Defining Resilience

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INTRODUCTION

The concept of building for resilience has been increasingly adopted by various organizations over the past five years. Organizations use different definitions or phrases to describe resilience and the hazards that are included in resilient design. These definitions from six sources are compared and a single definition incorporating these is developed.

RESILIENCE AS DEFINED BY SELECT ORGANIZATIONS

Industry Statement

Twenty-one organizations, including the U.S. Green Building Council (USGBC), the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), the American Institute of Architects (AIA), the American Society of Civil Engineers (ASCE), the Building Owners and Managers Association (BOMA), and the National Institute of Building Sciences (NIBS) issued an industry statement on resilience[1] that stated (the bold or red text is theirs):

> Representing more than 750,000 professionals, America's design and construction industry is one of the largest sectors of this nation's economy, generating over $1 trillion in GDP. We are responsible for the design, construction, and operation of the buildings, homes, transportation systems, landscapes, and public spaces that enrich our lives and sustain America's global leadership.
>
> We recognize that natural and manmade hazards pose an increasing threat to the safety of the public and the vitality of our nation. Aging infrastructure and disasters result in unacceptable losses of life and property, straining our nation's ability to respond in a timely and efficient manner. We further recognize that contemporary planning, building materials, and design, construction, and operational techniques can make our communities more resilient to these threats.
>
> Drawing upon the work of the National Research Council, **we define resilience as the ability to prepare**

Figure 1 – Overturned house from beach erosion after Hurricane Irma. (Image 3003931, www.pixabay.com)

and plan for, absorb, recover from, and more successfully adapt to adverse events.

As the leaders of this industry, we are committed to significantly improving the resilience of our nation's buildings, infrastructure, public spaces, and communities.

- We **research** materials, design techniques, construction procedures, and other methods to improve the standard of practice.
- We **educate** our profession through continuous learning. Through coordinated and continuous learning, design, construction, and operations, professionals can provide their clients with proven best practices and utilize the latest systems and materials to create more resilient communities.
- We **advocate** at all levels of government for effective land use policies, modern building codes, and smarter investment in the construction and maintenance of our nation's buildings and infrastructure.
- We **respond** alongside professional emergency managers when disasters do occur. Industry experts routinely work in partnership with government officials to survey damage, coordinate recovery efforts, and help communities rebuild better and stronger than before.
- We **plan** for the future, pro-

Figure 2 – Flooding in New Orleans after Hurricane Katrina. (Image 81669, www.pixabay.com)

Figure 3 – Hurricane damage to houses. (Image 63005, www.pixabay.com)

actively envisioning and pursuing a more sustainable built environment.

The promotion of resilience will improve the economic competitiveness of the United States. Disasters are expensive to respond to, but much of the destruction can be prevented with cost-effective mitigation features and advanced planning. Our practices must continue to change, and we commit ourselves to the creation of new practices in order to break the cycle of destruction and rebuilding. Together, our organizations are committed to build a more resilient future.

U.S. Department of Homeland Security

The Department of Homeland Security defines resilience[2] and states (red text added for emphasis):

> PPD-21 defines resilience as **the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions**. Resilience includes the ability to withstand and recover **from deliberate attacks, accidents, or naturally occurring threats or incidents**.
>
> Examples of resilience measures:
> - Developing a business continuity plan
> - Having a generator for back-up power
> - Using building materials that are more durable

National Institute of Standards and Technology (NIST)

NIST has many publications on resilience. NIST defines resilience, in the context of buildings and infrastructure systems,[3] and states (bold red added for emphasis):

> Community resilience is **the ability of a community to prepare for anticipated hazards, adapt to changing conditions, and withstand and recover rapidly from disruptions**.

Although communities cannot stop natural hazards and have limited ability to prevent technological and human-caused hazards, they can minimize disastrous consequences.

The extent of recovery and the ultimate outcome depend upon the nature and severity of the event and the community's preparedness to prevent incidents, mitigate risk, protect assets, respond in a timely and coordinated way, and recover community functions. Together, these measures determine the community's resilience.

