Efforts to promulgate green or sustainable building shave focused primarily on site selection and development, energy water and resource conservation, and indoor environmental quality. Such codes, standards and programs are remiss in that they do not adequately address the huge negative environmental impacts related to the performance of the building within its community. Enhanced functional resilience should be a key component in the design and construction of any green or sustainable building and any buildings located in disaster prone areas to minimize negative environmental impacts while facilitating security and community continuity.

The primary emphasis of current building code requirements is to provide minimum levels of performance for life safety. Thus, for events where evacuation can be managed in a timely fashion the building code requirements may not provide adequate protection for property or facilitate community preparedness, mitigation, response, relief and recovery when disasters occur. Such events include hurricanes, floods, storm surges, and wildland fires.

The destruction that occurs typically results in excessive amounts of 1) building materials and contents being disposed of in landfills; 2) resources expended on emergency response and disaster relief and recovery; and 3) time required for services, residents, and businesses to return. Each of these has a huge impact on the security, vitality, and continuity of the community and on the environment.

The need for programs that integrate enhanced resilience into the design and construction of buildings is emphasized. One approach, endorsed by the national association representing the insurers and re-insurers, the Institute for Business and Home Safety is described with a variety of options for enactment. The *High Performance Building Requirements for Sustainability*, while adoptable, are intended to serve primarily as an example of criteria for enhanced resilience of buildings in areas prone to natural or man-made disasters or intended to minimize negative environmental impacts as green or sustainable buildings.
BUILDING CODE MODIFICATIONS FOR ENHANCED RESILIENCY

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NEED FOR ENHANCED BUILDING RESILIENCE

Jurisdictions are encouraging building design and construction that exceeds the minimum requirements of nationally developed model building codes. This is being accomplished with a variety of strategies depending on the political and legal structure of the jurisdictions and the states in which they reside. Some programs are voluntary and encourage participation through incentives which may be as simple as facilitated plan reviews. Most are enhancements to the minimum requirements of national model building codes through amendments or modifications of the model codes or through local ordinances. Clearly, for jurisdictions integrating these enhancements, the minimum requirements of the national model codes are not adequate for local issues and conditions related to climate, demographics, disaster risk and recovery, economics, geography, geology, politics, and social needs.

Community Incentives

More resilient buildings and infrastructure provide many benefits to communities. Some communities recognize that more resilient buildings tend to have lower operation and maintenance costs; use less materials and resources for repair and replacement due to normal operation; have longer design service lives; and are more adaptive for re-use because the building designs are suitable for multiple types of occupancies. Such buildings allow for continuous and uninterrupted occupancy for businesses and residents which in turn provides continuous and consistent revenues for the community. In many instances the more robust buildings attract and retain businesses, residents, and investors. Less use of materials and resources for maintenance, repair and replacement; lengthened service lives; and adaptive re-use also minimize long term negative environmental impacts thereby improving sustainability. While these factors have significant political, economic, and societal impacts for the community, enhanced resilience is being required more frequently by communities in disaster prone areas.

Resilient Buildings

There are hundreds of thousands of examples of resilient buildings. They are most common in redeveloped older sections of communities where more robust buildings are re-used: warehouses, factories and offices transformed into mercantile and residential occupancies; or offices and residences being renovated to keep their original occupancy, often with the most significant change being from single occupancy buildings to multiple tenants. Newer building tend to be more disposal and limited to the single occupancy for which they were designed and constructed (1). While there is no individual quantifiable measure of enhanced resilience, it can be qualified
as the benefits provided in the form of increased longevity, robustness, sustainability, life safety, durability, adaptability for re-use, and ability to resist damage due to disasters. Two excellent examples of resilient buildings are shown in Figure 1.

- **Winecoff Hotel** - The concrete frame Winecoff Hotel in Atlanta, Georgia was built in 1913. A fire completely gutted the building in 1946. In 1951 it reopened as another hotel and subsequently used as housing for the elderly. Then the building was vacant for twenty years and left vulnerable to the forces of nature. However, due to its enhanced resilience, in more recent years, the building was renovated and in 2007 it was re-opened as the luxury Ellis Hotel.

