing-Climate-Resilience-through-Climate-Smart-Infrastructure-Investments.pdf.

[39] Presentation from Brad Guy at EPA's Resiliency and Natural Disaster Debris Workshops. (2021). https://www.epa.gov/homeland-security-waste/resiliency-and-natural-disaster-debris-workshops.

Opportunities to advance large-scale building reuse are growing as communities, such as Portland, Oregon[40] and Palo Alto, California,[41] adopt successful mandatory deconstruction policies, and communities work to find the highest and best use of materials and keep organic material, including wood, out of landfills. GSA's Federal Center South project that used nearly 200,000 board feet of structural and nonstructural lumber from an adjacent warehouse is a great example of reuse at scale. Some green building rating systems have also incorporated credits related to design for deconstruction, adaptation, and flexibility.[42]

Figure 24. The Federal Center South U.S. Army Corps of Engineers Seattle District Headquarters building is a LEED Gold building completed by GSA in 2012, using nearly 200,000 board feet of structural and nonstructural lumber from an adjacent warehouse that was deconstructed (Theresa Blaine, EPA). https://www.zgf.com/work/1136-u-s-general-services-administration-federal-center-south-building-1202.

Climate change hazards, such as sea level rise, will put many buildings that have not yet been damaged in harm's way. Investing in planning, infrastructure, and policies to reclaim those buildings and their valuable materials to rebuild inland is a circular economy opportunity that can both reduce embodied carbon emissions associated with new materials and provide local green building jobs and job training.[43]

After disasters such as hurricanes Katrina and Irene, organizations, including Mercy Corps and the Building Goodness Foundation, safely deconstructed homes to rebuild, repair, and develop disaster recovery sheds.[44] An important outcome for those impacted by the disaster: they

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[40] City of Portland, Oregon. (2022). *Deconstruction*. https://www.portland.gov/bps/climate-action/decon.

[41] City of Palo Alto, California. (2022). *Deconstruction & Construction Materials Management*. https://www.cityofpaloalto.org/Departments/Public-Works/Zero-Waste/Zero-Waste-Requirements-Guidelines/Deconstruction-Construction-Materials-Management.

[42] Lifecycle Building Challenge. (2013). *Rating Systems*. http://www.lifecyclebuilding.org/rating-systems.php.

[43] EPA. (2021). *Resiliency and Natural Disaster Debris Workshop Final Summary Report*. https://www.epa.gov/system/files/documents/2022-03/final-epa-rndd-summary-report_12.02.21_web_508_compliant.pdf.

[44] Denhart, H. (2010). *Deconstructing Disaster: Economic and Environmental Impacts of Deconstruction in Post-Katrina New Orleans*. Resources, Conservation & Recycling, 54(3), 194–204. https://www.sciencedirect.com/science/article/abs/pii/S0921344909001712.

received deconstruction job training, meaningful work, and income, as well as overall help with disaster recovery.[45]

[45] Denhart, H. (2009). *Deconstructing Disaster: Psycho-Social Impact of Building Deconstruction in Post-Katrina New Orleans*. Cities, 26(4), 195-201. https://www.sciencedirect.com/science/article/abs/pii/S0264275109000572.

Section 2. Lessons Learned from Natural Disasters

Lessons learned from community experiences in responding to natural disasters, such as using existing resources, debris segregation, and clear and consistent communication, have all proven to be essential practices in making debris prevention and management as efficient as possible. More information on best management practices based on past disasters is found in EPA's *Planning for Natural Disaster Debris* guide (https://www.epa.gov/homeland-security-waste/guidance-about-planning-natural-disaster-debris). Below are some examples of lessons learned from natural disasters and recommendations for creating more adaptable and resilient buildings and infrastructure.

2.1. Extreme Coastal Storm Events

There has been a substantial increase in the severity and frequency of hurricane and typhoon activity in the Atlantic since the 1980s, and there are more catastrophic typhoons and hurricanes in the Pacific Islands area, including the U.S. territories of Guam, American Samoa, and the Commonwealth of the Northern Mariana Islands, than in any other place on earth.[46]

Climate change impacts are also expanding the range of locations that can experience hurricanes. Increases in the severity and frequency of these storm events will affect buildings and increase exposure and vulnerability, thereby increasing the impacts of these disaster events.[47] Increased debris quantities will be challenging to manage, and damage to buildings and infrastructure will be costly to repair, particularly in rural areas. Without resilient and adaptive building strategies, the negative impacts and costs will continue to rise.[48]

Disaster Example: Typhoon Soudelor, Saipan, Commonwealth of the Northern Mariana Islands

In the summer of 2015, Typhoon Soudelor hit Saipan, an island in the Commonwealth of the Northern Mariana Islands with a population of approximately 48,000 people. It was the strongest typhoon of the 2015 Pacific typhoon season, and it caused severe damage and 40 fatalities in the Pacific

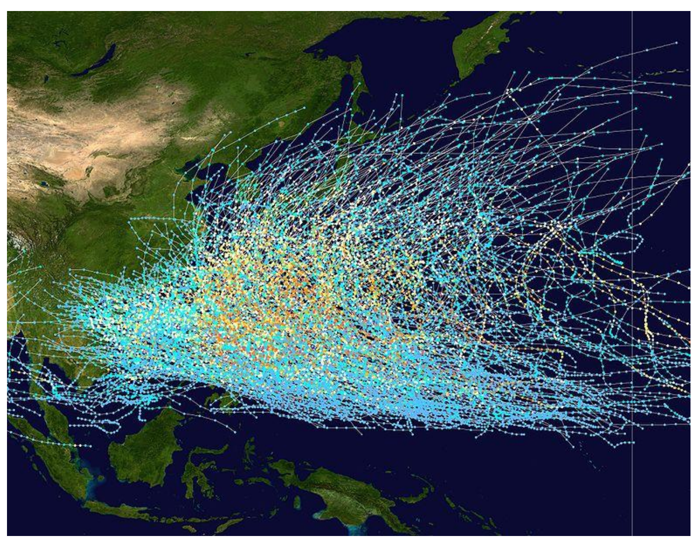

Figure 25. Historical storm tracks in the Pacific Islands area.