Prevailing hazards. Each community has its own prevalent hazards to consider when planning for long-term community resilience. The following is a partial list of hazards that communities may face:

- Wind – wind storms, hurricanes, tornados
- Earthquake – ground shaking, ground faults, landslides, liquefaction
- Inundation – river flood, flash flood, coastal flood/storm surge, tsunami
- Fire – urban/building, wildfire, and fire following another hazard event
- Snow or rain – snow storms, ice storms, blizzards, drifts, ice dams, freezes or thaws, rain storms that overwhelm drainage systems
- Technological or human-caused – blasts, vehicular (including rail) impacts, toxic environmental contamination as a result of industrial or other accidents as well as due to cleanup/disposal methods after a hazard event

Hazards or events include wind and flood caused by hurricanes (*Figures 1* through *3*), other floods (*Figure 4*), wind caused by tornados (*Figure 5*), wildfires (*Figures 6* and *7*), and blasts from terrorism (*Figure 8*).

Community and Regional Resilience Institute

This organization defines community resilience[4,5] and states (bold red added for emphasis):

> The goal of the Community and Regional Resilience Institute (CARRI) **is to strengthen any community or region's ability to prepare for, respond to, and rapidly recover from a significant human-caused or natural disaster with minimal downtime for the community.**
>
> **Resilience is the ability to anticipate risk, limit impact, and bounce back rapidly through survival, adaptability, evolution, and**

Figure 4 – Flood damage to neighborhood houses. (Image 642586, www.pixabay.com)

growth in the face of turbulent change.

Resilient communities minimize any disaster's disruption to everyday life and their local economies. Resilient communities are not only prepared to help prevent or minimize the loss or damage to life, property, and the environment, but they also have the ability to quickly return citizens to work, reopen businesses, and restore other essential services needed for a full and timely economic recovery.

Our approach to resilience is based on a simple economic rationale: communities have a quantifiable level of functional capacity. In a crisis situation, that capacity declines at a rate and to a depth that is largely dependent upon the nature of the disruption, the community's level of preparedness for that specific disruption, and the rapidity and effectiveness of that response. More importantly, the recovery rate depends on those same factors.

Figure 5 – Wind damage to house caused by tornado in Joplin, MO. (Image 642586, www.pixabay.com)

Resilient Design Institute

Alex Wilson, the founder of Building Green, founded and is president of the Resilient Design Institute, which defines resilience[6,7] as follows, and also provides additional information (the bold is theirs):

Resilience is the capacity to adapt to changing conditions and to maintain or regain function-

Figure 6 – Helicopter mitigates wildfire approaching buildings. (Image 2142140, www.pixabay.com)

Figure 7 – Wildfire approaching buildings. (Image 3747355, www.pixabay.com)

ality and vitality in the face of stress or disturbance. It is the capacity to bounce back after a disturbance or interruption.

At various levels, individuals, households, communities, and regions can maintain livable conditions in the event of natural disasters, loss of power, or other interruptions in normally available services.

Relative to climate change, resilience involves adaptation to the wide range of regional and localized impacts that are expected with a warming planet: more intense storms, greater precipitation, coastal and valley flooding, longer and more severe droughts in some areas, wildfires, melting permafrost, warmer temperatures, and power outages.

Resilient design is the intentional design of buildings, landscapes, communities, and regions in response to these vulnerabilities.

The Resilient Design Principles:

1. Resilience transcends scales. ...
2. Resilient systems provide for basic human needs. ...
3. Diverse and redundant systems are inherently more resilient. ...
4. Simple, passive, and flexible systems are more resilient. ...
5. Durability strengthens resilience. ...
6. Locally available, renewable, or reclaimed resources are more resilient. ...
7. Resilience anticipates interruptions and a dynamic future. ...
8. Find and promote resilience in nature. ...
9. Social equity and community contribute to resilience. ...
10. Resilience is not absolute. ....