- **90 West Building** - Reports on the World Trade Center (WTC) disaster provided significant detail on buildings that collapsed as a result of the collapse of the WTC Twin Towers. One such building, designated as WTC 7, more than satisfied the intent of the minimum building code requirements. The steel frame WTC 7 building was struck by debris from the collapsing WTC Towers which precipitated an ensuing eight hour fire and resulted in the total collapse of WTC 7. However, the more robust 90 West building, also constructed of steel frame but with more substantial passive fire protection, was also struck by World Trade Center Tower debris which resulted in an uncontrolled fire which lasted for five days. Significant though is 90 West did not collapse and was renovated and reopened as an apartment building in 2005.

**Disasters and Property Losses**

Property losses due to disasters are increasing dramatically in the United States. These dramatic increases appear to have occurred since the 1970s. Losses by disaster as reported by the Property Claims Service of Munich RE are shown in Table 1 and total losses illustrated in Figure 2 (2). Losses in the 2000s totaled 190 billion dollars. This amount is more than 30 times the 6 billion dollars of total losses that occurred in the 1970s or a 3000% increase. Two misconceptions about the reason for this huge increase in losses are changes in population and frequency of disasters.

As shown in Figure 3 the rate of population growth has not increased nearly as dramatically as the property losses. The regional population growth demonstrates that shifts in population also do not reflect the dramatic increase in property losses. According to the U.S. Census Bureau, from 1970 to 2010, the U.S. coastal watershed county population increased 45% (3). This does not correspond to the 3000% percent increase in property losses over the same time period.

There is also no good correlation between the frequency of catastrophic events and the amount of property loss. The bar chart in Figure 4 shows the frequency of hurricanes reported by the National Oceanic and Atmospheric Administration making landfall in the U.S. (4) and the line chart shows the property losses due to hurricanes. The frequency of hurricanes does not start to dramatically increase in the 1970s, but remains relatively constant. However the property losses due to hurricanes make a dramatic increase starting in the 1970s. The lack of a good correlation between frequency and losses also exists for tornadoes. The frequency of Enhanced Fujita (EF) Tornado Damage Scale tornadoes in the range of EF 3 to EF 5 reported by National Oceanic and Atmospheric Administration (4) and the large increase in property losses due to tornadoes since the 1970s are shown in Figure 5. There haven’t been any catastrophic earthquakes in the U.S.
since the 1970s and flood data is not included in the total losses shown in Table 1 or in the plot in Figure 2.

The total amount of construction put in place also does not agree with the rapid increase in property losses that started to occur in the 1970s. According to the U.S. Census Bureau the cumulative number of residential units put in place per decade (3) is shown in Figure 6. The slope of the number of units put in place is relatively constant with no sharp increase occurring in the 1970s or 1980s. Commercial construction put in place as reported by the U.S. Census is also shown in Figure 6 (3). The amount of commercial construction put in place shown as billions of dollars per decade also remains relatively constant while the property losses increased dramatically.

**Other Factors That May Be Contributing to Property Loss Increases**

There have also been significant changes in construction practices in the United States since the 1970s. Each of these alone may not have had a significant effect, but each warrants consideration with regard to its role in increased property losses.

While primarily impacting one- and two-family and multi-family construction, Federal government deregulation in the 1980s resulted in the elimination of enhanced design and construction criteria for residential construction. While the Minimum Property Standards (5) continue to exist the majority of criteria that resulted in more robust building construction have been stripped from the standard in favor of using minimum building code requirements. The more stringent criteria were promulgated for enhanced energy efficiency, comfort, productive, safety and encouraged more resilience construction to better assure longevity over the life for federally insured financing. Most residential buildings, excluding custom homes, would be constructed to the government standards in lieu of minimum building code requirements because builders and developers did not know what type of financing would be used for mortgages.

Due to competition and the need to maximize returns on investments, the trend in the U.S. is to provide buildings at least initial cost. This equates to minimum building code which has, for the most part, become the norm for projects that are not owner designed, built, and occupied. In many instances designers and builders also provide construction the does not meet the minimum building code criteria specifically cited in the building codes, but instead satisfy the intent of code through alternative methods.

