

Integrating Resilience into a Sustainability Program: Process, Guidelines and Tools

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ABSTRACT

Sustainability and resilience are different sets of design goals that establish relationships between the built environment (buildings, neighborhoods, campuses etc.) and their social and ecological context at many scales. The goals can be complementary, in conflict, or unrelated. A key decision for policymakers is whether to establish separate or integrated resilience guidelines with existing sustainability programs. This paper outlines an integrated approach to sustainability and resilience in the Minnesota Sustainable Building Guidelines (B3) which have been used for state funded construction in Minnesota for over twenty years to meet sustainability goals. Building upon previous research based on regenerative design as a methodology to align resilience and sustainability, the work has moved to developing specific guidelines and tools to set goals for 20-30 state funded construction projects per year. These projects vary in size from environmental centers in state parks to large university buildings, in transects from urban to suburban to rural and in multiple climate zones.

This paper previews new guidelines and a “resilience worksheet” for projects to implement. Multiple roles and use cases for buildings are considered during design to facilitate optimal system choices that provide appropriate functionality during and after disasters or disruptions. The tool also includes a rough analysis and estimate of what a building mimicking a regenerative energy system would require: efficient building envelope, solar panels, and storage enable the building to interact with the grid and benefits occupants, building owners, and the utility. The new guideline and tool integrate resilience into B3 and avoid the clutter and confusion of separate programs. This approach has made clear the critical importance of aligning sustainability and resilience guidelines in sustainable building programs.

Introduction

Environmental and social systems are undergoing tremendous change in the face of global climate change, technological change, and globalization. The built environment is facing increasingly dynamic future conditions to be considered as design criteria. As a result, performance design guidelines for the built environment (buildings, neighborhoods, campuses etc.) need to integrate a resilience perspective into their requirements. A fragmented approach to high performance building guidelines risks fragmented guidance at best, and at worst, critical areas of consideration to be forgotten entirely. Resilience, generally thought of as the ability to respond, absorb, adapt to, and recover from a disruptive event, and other critical topics should be integrated and optimized into sustainability programs to address all the challenges and opportunities facing the built environment.

Since 2002, Minnesota has pursued energy efficiency and other sustainability goals for buildings funded by the state, as an investment in public infrastructure and as a demonstration of what is possible in the private sector. This effort is codified in a legislative statute (State of

Minnesota, 2021) that establishes the Minnesota Sustainable Building Guidelines: Buildings, Benchmarks and Beyond or “B3” system. This collection of programs provides performance guidelines to all state funded construction in Minnesota. The guidelines cover five areas: Performance Management, Site and Water, Energy and Atmosphere, Indoor Environmental Quality and Materials/Waste. The Center for Sustainable Building Research (CSBR) at the University of Minnesota manages and updates the system for the Minnesota State Departments of Commerce and Administration. Guideline requirements are regularly reviewed and evaluated in comparison to other green building standards and policies both domestic and international. New guideline development is occasionally guided by research funded and performed outside of the program, as is the case with the resilience guidelines. The creation and maintenance of a Minnesota-specific sustainable building program allows for targeted strategies and goals, and for greater control of project outcomes by using required measures rather than accumulating points to achieve a rating, which may result in buildings that claim sustainability but do not meet the performance targets as established by legislation. The B3 guidelines take inspiration from national standards that have been developed and updated throughout the program’s history.

This paper explores the benefits of integrating resilience into an existing sustainability program, specifically the B3 guidelines, instead of creating a separate program. The integrated approach forces the policy development team to address the conflicts between different design goals. (Rajkovich and Holmes, 2022). Some of these conflicts should be resolved at the program level, however some are best reviewed by the design team and are specific to the site, project, or other considerations. The sustainability guidelines in Minnesota take a “place-based” approach to guidelines. In other words, the program requires design teams to understand the unique context of their project: site, watershed, climate, soils, density, neighborhood, and other factors should shift the specific design goals to optimize the impact and benefits to social and ecological systems for a project. The program uses a variety of approaches and tools to create place specific guidelines for projects. This approach is quite different from other green building programs (LEED etc.) that prefer more universal guidelines.