U.S. Green Building Council (USGBC)

With the help of Alex Wilson and others, USGBC developed three pilot credits on resilience.[8]

> The three credits are intended to ensure that a design team is aware of the type of natural and human-made disasters that are most likely to occur in the project's region (taking into account longer-term trends like climate change), and that the team addresses the riskiest vulnerabilities through the project's design. The credits include:
>
> - Credit IPpc98: Assessment and Planning for Resilience
> - Credit IPpc99: Design for Enhanced Resilience
> - Credit IPpc100: Passive Survivability and Functionality During Emergencies

The three credits are summarized on The Resilient Design Institute website.[9] They are Integrative Process (IP) credits and pilot credits (pc), and they can be used for all Leadership in Energy and Environmental Design (LEED) Building Design and Construction (BD+C) rating systems, along with Homes and Mid-Rise Residential rating systems. Per the website (the bold is theirs):

> These three credits are designed to ensure that a design team is aware of vulnerabilities and addresses the most significant risks in the project design, including functionality of the building in the event of long-term interruptions in power or heating fuel.
>
> **Credit IPpc98 – Assessment and Planning for Resilience**
>
> ...To earn this credit, one must satisfy a prerequisite and one of two optional measures.
>
> The prerequisite is substantial: to

Figure 8 – Damage from impact and blast due to terrorism at Pentagon on September 11, 2001. (Image 60569, www.pixabay.com)

complete a hazard assessment for the project site. This involves identifying the potential high risks associated with natural hazards that could affect the site. Specific requirements for such assessment are provided for the following hazard types: flooding, hurricane, tornado/high wind, earthquake, tsunami, wildfire, drought, landslide/unstable soils.

...In addition to satisfying the prerequisite above, to earn Credit IPpc98, the design team must implement one of the following:

- **Option 1 – Climate-Resilient Planning...**
- **Option 2 – Emergency Preparedness Planning...**

Credit IPpc99 – Design for Enhanced Resilience

This credit is designed to ensure that each of the top hazards identified in Credit 1 are addressed through specific mitigation strategies. To earn Credit IPpc99, you have to, first of all, satisfy the hazard assessments in Credit IPpc98.

Then you have to implement specific mitigation measures for the identified hazards. (If more than three hazards are identified for a particular site, only the top three need to be addressed.)

Credit IPpc100 – Passive Survivability and Functionality During Emergencies

The intent of this credit is to ensure that buildings will maintain reasonable functionality, including access to potable water, in the event of an extended power outage or loss of heating fuel. Power outages are often one of the primary impacts of natural disasters, and there is growing concern about terrorist actions targeting energy infrastructure.

This credit includes three options, any two of which are required to earn the LEED point.

Option 1 – Thermal Resilience

...Livable conditions are defined as SET temperature between 54°F and 86°F...

Option 2 – Backup Power...

Option 3 – Access to Potable Water...

DISCUSSION

The general nomenclature for the events, what they consist of, and the phases of resilience that are included in resilient design definitions vary across organizations.

The adverse events are described as:

- "Adverse events" per the Industry Statement
- "Disruptions" per the Department of Homeland Security, NIST, and CARRI
- "Events" or "hazards" per NIST
- "Turbulent change" per CARRI
- "Stress or disturbance" or "interruption" per the Resilient Design Institute
- "Hazard" or "interruption" per USGBC

These adverse events, disruptions, or hazards are described as:

- "Natural" or "naturally occurring" per all six organizations
- "Technological" per NIST
- "Manmade," "human-caused," "deliberate attacks," or "terrorist attacks" per the Industry Statement, the Department of Homeland Security, NIST, or CARRI
- "Accidents" per the Department of Homeland Security
- "Loss of power or other interruptions" per the Resilient Design Institute and USGBC

These can include designing for climate change, floods, wind (tornados and hurricanes), earthquakes, tsunamis, droughts, landslides and unstable soils, fires (including wildfires), terrorism, and other events.