In the 1970s and 1980s where automatic sprinkler systems are present, the major model building codes, commonly referred to as the legacy codes, began to allow significant reductions in the minimum requirements for passive fire protection (6, 7, and 8). Further the development of codes and standards have continued to erode the passive fire protection features incorporated into buildings. Examples include:

- The allowable areas of buildings where sprinklers are present can be increased by 300%.
- Building heights can be increased by one story.
- Length of egress routes to reach exits can be increased.
- The use of non-fire-rated and combustible exteriors is more readily permitted.
- Areas of refuge for persons with disabilities or others directed to shelter-in-place can be eliminated.
- Fire resistance ratings for structural elements and elements intended to contain fire spread can be reduced.
- Fire walls can be constructed of combustible materials.

Reducing the minimum amount of passive fire protection from buildings has removed a significant amount of inherent robustness. This was all accomplished even though data reported by the U.S. Fire Administration and complied and analyzed by the National Fire Protection Association (9) shows that fire sprinkler systems only extinguish or control fires 84% of the time when called upon by fires large enough active the systems.

In general, many minimum building code requirements are becoming less stringent. Whether a code change will increase the cost of construction must be clearly stated on any code change proposal put forward in the code development process. This is a flag for supporters of least-initial-cost to oppose changes regardless for the potential to save lives or protect property. As a result it appears that the minimum codes are becoming more about minimum life safety and less about public welfare which includes property protection. This means that if occupants can safely evacuate a building, the building could be a total loss and the intent of the code is still satisfied. However this is no longer being found acceptable to many jurisdictions. States are now developing criteria that are considered minimum building code “plus” that could be voluntarily adopted by local jurisdictions that see the need for enhanced resiliency. Planning and research groups (10) are identifying “resilience” as a necessary step above minimum life safety.

In general, when the legacy model building codes (6, 7, and 8) were merged to form a single national model building code, the International Building Code (11), the most stringent structural design criteria from each of the codes was used in the newer single model code. However, usually the least stringent passive fire protection features from each of the codes were incorporated into the single model code.

Another trend in construction practices is to use lighter and less expensive construction. This appears to be driven by development of engineering products and systems to just meet minimum building code requirements. An example is exterior wall sheathing. Over time sheathing transitioned from plywood to structurally similar orient strand board (OSB) and then to foam sheathing that offers little bracing resistance or impact protection.

Another factor was a change in liability for construction projects in the 1980s. Owners began to hire consultants to value-engineer construction projects. This resulted in modifications to specifications and construction requirements developed by the design firms. This forced design professionals to shed a significant amount of responsibility for the design and construction of projects. For many projects the cost of the consultants was justified by simply using less costly materials, components and systems which often have shorter service lives and are less robust.

These many changes, individually and in combination, appear to have a more significant impact on the dramatic increases in property losses than changes in demographics, frequencies in severe weather events, or the amount of construction put-in-place. Many states and local jurisdictions are developing and implementing programs that include mandatory design and construction criteria that exceed minimum life safety criteria in an effort to reverse this trend.
Impacts of Disasters Are Rarely Local

In addition to the desire for enhanced resiliency at the state and local levels, there are increased activities at the national level. Communities impacted by disasters can be far reaching. Closure of ports, terminals, factories, refineries, etc. due to disasters may impact the availability of goods not only locally, but also regionally or nationally. Shortages can drive increases in the costs of goods. Insurance premiums may increase over broad areas or even nationally.

While essential facilities tend to be designed to be more resilient, often based on special provisions in building codes, the facilities cannot operate if workers manning these facilities do not have places to live. In order for workers to return to places to live they at least need to be able to obtain water, food, other essential goods and services. Communities are now recognizing that residences and neighborhood businesses must start to operate shortly after disasters in order for communities to be resilient. More resilient buildings and infrastructure result in more resilient communities which in turn allow regions and even the nation to be more resilient.

ACHIEVING ENHANCED RESILIENCE

There are a variety of strategies that may be used for communities to improve their resilience, continuity and sustainability. There are methods to model disaster risk and impacts, such as HAZUS, Integrated Rapid Visual Screening Series, and the Urban Blast Tool (12, 13, and 14). While modeling is a preferred method to accurately predict the impacts of disasters, these models are sophisticated and to be useful require an inventory of the buildings within the area impacted by the disaster. The inventory is not simply the type and size of the building but must also include how the building is expected to respond to the exposure. As such, these modeling approaches are currently cost prohibitive for most jurisdictions. While not nearly as accurate, an approach that is more simplistic and less costly to implement is to require buildings to exceed the minimum building code requirements on a building by building approach.