After exploring the process of developing and integrating resilience guidelines into a sustainability program, the development of a resilience tool for design teams is discussed in detail. The shifting factors and specific context affecting design guidelines require the development of tools to streamline the process for design teams. A number of tools and approaches are discussed. The development of the Resilience Worksheet is discussed that gives an example of a tool provided for design teams to input site specific data for their project, develop a risk assessment and create effective design goals.

Integrating resilience into green building programs is still emerging in research and many lessons are being learned to in the development process, application in projects and analysis of new climate data. The paper discusses the lessons learned from this process of developing a potential tool for project team use in state-funded construction, and future research needed.

Integrating Resilience into Sustainability Guidelines

In 2018, The Center for Sustainable Building Research (CSBR) received funding from the Minnesota Pollution Control Agency to use a regenerative design approach to explore the intersection of resilient and sustainable design. (Graves, Kutschke, and Weber, 2018.) In that research, two buildings designed to be net zero energy and carbon The regenerative systems model utilized was defined by John Tillman Lyle in 1994 (Lyle 2014). Lyle contrasted the

typical built environment development model that use resources (energy, water, materials) in one-way flows versus an approach that mimics natural systems. According to Lyle, in nature development means increasing the complexity of a system to enhance its vitality and resilience. Natural systems use multiple sources for resources, store resources to align collection with use and work in cycles. Waste from one process feeds the input of other processes. The research team used Lyle's regenerative system diagram as the model for adapting high performance building prototypes.

Multi-family housing and library building prototypes were developed and modeled to achieve net zero energy (Pless and Torcellini 2010) and net zero carbon and were adapted to function as regenerative systems to improve their performance in response to a series of shocks causing disruptions building function such as electricity or water outages. The original prototypes were designed to achieve net zero energy using historic weather files for energy modeling. When the projects were reconsidered using a regenerative design approach, they were also reviewed for energy analysis using future weather files generated by Climate Shift¹ based upon the Representative Concentration Pathway 8.5², the then-current 'business as usual' scenario for greenhouse gas emissions which was considered to be the most likely future (Dickinson and Brannon, 2016). This was an initial approach to resilient energy design modeling that is the subject of significant emerging research (Holmes, 2022). While the initial approach provided valuable insight in the research, future work will consider alternative ways of "dynamically" downscaling weather files for resilience design modeling in Minnesota.

The research project explored the following hypothesis: "A building adapted to replicate a regenerative system state will be both sustainable and resilient." The process to probe resilience in parallel with regenerative outcomes utilizes a vulnerability assessment process to identify critical functions, environmental risks, and opportunities for mitigation in the assessment of two building prototypes: a library (community hub) and a multifamily residential building (shelter in place). An examination of seasonal impacts based on hazard potential was also conducted. A scenario planning process was used to test underlying assumptions with an advisory group. The scenarios were based on disruption of critical functions (power, water, etc.) rather than specific natural or human-made disasters. The analysis of the effects of a changing climate in winter versus summer on the built environment forced the research to consider disruptions during cold weather and hot-humid weather. These conditions both benefit from a high-performance building envelope with more insulation but may require other adaptations unique to summer or winter. In addition, providing roof top solar in combination with battery storage was an important energy strategy to enable buildings to respond to a number of resilience load challenges. This approach gives additional tools for projects to seek Net Zero energy and carbon goals at the building and site scale. Distributed solar energy at the building scale may be more expensive than utility or neighborhood scale solar when considered for the overall sustainability of the energy system, however the resilience benefits at the building scale should also be considered. The energy strategies to mimic natural systems that combine solar roofs and battery storage may also have benefits in allowing high performance buildings to be "grid

¹ A collaboration between IES, Arup, and Argos Analytics to create location-specific future weather data available to designers and researchers. Limitations in use of these files is similar to conventional weather files, in that they cannot assess specific micro climates or regional factors that may affect local conditions

² Representative Concentration Pathway: a greenhouse gas concentration trajectory adopted by the Intergovernmental Panel on Climate Change in 2014. Of the four possible climate futures adopted, RCP 8.5 refers to the highest predicted emissions levels over time.

interactive” (New Buildings Institute, 2019) with the proper controls. Grid interactivity along with resilience represent a larger set of benefits than sustainability alone and are another example of why an integrated approach to guidelines is preferred.