[46] National Climate Assessment. (2018). *Fourth National Climate Assessment*. https://nca2018.globalchange.gov/.

[47] Ibid.

[48] Ibid.

Islands and Asia. The Category 5 storm had sustained winds of 130 mph and gusts of more than 160 mph.[49]

Figure 26. Waste caused by Typhoon Soudelor included 733 transformer carcasses and six drums of transformer oil contaminated with polychlorinated biphenyls, or PCBs.

An assessment found that Typhoon Soudelor impacted over 1100 homes. Of this total, almost 600 were completely destroyed or had sustained major damage. About 600 people sought shelter due to damaged homes.[50] On Saipan, all of the homes destroyed or damaged had been constructed using outdated building codes.

In the first few weeks after the storm, almost no municipal power or drinking water were available to island residents, and it took nearly three months for residents to regain basic services. The typhoon destroyed approximately half the island's primary power distribution system. In addition, the island's power plant lost part of its roof and was flooded. The storm also knocked down many trees and 188 utility poles, which damaged 733 transformers and made many roads impassable.

The U.S. Army Corps of Engineers, EPA, the government of Guam, the Guam Power Authority, and other entities provided emergency supplies and restored services. EPA led efforts to safely reuse, recycle, mulch, and dispose of the disaster debris generated.

The local power company, Commonwealth Utilities Corporation, had only 77 replacement power poles and no replacement transformers. Repairs to the electric grid, water supply network, and wastewater systems took months.

[49] National Oceanic and Atmospheric Administration. (n.d.). *National Centers for Environmental Information Storm Events Database.* https://www.ncdc.noaa.gov/stormevents/eventdetails.jsp?id=601887.

[50] "*Red Cross Updates Saipan Relief Efforts,"* Maui Now, August 16, 2015, https://mauinow.com/2015/08/16/red-cross-updates-saipan-relief-efforts/.

Figure 27. Corrugated metal roofing separated for recycling in a designated staging area after Typhoon Soudelor in Saipan.

Figure 28. Clean wood and vegetative debris chipped into mulch and given away to the public following Typhoon Soudelor.

Lessons Learned: Typhoon Soudelor

Category	Issue	Recommendations
Post-Disaster Recovery Planning	Resilient building and zoning requirements were not in place to limit future disaster impacts	• Develop and enact resilient building code requirements addressing the types of disasters found in the area
Power Poles and Transformers	Damage to transformers and to utility poles made of treated wood	• Replace treated wood poles with storm-resistant power poles made of concrete or composite material
	Management of wood utility pole	• Over 90 percent of damaged utility poles were reused for a variety of purposes, including fence posts, parking blocks, retaining walls, landscape timbers, and non-residential building materials • Note: Do not reuse treated utility poles for residential building materials or in applications that may come into contact with food or drinking water
	Utility had limited replacement power poles and no replacement transformers	• Store additional replacement utility poles and transformers

Category	Issue	Recommendations
Power Plants	Power plant lost part of roof and flooded	• Use typhoon-resistant building techniques and roofing for key facilities. Install emergency floor drains • Raise key utility equipment above anticipated flood levels when possible
Circular Economy: Disaster Debris	Reduce generation of waste through building and facility siting and design	• Use appropriate siting, planning, design, and disaster-resilient building techniques to reduce the generation of disaster debris from anticipated future disasters • Incorporate disaster-resistant siting and building practices in building codes and zoning requirements
	Reuse, recycling, food recovery, and composting	• Designated staging sites collected 49,388 cubic yards of vegetative debris, lumber, and tin for mulching and recycling • Develop plan for covered storage areas to support reuse of undamaged building materials and assemblies • Develop a plan, in cooperation with local recycling and compost facilities, specifying which materials can safely be recycled (e.g., metal, paper, appliances) and mulched or composted (e.g., clean wood waste, vegetative debris) • Develop a plan, in cooperation with local food recovery facilities, for safe food recovery associated with power outages (e.g., animal feeding, composting, anaerobic digestion) • Follow successful model of using onsite segregation and chipping of clean vegetative debris to give away to residents • Require tracking of volumes and/or weights of recovered and discarded materials
	Hardfill disposal capacity[51]	• Construct and plan to use a permitted hardfill site instead of valuable Resource

[51] Hardfill means a method of compaction and earth cover of solid wastes other than those containing garbage or other putrescible (putrescent) waste, including, but not limited to, demolition material and like materials, not constituting a health or nuisance hazard, where cover need not be applied on a per day used basis. No combustible materials shall be deposited in a hardfill.

Category	Issue	Recommendations
		Conservation and Recovery Act Subtitle D[52] permitted landfill facilities to dispose of non-hazardous disaster debris that cannot be reused, recycled, fed to animals, mulched, composted, or anaerobically digested
	Household hazardous waste (HHW)	• Reduce the amount of HHW used and stored in homes to reduce potential health risks during and after typhoons[53] • Move HHW storage off floors and unsecured areas to secured storage above anticipated flood levels • Designate drop-off areas for HHW and develop clear lists of HHW, electronics, and appliances accepted through post-disaster outreach, including press releases, signs, and events

2.2. Wildfire and Fire Events

Changes in temperature, precipitation, wind patterns, and other phenomena are causing extreme wildfire events that are creating new risks to communities. More intense droughts and warmer temperatures cause larger wildfires and longer fire seasons, and they generate even larger amounts of debris.[54] For example, heavy rainfall in an area devastated by wildfires can increase the possibility of massive mudslides due to destroyed vegetation on slopes.

[52] A Subtitle D landfill is a Municipal Solid Waste Landfill specifically designed to receive household waste, as well as other types of nonhazardous wastes.

[53] U.S. EPA. (n.d.). *Reducing HHW in Your Home*. https://www.epa.gov/hw/household-hazardous-waste-hhw#Reducehttps://www.epa.gov/hw/household-hazardous-waste-hhw.

[54] National Climate Assessment. (2018). *Fourth National Climate Assessment*. https://nca2018.globalchange.gov/.