A Building by Building Approach

Popular perceptions by the general public regarding disasters include: “It won’t happen to me.” or “I’m safe because my home or place of work was built to code.” And when disasters occur and a building or storm shelter is left standing, Figure 7, the comment is “They were lucky.” They weren’t “lucky,” they had more disaster resistant buildings. More resilient construction need not be a bunker either. All that needs to be done is to require buildings to be designed and constructed to resist larger loads and be more resistant to damage due to flooding and fire. Voluntary programs have been in place to encourage increased resilience for decades. One such program is offered by the national association representing insurers and re-insurers (15). The recommendations which are consistent with the insurance industry program are presented as modifications to the most widely used national model building code, International Building Code (11). Specific criteria written in mandatory code language and formatted as modifications to minimum building code requirements have been developed. The High Performance Building Code Requirements for Sustainability are available for free download from the Portland Cement Association, www.cement.org. (16). The criteria have an emphasis on structural components, fire protection and safety, and building cladding components.
Criteria for Structural Components

Criteria for structural components address exposure to fire, flood, earthquakes, snow, and wind.

- Fire Damage Resistance - Enhanced resistance to fire damage is addressed by requiring no less than one-hour fire resistance rating for all structural components, regardless of the presence of automatic fire suppression systems.

- Flood Damage Resistance - Comply with the existing standard for flood resistant design and construction (17), but include two modifications. First, extend the Coast Zone V construction requirements to be applicable in Coastal A Zones. Second, do not permit areas levees and floodwalls to be considered as flood protective works in lieu flood resistant design because they are more frequently being beached or overtopped, see Figure 8. In addition the elevation of habitable spaces should be no less than 3 feet above base flood elevation.

- Seismic Damage Resistance – The seismic design load is increased by 20 percent in areas of high seismic risk where the 0.20 second spectral response acceleration parameter is equal to or greater than 0.4g.

- Wind Damage Resistance – Enhanced wind damage resistance and enhanced life safety are provided with increases to design wind speeds and by requiring storm shelters in high wind hazard risk areas. Design wind speeds are increased by 20 miles per hour for all locations. In addition attachment methods for cladding components are required to be in accordance with appropriate standards referenced in the model codes. Attachment is an important feature not only to keep building enclosures intact to minimize interior damage, but also to reduce the potential for these components to become projectiles driven at very high speeds causing damage to other structures. The national model building codes require storm shelters to be designed and constructed in accordance with appropriate standards (18) but provide no criteria or guidance as to where storm shelters are required. The provisions for enhanced resilience require storm shelters in all buildings located in hurricane or tornado prone areas except where adequate accessible community shelters are located within one-quarter mile.

Fire Protection and Safety

Enhanced resilience for fire safety and property protection are in the form of criteria for automatic sprinkler systems, passive fire protection and protection against exterior fire exposure from adjacent properties or wildland fires.

- Automatic sprinkler systems – Enhanced fire safety is achieved by requiring fully sprinklered buildings in accordance with existing industry standards, Standard for the Installation of Sprinkler Systems (19) and requiring automatic sprinkler systems for all occupancies except low hazard manufacturing and storage facilities. However, since the sprinklers are most effective at increasing evacuation and studies (9) have shown that operating sprinkler systems only perform about 84% of the time when called upon by a large enough fire, it is imperative that these sprinkler criteria be combined with the criteria for enhanced passive fire protection. Further, when disasters occur it is not uncommon for fires after the primary disaster to cause more property loss than the primary disaster, such as fires after earthquakes. Also, when people return or survive after a major disaster they tend to use open flames for light, water purification, heat, and cooking increasing the risk of fire when water supplies may have been disrupted. When the issue is expanded from life safety to property loss, smoke and water damage, even where sprinklers ultimately control the fire, may be as significant as the fire damage.
Passive fire protection – The primary criteria for enhanced resilience related to passive fire protection is associated with what is commonly termed sprinkler trade-offs. In efforts to justify the cost of adding sprinkler systems to buildings trade-offs in the amount and type of passive fire protection have been integrated in the national model building codes. Generally, passive fire protection required without consideration of sprinkler trade-offs results in more robust buildings and will better contain and limit the spread of fires should sprinklers fail to operate, which is common during and after major disasters because water supply has been disrupted. The requirements simply do not allow reductions in fire resistance ratings of building elements, increases in travel distances to exit ways, elimination of areas of refuge, increases in building heights, increases in building areas, and increases in the flame spread on interior finishes simply because sprinklers have been added to the building.