To identify adaptation strategies required in the prototype buildings, the team used disruptions in services potentially caused by disaster events, rather than specific disaster scenarios, (tornado, ice storm, flood etc.) to test the prototypes. The three service disruptions used were:

- Disruption of energy supplied by the electrical grid and natural gas service
- Disruption from municipal water supply and wastewater removal
- Disruption from vehicle transportation

Disruptions were assumed to last ten days with “relief” coming after four days with supplies of food and water. This determination was made based on the recovery and relief efforts of recent catastrophic storm events. In addition to mapping the resilience goals to the goals of a regenerative systems state, it was necessary to develop macro strategies and real-world outcomes that Lyle’s conceptual diagram does not address. This was first achieved by translating resilient and regenerative goals such as “renewable sources of energy” into specific outcomes, strategies and services provided by an energy system, for example maintaining habitable temperature, store energy, and operate the building in low power mode. Second, these outcomes needed to be connected to actionable strategies for integration into the building prototypes to improve system resilience in response to disruptions and therefore improve resilience in the buildings.

It was determined that the B3 guidelines provided a good start towards buildings that are both sustainable and resilient with high levels of energy efficiency and building envelope insulation. However, the guidelines could expand on the intentionality and impact of resilient design considerations. Unfortunately, due to the authorizing legislative language of the Minnesota Sustainable Building Guidelines, resilience measures that do not explicitly connect to a sustainability measure are not permitted to be required guidelines. This restriction shaped the overall approach to resilience within B3, including the creation of a new guideline, additions to some existing guidelines, and identification of those guidelines with co-benefits to sustainability and resilience.

Given that the B3 guidelines apply to a wide range of building sizes, use types, and budgets, it became apparent that requiring any specific set of resilience measures would not be realistic or appropriate. Minnesota is home to two climate zones, three eco regions, and municipalities with fewer than a thousand and more than 400,000 residents. Therefore, the hazards and risks and the populations affected by them cannot be captured and managed with a single set of guidelines or design strategies. This decision led to the development of one new guideline to require all projects to create a B3 Resilience Worksheet. (Kutschke 2020). The use of this worksheet will be required in a new Performance Management guideline. The intent of this new guideline is to bring awareness and intention to the functionality and role of the project in the event of a service disruption of energy, water, communication, or other services. Building measures identified in this requirement contribute to the ongoing operational sustainability and resilient response to a disaster event, and implementation of at least one identified measure is required.

Resilience Tool Development Process

The increasing complexity of climate models and the amount of climate data call for the development of tools to simplify and process information for design teams. Resilience tools have been developed for a variety of purposes and audiences (Laboy and Fannon, 2022). The resilience Worksheet for the B3 guidelines is being developed for building owners, agencies, and design teams to use in the early planning phases of a project to allow for place-based and project-specific assessment based on historic data and localized knowledge.

The initial research phase included reviews of local, national, and international resilience plans and of guidelines and measures from other green building programs such as LEED and Enterprise Green Communities. This study led to the preliminary version of the B3 Resilience Worksheet which was developed and shared in March 2020. During the initial stages of the guideline and tool creation, the input of experts was deemed to be particularly important and resulted in convening a small group of Minnesota-based experts in their fields - Laura Millberg from the Minnesota Pollution Control Agency, Kenny Blumenfeld from the State Climatology Office, and Terry Zein from the US Army Corps of Engineers. All three contributed to the Minnesota State Hazard Mitigation Plan (MNHMP) and have deep knowledge of resilience issues facing Minnesota. The group met to offer feedback on guideline language and on the worksheet tool, including identifying gaps in assessment and providing resources both for process and for those to consult for additional feedback.

Following review by the expert group, the Worksheet was revised and shared with B3 project partners for review and comment. This process led to the current version of the tool as described below. The use of the Worksheet is not yet required for B3 projects; however, the guideline language and spreadsheet tool are available for project use. Feedback is accepted on a continual basis, and the tool will continue to be updated with new data, ratings, and information as it becomes available. Since the tool has been introduced and training on utilization has been provided, a small handful of projects have requested the tool for use, however, at this time, we are unaware of measures that have been implemented based on the Worksheet and guidelines.