Disaster Example: Wildfires in California

Figure 29. La Tuna Canyon Fire with the city of Los Angeles in the foreground, 2017 (Source: Los Angeles Fire Department).

In 2017 alone, over 9,000 fires in California burned more than 1.2 million acres, which is a dramatic increase from the previous year when fires statewide burnt about 564,000 acres, according to the California Department of Forestry and Fire Protection (CAL FIRE). Due to climate change, wildfires are expected to continue increasing in intensity and frequency in California.[55] More than 1.1 million structures, or roughly one out of every ten buildings in California, lie within the highest risk fire zones in maps drawn by CAL FIRE.

The combination of dry and windy weather, continuous fuels, and proximity to residential development creates a strong potential for wildfires to burn homes. In 2017, CAL FIRE listed more than 5,700 residential properties in California as total losses due to wildfires and over 15,000 residential properties as partial losses. Specifically, the Tubbs Fire claimed 22 lives, charred over 36,000 acres in the state's wine country, and destroyed 5,643 structures in Northern California's Sonoma and Napa counties. In November of 2018, the Camp Fire in Butte County burned over 153,336 acres, destroying over 18,800 structures and claiming 85

[55] U.S. EPA. (n.d.) *California Prepares for Increased Wildfire Risk to Air Quality from Climate Change*. https://www.epa.gov/arc-x/california-prepares-increased-wildfire-risk-air-quality-climate-change.

lives, making this the deadliest and most destructive fire in California history.[56] In August 2020, the August Complex fire (which originated as 38 separate fires started by lightning strikes) became the largest wildfire in California's recorded history, burning over 1,032,648 acres in the coastal range of Northern California.[57] The Dixie Fire in July 2021 became the largest single source wildfire in California history, burning over 963,309 acres in Northern California and damaging over 1,329 structures.[58]

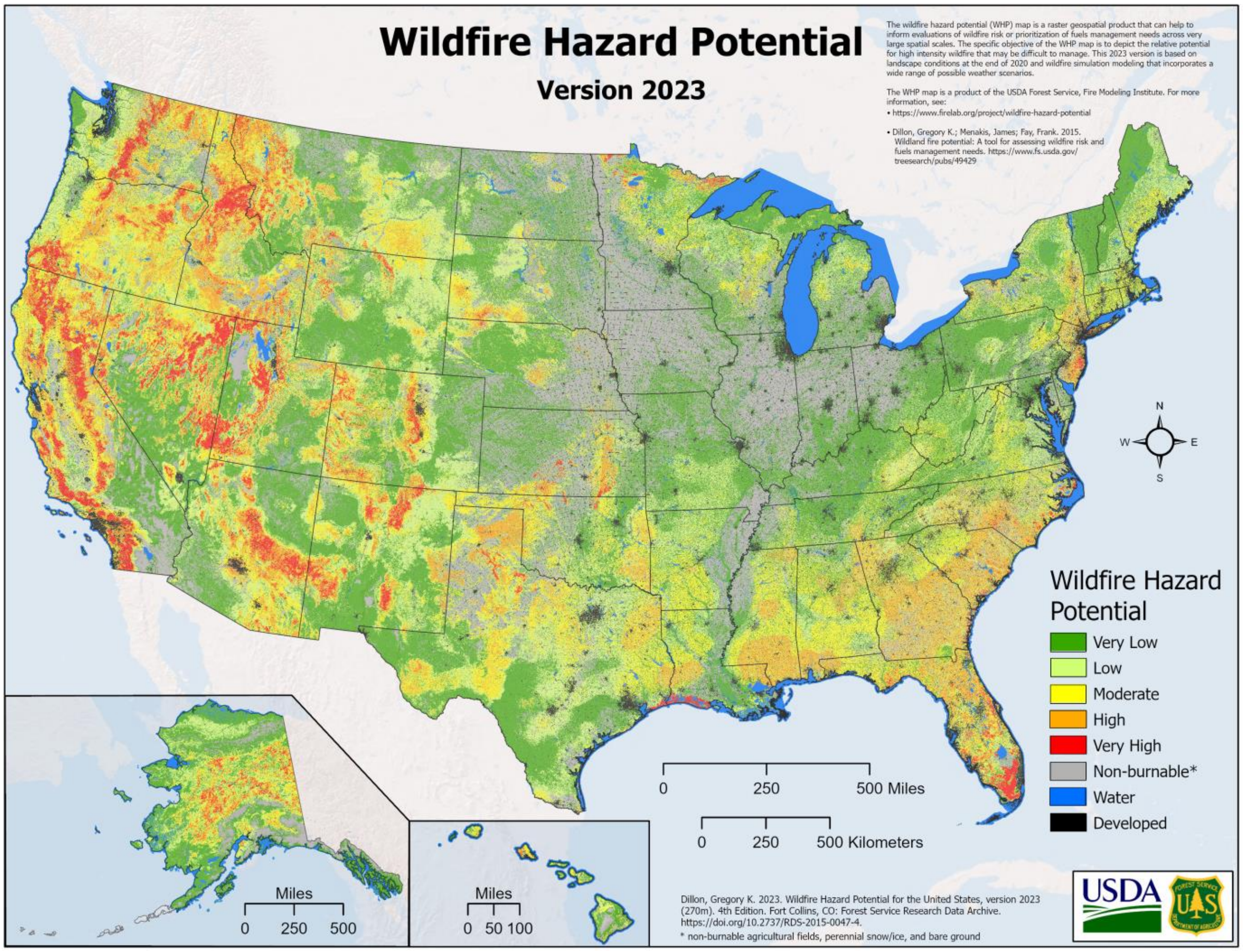

Figure 30. Dillon, G.K. (2023). Wildfire Hazard Potential. https://www.firelab.org/project/wildfire-hazard-potential.

EPA provided support to FEMA, the U.S. Army Corps of Engineers, and state and local partners in a joint response to the Northern California wildfires.

[56] CAL FIRE. (n.d.) Remembering the Camp Fire. https://www.fire.ca.gov/our-impact/remembering-the-camp-fire.