Exterior fire protection – To reduce the exposure to external fires two primary criteria are put forward. The first increases from 5 feet to 30 feet the distance from property lines where combustible finish materials are permitted on the exterior of buildings. The second is to require compliance with the requirements of the International Wildland-Urban Interface Code (20). While the code exists and the requirements are only applicable where certain climate, topography, vegetation, and proximities exist, the requirements are not readily adopted as mandatory. The requirements for enhanced resilience include mandatory compliance with the wildland-urban interface fire protection requirements where applicable.

Building Cladding Materials

In addition to satisfying applicable criteria for enhanced fire protection and structural attachment, cladding materials must also be resistant to wind damage as shown in Figure 9, and hail damage as shown in Figure 10.

Wind damage resistant – The national model building codes already limit the types of cladding materials that may be used in high wind exposures specifically citing limitations for vinyl siding. For enhanced resilience these criteria are expanded to include exterior insulation and finish systems (EIFS). The prohibition for the siding materials is retained at elevations above 40 feet. In addition, both vinyl and EIFS are prohibited as cladding materials in hurricane prone regions unless tested to demonstrate adequate performance.

Hail damage resistance – Both vinyl siding and EIFS are prohibited in moderate and severe hail exposures regions as defined by the code unless tested to demonstrate adequate performance using appropriate test methods. Similarly, roofing materials must also demonstrate compliance with criteria based on appropriate test methods. These failures jeopardize the integrity of the building enclosure which may result in further damage to other components of the exterior envelope and interior components.

CONCLUSION

According to Natural Hazard Mitigation Saves: an Independent Study to Access the Future Savings from Mitigation Activities, for every dollar spent on design and planning for disaster mitigation four dollars are saved when disasters occur (21). Nearly one-third of all existing buildings will need to be replaced by 2030 simply because they were not designed and constructed to last any longer (1). Where feasible, programs should be implemented to enhance the resilience of existing buildings. Unfortunately, improvements to the core and shell of
existing buildings are often too difficult and expensive. However, by changing the way new buildings are designed and constructed, more resilient buildings would replace less resilient buildings as they are demolished. If started now, within decades, a return to more resilient construction could result in the majority of existing buildings, communities, regions, and the nation becoming more resilient.

ILLUSTRATIONS

Figure 1
Robust Buildings: Winecoff Hotel, Atlanta, GA in Left Images and 90 West, New York City, NY in Right Images
Figure 2
U.S. Total Property Loss Due to Disasters in Billions of 2010 Dollars per Decade

Figure 3
U.S. Total Property Loss Due to Disasters in Billions of 2010 Dollars per Decade
Figure 4
Frequency of Hurricanes Making Landfall in the U.S. Shown on the Left and Property Losses Due to Hurricanes in Billions of 2010 Dollars per Decade Shown on the Right

Figure 5
Frequency of EF3 to EF 5 Tornadoes in the U.S. Shown on the Left and Property Losses Due to Tornadoes in Billions of 2010 Dollars per Decade Shown on the Right

Figure 6
Construction Put In Place Per Decade, Showing Residential Millions of Units on the Left and Commercial Construction Put in Place in Billions of 2010 Dollars on the Right
Figure 7
Typical Examples of Resilient Buildings, Wildland Fire on the Left and Hurricane on the Right

Figure 8
Levees May Be Breached or Overtopped

Figure 9
Examples of Wind Damage
Table 1: U.S. Property Losses Due to Disasters in Billions of 2010 Dollars

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References

(3) U.S. Census Bureau, 4600 Silver Hill Road, Washington, DC 20233 www.census.gov.