Resilience Worksheet

The intent of the newly created (recommended) guideline, ‘Vulnerability and Capacity Assessment and Resilience Planning’ is to bring awareness and intention to the functionality and role of the project in the event of a disruption of energy, water, communication, or other services. Building measures identified in this requirement contribute to the ongoing operational sustainability and adaptation to a changing climate and enhance a resilient response to a disruptive event. Guideline requirements are as follows:

- A. Using the B3 Resilience Worksheet, beginning at the pre-design or equivalent phase:
 - a. Perform assessment of potential natural and human-made hazards and identify highest priority hazards and impacts at the site scale.
 - b. Assess project attributes including building systems, occupants, and potential for back-up power. Identify vulnerabilities of building attributes during a disruption event.
 - c. Establish goal(s) for response to highest priority hazard(s) during a hazard or disruption event.

- d. Identify resilient design strategy or strategies to implement in project to accomplish the resilience goal.
- B. Integrate and implement at least one design strategy to mitigate a disruption event, based on the highest priority hazards and goals identified.
- C. Provide documentation and information to building end users or occupants explaining resilient design features and the operation and maintenance of those features, if necessary.

This process should include engagement with all applicable stakeholders for the project, including but not limited to building owners, building operators, property managers, engineers, trade members, and design team members. The Worksheet provides a process for engaging the diverse stakeholders in a productive discussion of the vulnerabilities, strengths, and resilience strategies for the project. An in-depth description of the Worksheet follows.

Vulnerability Assessment

The first step in completing the worksheet is a vulnerability assessment of the project site. This includes referencing local and national resources and maps that identify historic weather-based hazards, primarily at the county level. Site-specific considerations are then incorporated by project stakeholders, ideally those closely related to and highly familiar with the project and its site. Project teams start by identifying their project address and county, which will indicate if that county has a hazard mitigation plan, based on the 2019 Minnesota State Hazard Mitigation Plan³ (MNHMP). If the project county does have a plan in place, the user may proceed by identifying the top natural hazards for their county per the plan, which is linked inside the tool if available, as shown in Figure 1. If there is no plan in place, or the project team wishes to perform their own analysis, the user(s) will proceed to access information to provide historic data and/or context to assess the following hazards: flooding, high wind, tornado, wildfire, drought, hail, winter storm, and social vulnerability. These assessments are based on a combination of user inputs from external sources and pre-populated information provided by the MNHMP, all of which is based on historic weather and climate data, as shown in Figure 2.

³ This plan is developed by the Department of Public Safety's Homeland Security and Emergency Management division and approved by FEMA. It includes a county-level survey of the history and potential future of natural hazards across the state.

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D32 Represents potential for negative impacts resulting from natural hazards, calculated based on annual loss, social vulnerability, and community resilience

This is a high level assessment of hazards from natural events based on historic data and man-made events based on discussion. This page is intended to identify potential risks to the project.

Directions for Vulnerability Assessment:

Step 1. Enter project address and select county
If project county has an active and available Hazard Management / Mitigation Plan, review plan for identified hazards. Enter data from Hazard Mitigation Plan in appropriate fields, if available.
Review FEMA's National Risk Index Ratings and reference online mapping tool for additional information.
Blue fields will be auto-populated by county selection
Use the resources linked to identify remaining risk levels or data points

Step 2. For each hazard type, determine the risk level to the project (high, medium, low)

Step 3. For each hazard type, identify the building service system(s) most likely to be impacted by an event

Step 4. Based on assessment, identify building service system(s) most likely to be impacted by events of any kind

Step 5. Based on assessment, identify highest priority hazard(s) for mitigation or adaptation

KEY:
Blue highlighted areas show constants or outputs calculated by the spreadsheet
Yellow highlighted areas show required inputs
Grey highlighted areas will remain blank

Step 1
Project Address:
Project County (select from dropdown):

Hazard Mitigation / Management Plan Status: (Approved, Draft, Pending, or Expired) PDF Available? <https://www.chisagocounty.us/DocumentCenter/View/5588/Hazard-Mitigation>