[57] CAL FIRE. (2022). *Top 20 Largest California Wildfires. https://34c031f8-c9fd-4018-8c5a-4159cdff6b0d-cdn-endpoint.azureedge.net/-/media/calfire-website/our-impact/fire-statistics/top-20-largest-ca-wildfires.pdf?rev=037e566cdfd540b9a9fe607b809b855c&hash=D7AC28D89B9F8FE36F3C7E5958CEE016*.

[58] Ibid.

EPA led the survey, collection, and disposal of household hazardous waste at nearly 7,000 residential and commercial parcels affected by the fires in Sonoma and Napa counties. This work cleared the way for proper removal of ash and debris, allowing the rebuilding process to begin. EPA also removed asbestos from burned properties and collected and disposed of hazardous drums and containers.

Figure 31. An EPA team member removes HHW during the Agency's response to the Northern California wildfires. Coffey Park, Santa Rosa, California.

Lessons Learned: Wildfires in California

Category	Issue	Recommendations
Address Markings	Lack of clear address markings to help first responders and post-fire cleanup efforts	• Mark addresses with numbers more than 3 inches tall and with curb painting • Note: Check with local government and community associations for curb painting requirements
Power Lines	Aging power lines with overgrown trees	• Maintain and update power lines and ensure trees are trimmed around the power lines
Debris and Vegetation	Debris and vegetation around homes acted as tinder	• Clear flammable debris, leaves, branches, and other vegetation around the house perimeter

Category	Issue	Recommendations
Post-Fire Recovery	Resilient building and zoning requirements were not in place to limit future disaster impacts	• Develop and enact resilient building code requirements addressing the types of disasters found in the area
	Plastic storm drains melted, resulting in post-fire flooding and landslide concerns	• Install concrete or steel storm drain infrastructure
	Plastic septic tank covers melted, making tanks unsafe for fire response crews and homeowners; some recovery workers fell into septic tanks	• Install concrete septic tank covers
	Household Hazardous Waste (HHW) management	• Reduce the amount of HHW used and stored in homes to reduce potential health risks during and after fires[59]

[59] U.S. EPA. (n.d.). *Reducing HHW in Your Home*. https://www.epa.gov/hw/household-hazardous-waste-hhw#Reduce .

Conclusion

The need for effective natural and sustainable disaster debris management is growing rapidly as the frequency and intensity of disasters continue to increase. Considering the cost and community impacts associated with response and recovery, developing effective strategies to plan for, mitigate, and respond to natural disaster debris is critical to helping all communities become more resilient. Incorporating resilient building design and best practices are important strategies for mitigating disaster debris, creating resilient communities, and advancing a circular economy and environmental justice.

Every step of building planning, design, retrofit, and post-disaster deconstruction and reconstruction presents opportunities to revisit building practices and embrace new approaches, such as designing for increased resiliency and increasing safe reuse, recycling, and composting to reduce waste and embodied carbon.

Communities can adapt the strategies and best practices in this document to each disaster event they experience now and in the future. Planning for a climate event is critical to minimizing disruption to a community, conserving resources, and generating less disaster debris. In addition, planning for and developing healthy, disaster resilient buildings can reduce waste and conserve valuable resources over the life cycle of a built environment—including the post-disaster response and rebuilding phases—to protect the health of building occupants and disaster responders.

Creating disaster-resilient buildings to minimize disaster debris should be guided by environmental justice principles and values and informed by the perspectives and experiences of communities with environmental justice concerns. This work can have positive environmental justice impacts by reducing the vulnerability and enhancing the resilience of these communities to natural disasters and climate events and by promoting their agency and equity in the circular transition. It is critical to ensure that communities with environmental justice concerns are not left behind or left out of these conversations and decisions.

EPA is interested in learning about your resilient building experiences and recommendations. We welcome feedback at https://www.epa.gov/homeland-security-waste/forms/contact-us-about-managing-materials-and-wastes-homeland-security.

Additional Resources

EPA Resources

Disaster Debris Planning Website. The website provides EPA reports and resources on large-scale residential disaster debris management. https://www.epa.gov/large-scale-residential-demolition/disaster-debris-planning.

All-Hazards Waste Management Planning Tool. The online tool assists emergency managers and planners in creating or updating comprehensive, pre-incident plans for managing waste and materials generated from manmade and natural disasters. https://wasteplan.epa.gov/welcome.

Guidance about Planning for Natural Disaster Debris. This guidance assists communities in planning for natural disaster debris *before* a disaster occurs by providing information, including the recommended components of a debris management plan and suggested management options for various debris streams, that is intended to increase community preparedness and resiliency. https://www.epa.gov/homeland-security-waste/guidance-about-planning-natural-disaster-debris.

Resiliency and Natural Disaster Debris Workshop Final Summary Report. Suggested actions from workshop participants to advance equity and resiliency in planning for and managing natural disaster debris, including buildings impacted by sea level rise. http://www.epa.gov/homeland-security-waste/resiliency-and-natural-disaster-debris-workshops.

Disaster Resilient Design Concepts. This document showcases disaster-resilient designs, organized by hazard type, to help communities reduce the impact of disasters, recover more quickly, strengthen local economies, and create safer, more equitable places to live by reducing hazards especially for those most vulnerable. https://www.epa.gov/smartgrowth/disaster-resilient-design-concepts.

Disaster Debris Recovery Tool. An interactive mapping tool of 12 types of recyclers and landfills that manage disaster debris. This tool provides information for all 50 states, Puerto Rico, and the U.S. Virgin Islands for over 20,000 facilities capable of managing different materials that may be found in disaster debris and can be used to support disaster planning and emergency response. http://www.epa.gov/large-scale-residential-demolition/disaster-debris-recovery-tool.

Smart Growth Strategies for Disaster Resilience and Recovery Website. Site sharing EPA resources, agreements, and publications related to disaster resilience smart growth strategies. https://www.epa.gov/smartgrowth/smart-growth-strategies-disaster-resilience-and-recovery.

Environmental Resilience: Exploring Scientific Concepts for Strengthening Community Resilience to Disasters. Report exploring scientific concepts for building an index of indicators of community environmental resilience to natural or human-caused disasters. The index could be used to support disaster decision-making. https://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryID=310052.