The phases to be included before, during, or after the adverse event also vary. These include three primary phases:

1. **Before the adverse event:** Planning for or preparing for the adverse event or hazard, or by anticipating risk (per all six organizations). This can include addressing risk (per USGBC) or mitigating risk (per NIST).
2. **During the event:** Absorb or limit impact (per the Industry Statement and CARRI) or withstanding the event (per the Department of Homeland Security and NIST).
3. **After the event:** Recover, bounce back, or regain functionality (per all six organizations). To do this "rapidly" was mentioned by the Department of Homeland Security, NIST, and CARRI.

In addition, all six organizations included "adapt." The Department of Homeland Security, NIST, and CARRI included "adapt to changing conditions."

Resiliency can be accomplished through risk assessment, design, construction, and preparation.

CONCLUSION

The definitions and phrases used to define resilience from six sources were compared.

In summary, resilience is to:

- Plan or prepare for the natural or human-caused hazard or event by anticipating the risk, which can include addressing risk and mitigating risk
- Adapt to changing conditions
- Withstand, absorb, or limit the impact while preferably maintaining functionality during the event
- Recover (preferably rapidly) and regain functionality after the event

Resiliency can be accomplished through risk assessment, design, construction, and preparation.

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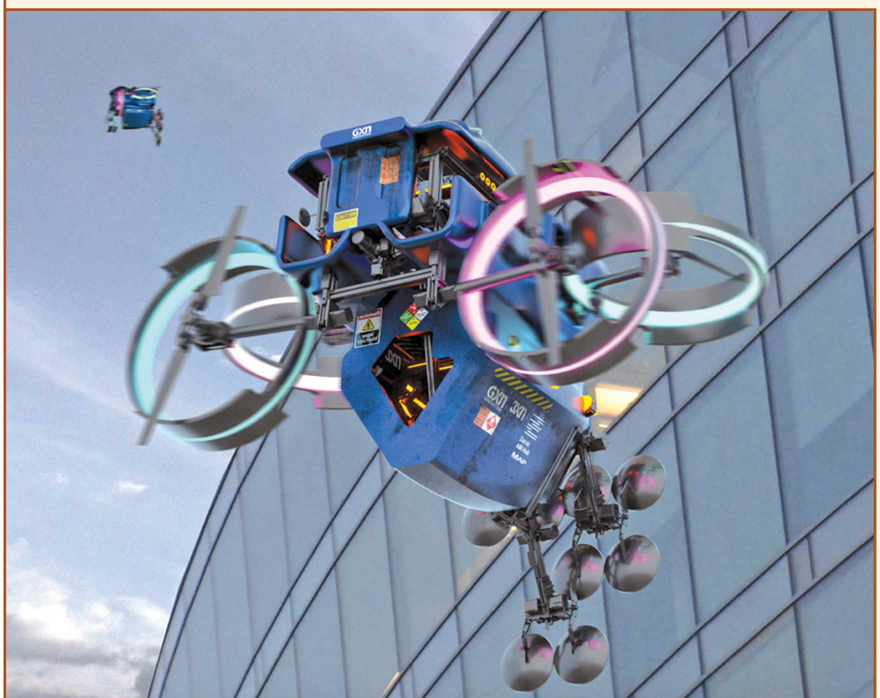
Mobile 3-D Printing Envisions Façade Repair Robots



Robotic printer fixing building enclosure façade. Image courtesy of GXN.

What if sometime soon a "drone printer" could repair the façade of a high-rise building much as a 3-D printer can lay concrete to print a basic building?

GXN, the research spinoff of Danish architectural firm 3XN, is studying high-tech robotics that could repair, enhance, and build sections of high-rise façades. GXN is working with government-sponsored Dansk AM Hub and MAP Architects on experimentation in additive manufacturing to create prototypes that imagine a future where our buildings and infrastructure could be created and maintained with the help of autonomous robotic 3-D printers.

They created both mechanical and virtual prototypes—from spidery drones that could print fungus into micro-cracks on highways to prevent further damage, to futuristic drones that could seal thermal enclosures of high rises.

— The Architect's Newspaper