[FEMA's National Risk Index](#)

National Risk Index Rating	Very Low	Represents potential for negative impacts resulting from natural hazards, calculated based on annual loss, social vulnerability, and community resilience
Expected Annual Loss Rating	Relatively Low	Represents annual dollar loss from building value, population, and/or agriculture exposure due to natural hazards
Social Vulnerability Rating	Very Low	Represents susceptibility of social groups to adverse impacts of natural hazards, proportional to total risk
Community Resilience Rating	Very High	Represents ability of a community to prepare for natural disasters, adapt to changing conditions, and withstand and recover from disruptions, inversely proportional to total risk

Scale: Very High, Relatively High, Relatively Moderate, Relatively Low, Very Low

DIRECTIONS 1 - Vulnerability Assessment 2 - Project Assessment ASCE 7 - Table 1604.5 3 - Design Strategies References

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Figure 1. B3 Resilience Worksheet, Vulnerability Assessment Step 1

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Step 2

Natural Hazards	Scale / Metric				
Flooding	Moderate Risk (Zone X, Shaded)	FEMA Flood Zone Types - High, Moderate, Minimal Risk			
		FEMA/NIST Wind Zone, Max Windspeed in Extreme Events			
		Minimum Design Load Wind Speed for 100-year Mean Recurrence Interval (MRI)			
High Wind	34	Windstorm Vulnerability Ranking (1 = most vulnerable, 87 = least vulnerable)			
	0.82	Average Windstorm Events per Year			
	0.92	Expected Windstorm Events per Year (highlighted if expected increase)			
		Design Load Windspeed for Tornado, if ≥ 250mph some project types require a shelter			
		FEMA Tornado Risk By Tornado Count and Wind Zone			
Tornado	46	Tornado Vulnerability Ranking (1 = most vulnerable, 87 = least vulnerable)			
	0.13	Historic Storm Count per Year			
	0.1	Expected Storm Count per Year (highlighted if expected increase)			
Wildfire		USDA/USFA Wildfire Hazard Potential - average rating within 5 miles			
Drought	27.6-30%	% of Time from 2000-2018 in Moderate Drought or Worse			
	39	Hail Storm Vulnerability Ranking (1 = most vulnerable, 87 = least vulnerable)			
Hail	1.02	Average Hail Storm Events per Year			
	0.65	Expected Hail Storm Events per Year (highlighted if expected increase)			
Winter Storm	Low	Perceived Risk - Minnesota Hazard Mitigation Plan			

Step 3

Risk	Primary Service Impact	Secondary Service Impact (Optional)	Source
Low	Electricity	Structure / Safety	Flood Zone (FEMA)
			Wind Zone (NIST)
			Wind Speed for 100 Year Event (ATC)
			2019 Minnesota Hazard Mitigation Plan - County Rankings
			Tornado Windspeed (ATC)
			Tornado Risk Level (FEMA)
			2019 Minnesota Hazard Mitigation Plan - County Rankings
			USDA/USFA Wildfire Hazard Potential
			2019 Minnesota Hazard Mitigation Plan
			2019 Minnesota Hazard Mitigation Plan - County Rankings
			2019 Minnesota Hazard Mitigation Plan

Man-Made Hazards

Metric / Rationale	Risk	Primary Service Impact	Secondary Service Impact (Optional)	Reference
Epidemic / Pandemic				
Civil Unrest				
Cyber Attack				
Infrastructure Failure				
Fire				
Explosion				
Major Accident				
Air or Water Pollution				

DIRECTIONS 1 - Vulnerability Assessment 2 - Project Assessment ASCE 7 - Table 1604.5 3 - Design Strategies References

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Figure 2. B3 Resilience Worksheet, Vulnerability Assessment Steps 2 and 3

After this information gathering phase, the user/ project team is asked to identify the top natural hazard and has the option to identify additional significant hazards. It should be noted that these assessments are not intended to describe probability, only to acknowledge the possibility of a natural hazard occurrence based on past events. A more detailed list of the natural hazards, metric for risk, and source of assessment can be found in Table 1.