Sustainable Management of Construction and Demolition Materials. Information on construction and demolition materials often present after disasters and the benefits of reuse and recycling of building materials. https://www.epa.gov/smm/sustainable-management-construction-and-demolition-materials.

Analysis of the Life Cycle Impacts and Potential for Avoided Impacts Associated with Single-Family Home. Analysis on how recovered construction and demolition materials from single-family homes that are reused in building, road construction and other applications help offset the environmental impacts associated with single-family homes. http://www.epa.gov/smm/analysis-lifecycle-impacts-and-potential-avoided-impacts-associated-single-family-homes.

Construction and Demolition Materials in America. National and state reports on the types and quantities of construction and demolition materials that can be helpful in estimating the types and quantities of materials generated by disasters. https://www.epa.gov/smm/sustainable-management-construction-and-demolition-materials#America.

Managing and Transforming Waste Streams – A Tool for Communities. Examples and resources for transforming waste streams in communities, including zero waste strategies and construction and demolition debris management models. https://www.epa.gov/transforming-waste-tool/browse-examples-and-resources-transforming-waste-streams-communities.

Deconstruction Rapid Assessment Tool. Enables organizations to assess buildings damaged in a disaster or slated for demolition by assembling data that can help prioritize structures for deconstruction and salvage. https://www.epa.gov/large-scale-residential-demolition/deconstruction-rapid-assessment-tool.

Best Practices for Reducing, Reusing, and Recycling Construction and Demolition Materials. Information on designing buildings for deconstruction, reuse, and recycling. https://www.epa.gov/smm/best-practices-reducing-reusing-and-recycling-construction-and-demolition-materials.

Harmful Materials and Residential Demolition. Information on hazardous materials that may be present in building-related disaster debris such as lead-based paint, asbestos, mercury-containing devices and lights, refrigerant-containing appliances, and mold. https://www.epa.gov/large-scale-residential-demolition/harmful-materials-and-residential-demolition.

Biomimicry

Biomimicry: Designing to Model Nature. National Institute of Standards and Technology's (NIST's) Whole Building Design Guide website discusses the concept of biomimicry, relevant codes and standards, and related resources. https://www.wbdg.org/resources/biomimicry-designing-model-nature.

Design for Deconstruction, Disassembly, Reuse, and Adaptation

EPA Fact Sheets on Designing for the Disassembly and Deconstruction of Buildings. Fact sheets highlighting the innovative approaches, results, and environmental and economic benefits from pilot projects that may be replicated across various sectors, industries, communities, and regions. https://www.epa.gov/smm/fact-sheets-designing-disassembly-and-deconstruction-buildings.

American Institute of Architects, Buildings that Last: Design for Adaptability, Deconstruction, and Reuse. A practice guide on being more intentional about the flexibility of a structure, so buildings can hold neighborhoods together, encourage social equity, and contribute to community resilience for extended periods of time. https://content.aia.org/sites/default/files/2020-03/ADR-Guide-final_0.pdf

City of San Antonio Office of Historic Preservation, Treasure in the Walls: Reclaiming Value Though Material Reuse in San Antonio. An assessment of opportunities for a local government to transition from a linear economy model to a circular economy to allow the City to recover and leverage existing assets to meet its stated economic, equity, sustainability, waste diversion, and housing goals. http://www.sanantonio.gov/Portals/0/Files/HistoricPreservation/Deconstruction/Treasure%20in%20the%20Walls.pdf?ver=2021-04-25-115830-417.

Google and Ellen MacArthur Foundation, Accelerating the Circular Economy through Commercial Deconstruction and Reuse. An initial exploration into the importance of deconstructing commercial buildings and reuse of building materials for an increasingly circular built environment based on insights from over 25 interviews with leading deconstruction and reuse experts, primarily in the U.S. and Europe. http://www.gstatic.com/gumdrop/sustainability/google-deconstruction-and-reuse.pdf.

Lifecycle Building Challenge. A past EPA, American Institute of Architects, and Building Materials Reuse Association competition cataloging built projects and designs that promote adaptation, reuse, and portability. Includes an extensive list of resources and related building rating systems credits. http://www.lifecyclebuilding.org/.

Public Architecture, Design for Reuse Primer. With U.S. Green Building Council funding, Public Architecture developed a Design for Reuse Primer, featuring 15 detailed reuse and design for reuse project case studies. https://issuu.com/publicarchitecture/docs/design_for_reuse_primer_issuu.

Federal Center South Building 1202, U.S. Army Corps of Engineers Seattle District Headquarters. Project that reused approximately 200,000 board feet of lumber from an adjacent warehouse structurally and non-structurally. https://www.zgf.com/work/1136-u-s-general-services-administration-federal-center-south-building-1202.

EPA, Design for Deconstruction Manual. This handbook presents an overview of basic Design for Deconstruction principles and outlines the implementation of these principles in the design of Chartwell School in Seaside, California. http://www.epa.gov/sites/default/files/2015-11/documents/designfordeconstrmanual.pdf.

Organizations Supporting Building Materials Reuse and Recycling

All for Reuse. A network of building professionals committed to the reuse of commercial building materials. http://www.allforreuse.org/.

Bay Area Deconstruction Workgroup. A group of deconstruction and reuse leaders that meet quarterly from government, private, and nonprofit sectors working to improve policies and practices advancing safe building materials recovery and reuse. http://www.stopwaste.org/BADWG.

Build Reuse. A nonprofit educational and research organization that advances the recovery, reuse, and recycling of building materials. https://www.buildreuse.org/.

C40 Cities. A global network of mayors taking urgent action to confront the climate crisis and create a future where everyone can thrive. https://www.c40.org/. The group developed an implementation guide on how to start deconstructing and stop demolishing your city's buildings. http://www.c40knowledgehub.org/s/article/How-to-start-deconstructing-and-stop-demolishing-your-citys-buildings?language=en_US.

Construction & Demolition Recycling Association. Association that promotes the environmentally sound recycling of recoverable construction and demolition materials. https://cdrecycling.org/.