Table 1. B3 Resilience Worksheet – Natural Hazard Risk Metrics and Sources

Natural Hazard	Metric or Scale	Source
Flooding	Flood Zone Type	FEMA Flood Zone Maps
High Wind	Max Windspeed - Extreme Events	FEMA / NIST Wind Zone Map
	Min. Design Load Wind Speed	Applied Technology Council (ATC) Hazards Map
	Windstorm Vulnerability Ranking	2019 Minnesota Hazard Mitigation Plan
	Average Windstorms per Year	
	Expected Windstorms per Year	
Tornado	Design Load Windspeed for a Tornado	Applied Technology Council (ATC) Hazards Map
	Tornado Risk by Historic Count and Wind Zone	FEMA Tornado Risk Level
	Tornado Vulnerability Rating	2019 Minnesota Hazard Mitigation Plan
	Historic Storm Count per Year	
	Expected Storm Count per Year	
Wildfire	Wildfire Hazard Potential	USDA / USFA Wildfire Hazard Potential Map
Drought	Percent of Time from 2000-2018 in Moderate Drought or Worse	2019 Minnesota Hazard Mitigation Plan
Hail	Hailstorm Vulnerability Ranking	2019 Minnesota Hazard Mitigation Plan
	Average Hailstorm Events per Year	

	Expected Hailstorm Events per Year	
Winter Storm	Perceived Risk	2019 Minnesota Hazard Mitigation Plan

Selecting the project county will also auto-populate fields under the ‘FEMA National Risk Index’ heading, which is an online mapping application that identifies community risk to eighteen natural hazards and includes data about expected annual losses, social vulnerabilities, and community resilience. The ranking scale is very high, relatively high, relatively moderate, relatively low, very low. The numerical rating scale ranges from 0 to 100, with 0 representing the least risk and 100 representing the most. Categories include: Expected Annual Loss Rating, which represents annual dollar loss from building value, population, and/or agricultural exposure due to natural hazards, Social Vulnerability Rating, which represents susceptibility of social groups to adverse impacts of natural hazards, proportional to total risk, Community Resilience Rating, which represents the ability of a community to prepare for natural disasters, adapt to changing conditions, and withstand and recover from disruptions, inversely proportional to total risk, and the National Risk Index Rating, which represents the potential negative impacts resulting from the previous three categories. The Worksheet auto-populates information at the county level, if desired, the project team can access the National Risk Index website and examine data from the census tract of the project and adjust the results with more localized information. Figure 3 shows the National Risk Index for each county in the continental United States. While most of the counties in Minnesota are calculated to be very-and-relatively low, there are opportunities to increase resilience in the built environment across the state. The national average rating is 10.60 and the Minnesota average rating is 8.57. (FEMA, 2022)