BAMB – Buildings as Material Banks. The EU-funded BAMB project brings 15 parties throughout Europe together for one mission – enabling a systemic shift in the building sector by creating circular solutions. Their research and publications are under "Pilots" and "Library." http://www.bamb2020.eu/.

Habitat for Humanity ReStore. Home improvement stores and donation centers independently operated by local Habitat for Humanity organizations that sell new and used building materials, furniture, appliances, and more. http://www.habitat.org/restores.

US Composting Council. Nonprofit trade and professional organization promoting the recycling of organic materials through composting. https://compostingcouncil.org/.

Codes and Standards

Codes (General)

Codes And Standards Development. Provides an overview of building codes and standards. http://www.wbdg.org/resources/codes-and-standards-development.

ICC Performance Code for Buildings and Facilities. Provides "a framework to establish minimum levels to which buildings or facilities should perform when subjected to events such as fires and natural hazards" in Chapter 3 of the Code document. https://codes.iccsafe.org/s/ICCPC2015/chapter-1-general-administrative-provisions-2/ICCPC2015-UsersGuide-Pt01.

California Wildland Hazards and Building Codes. Provides information related to using building construction methods that reduce the likelihood of building ignition in conjunction with maintaining defensible space to reduce the severity of potential wildfire exposure. https://osfm.fire.ca.gov/what-we-do/code-development-and-analysis/wildland-hazards-and-building-codes.

National Fire Protection Association, List of Codes and Standards. Consensus-based and peer reviewed standards on a variety of topics, including wildland fire protection and management and reducing structure ignition hazards from wildland fire. https://www.nfpa.org/en/For-Professionals/Codes-and-Standards/List-of-Codes-and-Standards#aq=%40culture%3D%22en%22&cq=%40tagtype%3D%3D(%22Standards%20Development%20Process%22)%20%20&numberOfResults=12&sortCriteria=%40computedproductid%20ascending%2C%40productid%20ascendinghttps://www.nfpa.org/codes-and-standards/nfpa-1140-standard-development/1140.

Research

Buildings as Material Banks: Framework for Policies, Regulations and Standards. European Union roadmap for changes that will allow the transformation of the industry to circular principles through a set of recommendations to guide policymakers. http://www.bamb2020.eu/wp-content/uploads/2019/02/BAMB-Framework-for-Policies-Regulations-and-Standards-with-appendices.pdf.

Buildings as Material Banks: State of the Art Report on Policies and Standards. European Union overview of current policy instruments relevant to promoting, or possibly hindering, the adoption of circular economy opportunities in the built environment. The analysis covers the European level and Belgium, Portugal, Sweden and UK at the country level. http://www.bamb2020.eu/wp-content/uploads/2019/02/State-of-the-art-report-on-Policies-and-Standards_V2.pdf.

Voluntary Resilience Standards: An Assessment of the Emerging Market for Resilience in the Built Environment. Report developed for the Energy, Kresge, and Barr foundations that provides in-depth information about standards, organizations, and methodologies for addressing resilience. https://cadmusgroup.com/wp-content/uploads/2018/08/MCG-Voluntary-Resilience-Standards-Report.pdf.

Living Building Challenge: Code, Regulatory and Systemic Barriers Affecting Living Building Projects report. Cascadia Region Green Building Council report addressing many building code issues for more resilient green building projects. https://living-future.org/wp-content/uploads/2022/05/Code-Regulatory-Systemic-Barriers-Affecting-LB-Projects.pdf.

Systems and Standards

RELi. A national consensus, American National Standards Institute–approved resilience rating system that will become a global rating system under the U.S. Green Building Council's guidance. The system, patterned on LEED, prescribes methods for designing more resilient buildings, neighborhoods, and communities to better withstand events such as hurricanes, super storms, drought, heat waves, earthquakes, and social volatility. https://c3livingdesign.org/reli-resilientdesign/.

U.S. Resiliency Council Building Rating System. Rating system that identifies expected impacts of an earthquake or other hazards on buildings and considers the performance of a building's structure; its mechanical, electrical and plumbing systems; and architectural components such as cladding, windows, partitions, and ceilings. The rating system assigns one to five stars along the dimensions of safety, damage expressed as repair cost, and recovery expressed as time to regain basic function. https://www.usrc.org/usrc-rating-system/.

Insurance Institute for Business & Home Safety's FORTIFIED Standards. Research- and locality-based standards for building more resilient structures. https://fortifiedhome.org/https://disastersafety.org/.

Disaster Resilience Strategies

General

Catalog of FEMA Building Science Resources. A catalog compiled by FEMA's Building Science and Earthquake and Wind Programs Branches of available FEMA publications for natural hazards, including earthquake, flood, high wind, and hurricane. https://www.fema.gov/sites/default/files/documents/fema_building-science-catalog_12-29-21.pdf.

Climate Mapping for Resilience and Adaptation. Climate Mapping for Resilience and Adaptation (CMRA) helps people assess their local exposure to climate-related hazards. Understanding exposure is the first step in determining which people, property, and infrastructure could be injured or damaged by climate-related hazards and what options might be available to protect these assets. https://resilience.climate.gov/.

Climate Smart Brownfields Manual: This manual helps communities think about climate mitigation, adaptation, and resilience in the context of brownfield cleanup and redevelopment. https://www.epa.gov/sites/default/files/2021-06/documents/final_climate_smart_brownfields_manual_6-10-21_508_complaint.pdf.

Resilient Design Institute. A national nonprofit organization committed to advancing sustainability through a focus on resilience in our buildings and communities, providing accessible information and case studies. http://www.resilientdesign.org/.

Exploring Resilient Building Design. An Architecture and Construction Center free online continuing education course with examples and case studies of innovative resilient strategies. https://continuingeducation.bnpmedia.com/courses/multi-aia/exploring-resilient-building-design/1/.

American Institute of Architects Disaster Assistance Handbook, Fourth Edition. Comprehensive guidance for both architects and citizens involved in disaster planning and response. https://www.aia.org/resource-center/disaster-assistance-handbook.

American Institute of Architects Resilience Website. Professional association articles and information on resilient design. http://www.aia.org/topics/56-resilience.

Ready to Respond: Strategies for Multifamily Building Resilience. Enterprise's detailed collection of practical resilience strategies for multifamily and other building types. https://www.enterprisecommunity.org/resources/ready-respond-strategies-multifamily-building-resilience-13356.

National Trust for Historic Preservation 10 Steps to Mitigate Natural Disaster Damage. Toolkit to help historic property owners minimize the impact to their building and strengthen their building's resistance to extreme wind, rain, and other climatic forces. https://savingplaces.org/stories/10-tips-to-mitigate-natural-disaster-damage.

Insurance Institute for Business & Home Safety DisasterSafety.org Website. The website features projects to help home and business owners protect their property from damage caused by natural disasters. https://disastersafety.org/.

For Earthquakes

Techniques for the Seismic Rehabilitation of Existing Buildings. FEMA's selected compilation of seismic rehabilitation techniques that are practical and effective. https://www.fema.gov/node/techniques-seismic-rehabilitation-existing-buildings.

Homeowner's Guide to Earthquake Safety. The California Safety Commission's guide for addressing residential building earthquake safety, including examples of damage, insurance information, recommendations, and earthquake maps. https://ssc.ca.gov/wp-content/uploads/sites/9/2020/08/20-01_hog.pdf.

- Spanish version https://ssc.ca.gov/wp-content/uploads/sites/9/2020/10/Home-Owners-Guide-Spanish-Finalv2.pdf.

For High-Wind Events

Whole Building Design Guide, Wind Safety of the Building Envelope. NIST's comprehensive information about wind forces and interactions, vulnerabilities, priorities, costs, benefits, design, details, and more. https://www.wbdg.org/resources/wind-safety-building-envelope.

Resilient Design Guide: High Wind Wood Frame Construction Edition. Federal Alliance for Safe Homes' extensive guidance from basic structural concepts of wind forces to detailed information about each part of a wood frame home. The guide provides information on three levels: ordinary, high wind, and resilient construction with basic cost and difficulty comparisons for the recommendations. https://flash.org/wp-content/uploads/1/2023/05/resilientdesignguide.pdf.

Florida Division of Emergency Management's Hurricane Retrofit Guide. Information on hazards and risks and provides a range of practical methods to minimize wind and water damage to homes. Site includes comprehensive guidance for roof-to-wall connections including Gable End Bracing, Wood Frame Walls, Masonry Walls, Narrow Garage Walls, Roof Structure, and Water Leaks Through Walls. https://apps.floridadisaster.org/hrg/index.asp.

South Carolina Safe Home Mitigation Techniques Resources Document. State Department of Insurance program providing guidance on hurricane fortification, including gable end wall bracing techniques, as well as grant funding to homeowners to make retrofitting owner-occupied, single-family homes more resistant to hurricane and high-wind damage. https://doi.sc.gov/faq.aspx?qid=235.

For Floods

EPA Green Infrastructure. Tools, planning, design, research, and funding resources for supporting resilient green infrastructure. http://www.epa.gov/green-infrastructure.

NOAA Coastal Flood Exposure Mapper. A community screening-level tool with existing national data that are locally relevant. The mapper was developed to start a conversation around coastal flood hazard risks and associated vulnerabilities. https://www.coast.noaa.gov/floodexposure/#/splash.

Floodproofing Non-Residential Buildings. FEMA guidance document on dry floodproofing technologies for non-residential buildings, as well as an overview of wet floodproofing and the use of levees and floodwalls. The publication provides a vulnerability checklist and information about regulatory requirements, design considerations, and floodproofing equipment. http://www.fema.gov/sites/default/files/2020-07/fema_p-936_floodproofing_non-residential_buiildings_110618pdf.pdf.

Homeowners Guide to Retrofitting: Six Ways to Protect Your Home from Flooding. FEMA's detailed homeowner guide including information on elevating your home, raising and protecting equipment, and floodproofing. https://www.fema.gov/sites/default/files/2020-08/FEMA_P-312.pdf.

Fundamentals of Resilient Design: Floodproofing. Resilient Design Institute guidance on:

- Dry floodproofing techniques to keep floodwater out. http://www.resilientdesign.org/fundamentals-of-resilient-design-dry-floodproofing/.
- Wet floodproofing with materials that resist water damage and mold growth. http://www.resilientdesign.org/fundamentals-of-resilient-design-wet-floodproofing.

City of Hoboken Resilient Building Design Guidelines. Guidance developed by Hoboken, New Jersey, including an overview of the laws and regulations and approval process for construction in flood-prone areas, requirements, design standards, requirements, and examples for wet and dry floodproofing, foundation design, materials, mechanical systems, and utilities. https://betterwaterfront.org/wp-content/uploads/2016/05/Resilient-Buildings-Design-Guidelines.pdf. The 2022 addendum provides solutions for homeowners to help mitigate the risk of flooding at the building scale. https://assets-global.website-files.com/58407e2ebca0e34c30a2d39c/62d180a35a1957b9fb4569a2_Resilient_Building_Design_Guidelines_Addendum_Final_071422.pdf.

Whole Building Design Guide Flood Resistance of the Building Envelope. NIST's detailed guidance on flood zone management requirements and floodproofing techniques for various building occupancies. https://www.wbdg.org/resources/flood-resistance-building-envelope.

Design and Construction Guidance for Breakaway Walls. FEMA Technical Bulletin on designing breakaway walls to include National Flood Insurance Program considerations.

Includes information on wave loads and research on breakaway walls. https://www.fema.gov/sites/default/files/2020-07/fema_tb9_design_construction_guidance_breakaway_walls.pdf.

A Better City Passive Flood Barrier Overview and Product Comparisons. Information on passive flood barriers and different self-activating flood barrier products covering benefits, limitations, and potential funding sources. http://www.abettercity.org/docs-new/2015.09.09%20Passive%20Flood%20Barrier%20Publication.pdf.

Designing for Tsunamis: Seven Principles for Planning and Designing for Tsunami Hazards. Provides strategic and specific guidance for addressing tsunami hazards from the National Tsunami Hazard Mitigation Program developed by federal and state partners. https://www.preventionweb.net/files/1505_DesigningforTsunamis.pdf.

For Wildfires

Home Builder's Guide to Construction in Wildfire Zones. FEMA Technical Fact Sheets with information on wildfire behavior and recommendations for building design and construction methods in the wildland/urban interface. Implementation of the recommended design and construction methods can greatly increase the chances of a building's survival in a wildfire. https://defensiblespace.org/wp-content/uploads/2021/01/FEMA_2008_P-737-Home-Builders-Guide-to-Construction-in-Wildfire-Zones.pdf.

National Cohesive Wildland Fire Management Strategy. A strategy developed for federal, state, and local governments; tribes; and non-government organizations working to promote resilient ecosystems, protect communities, and provide effective response to wildfire. https://www.forestsandrangelands.gov/strategy/index.shtml.

Insurance Institute for Business & Home Safety (IBHS) Regional Wildfire Retrofit Guides. Customized guides for the risks, codes, building styles, and topography with very specific best practices and innovations. https://disastersafety.org/wildfire/regional-wildfire-retrofit-guides/.

Design with Fire in Mind: Three Steps to a Safer New Home. National Fire Protection Association and IBHS Firewise USA electronic book covering fire-safe building practices including landscaping and maintenance. https://www.greenbuildermedia.com/hubfs/VHMM/NFPA_Assets/NFPA-eBook-4.pdf.

Home Assessment Online: Fire Information Engine Homeowner Wildfire Assessment. An online assessment guide developed by the University of California, Berkeley that asks a series of questions about your home and yard and produces a customized report about your wildfire vulnerability and improvements and maintenance steps that may reduce wildfire vulnerability. The survey is anonymous, and no information entered is retained. https://berkeley.qualtrics.com/jfe/form/SV_egqVWb1tnb7pGhT?Q_JFE=qdg.

Home Assessment Checklist. Checklist for assessors and residents to determine problem areas around the home that can be retrofitted or restructured to mitigate damage when a wildfire strikes. Many of the items listed in the checklist are free or low-cost modifications; however, some items may require more significant investment. Most items include a key for estimating costs. https://www.nvfc.org/wp-content/uploads/2016/02/WFAP-home-assessment-checklist.pdf.

Wildfire Research Fact Sheet Series. Fact sheet series developed by the National Fire Protection Association (NFPA) and the Insurance Institute for Business & Home Safety (IBHS) on the wildfire research being done at the IBHS research facility to create more resilient communities. Fact sheets are on coatings, fencing, decks, attic and crawl space vents, and roofing materials, among others. https://www.nfpa.org/education-and-research/wildfire/firewise-usa/firewise-usa-resources.

Disaster Recovery Phase

Community Recovery Management Toolkit. FEMA compilation of guidance, case studies, procurement tools, and training to assist local communities in managing long-term recovery post-disaster. https://www.fema.gov/emergency-managers/national-preparedness/frameworks/community-recovery-management-toolkit.

A Debris Management Handbook for State and Local DOTs and Departments of Public Works. National Cooperative Highway Research Program guidance for infrastructure debris management. https://www.nap.edu/catalog/22239/a-debris-management-handbook-for-state-and-local-dots-and-departments-of-public-works.

Post-Disaster

Healthy, Resilient, and Sustainable Communities After Disasters. Book by the National Institutes of Health containing comprehensive public health-based, post-disaster guidance, including information on healthy housing and a broad spectrum of health-related resources and strategies. https://www.ncbi.nlm.nih.gov/books/NBK316532/.

Glossary

Biomimicry: A practice that learns from and mimics the strategies found in nature to solve human design challenges. (Biomimicry Institute)

Circular economy: An economy that uses a systems-focused approach and involves industrial processes and economic activities that are restorative or regenerative by design, enables resources used in such processes and activities to maintain their highest value for as long as possible, and aims for the elimination of waste through the superior design of materials, products, and systems (including business models). (Save Our Seas Act 2.0)

Climate adaptation: Taking action to prepare for and adjust to both the current and projected impacts of climate change.

Climate change: Changes in global or regional climate patterns attributed largely to human-caused increased levels of atmospheric greenhouse gases.

Climate resilience: The capacity of a system to maintain function in the face of stresses imposed by climate change and to adapt the system to be better prepared for future climate impacts.

Debris: The material and waste streams resulting from a natural disaster that often includes building materials, sediments, vegetative debris, personal property, and other materials.

Deconstruction: The selective dismantlement or removal of materials from buildings for primarily reuse or, secondarily, recycling.

Embodied carbon: Refers to the amount of greenhouse gas (GHG) emissions associated with upstream—extraction, production, transport, and manufacturing—stages of a product's life. Many initiatives to track, disclose, and reduce embodied carbon emissions also consider emissions associated with the use of a product and its disposal. It is also known as embodied GHG emissions.

Environmental justice: The just treatment and meaningful involvement of all people, regardless of income, race, color, national origin, Tribal affiliation, or disability, in agency decision-making and other Federal activities that affect human health and the environment so that people: are fully protected from disproportionate and adverse human health and environmental effects (including risks) and hazards, including those related to climate change, the cumulative impacts of environmental and other burdens, and the legacy of racism or other structural or systemic barriers; and have equitable access to a healthy, sustainable, and resilient environment in which to live, play, work, learn, grow, worship, and engage in cultural and subsistence practices.

Passive Survivability: The ability of a building to provide necessary shelter, thermal, and other life-support services during extended utility service disruptions.

Resilience: The capacity to plan for, withstand, adapt to, and recover from natural disasters with minimal damage in a timely, effective, and safe manner.

Resilient communities: Communities that are resilient recover faster, contain fewer harmful materials, generate less debris, and need fewer resources to rebuild.

Retrofit: A way to adapt to evolving hazards and a tool for disaster risk reduction by making changes to existing structures to mitigate the impacts of natural hazards.

Reuse: The utilization of a product or material that was previously installed for the same or similar function to extend its life cycle.