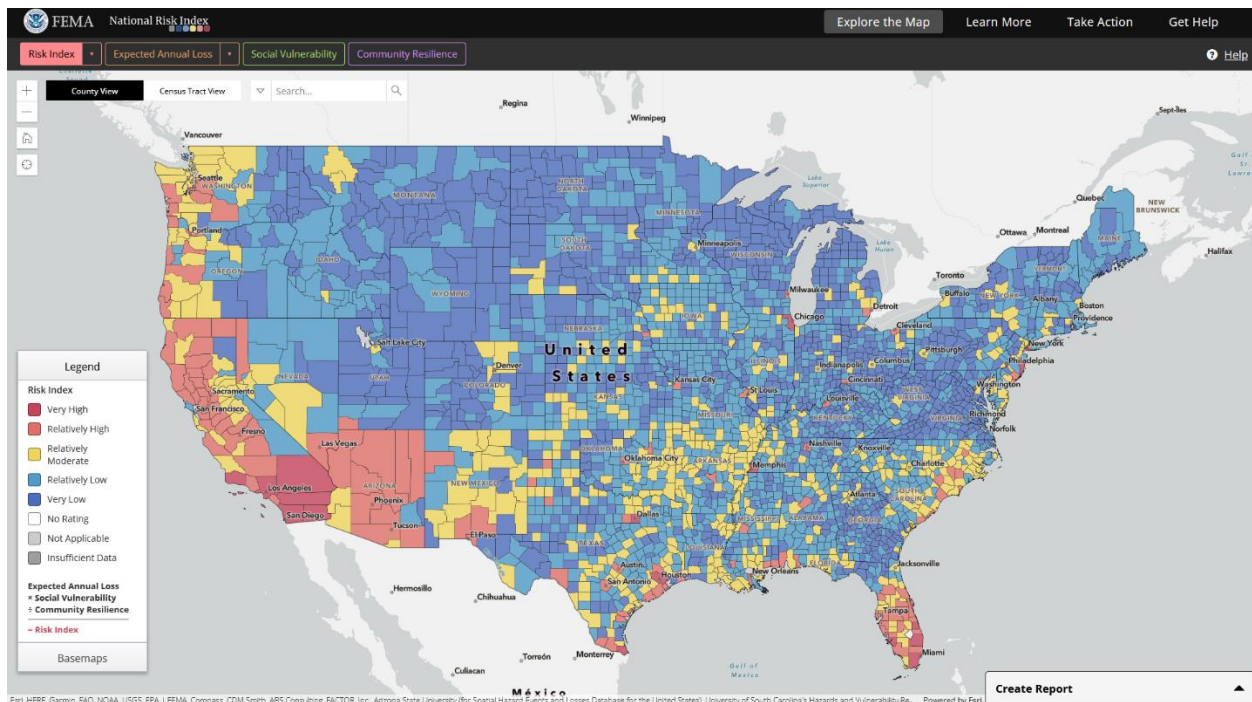


Figure 3. National Risk Index rating by County. Source: FEMA 2022

After compiling information about the listed natural hazards, project teams are asked to discuss and determine the risk level to their specific project site and program, and which building systems may be impacted by a significant natural hazard event. The impacted services in the tool include electricity, natural gas, potable water, wastewater or sewage, transportation to or from the project, the physical structure of the project, safety of occupants, communication, and food access to or from the project. The combination of larger scale natural hazard data and assessment and specific knowledge of the site is crucial for a comprehensive vulnerability assessment. Following the natural hazard assessment, the team is asked to consider human made hazards to the site. These hazards may include an epidemic or pandemic, civil unrest, cyber-attack, infrastructure failure, fire, explosion, major accident, or sudden and severe air or water pollution. These types of hazards are much harder to quantify risk in a general or broadly applicable way, for this section case design teams are asked to develop indicators associated with each hazard type. The following evaluation of risk and system impacts is the same process as with natural hazards – based on discussion and consensus.

The final component of this vulnerability assessment tab is the summarization of the services likeliest to be impacted, and the highest priority hazards. This determination is based on discussion and should be supported by the assessment performed. Hazards and impacts are documented on this worksheet tab and will be referenced in subsequent steps.

Project Assessment

This tab of the Worksheet identifies the expected use of the building, the American Society of Civil Engineers ASCE building risk category, and the intended service life of the building. The expected occupants of the building are also identified, with particular focus on the vulnerable populations of the old, the young, and the Center for Disease Control's (CDC) social vulnerability index value is determined. Project teams are asked to set a functional Resilience Goal from the options of Resilience Hub, Shelter in Place, or Evacuate and Shut Down. The primary and potential secondary systems for various aspects of the building (drinking water, heating, cooling, etc.) to support the resilience goal are identified, and a preliminary critical load for the electrical system is evaluated using NREL's REopt Lite tool. Each of these items are described in greater detail below.

The ASCE building risk category is an engineering classification of building types, the official definition of which is 'a categorization of buildings and other structures for determination of flood, wind, snow, ice, and earthquake loads based on the risk associated with unacceptable performance.' In practice, these risk categories are used by structural designers in determining the design pressures for structures and building components. The general theory is that a category one should fail before a two, a two before a three, and a three before a four. For this tool and the B3 Resilience process, it is intended to draw attention to the risk category of the building in conjunction with the previously assessed considerations of natural hazard risks and impacts.

The CDC's social vulnerability index value is based in how the CDC defines social vulnerability - as the 'potential negative effects on communities caused by external stresses on human health, including natural or human-made hazards or disease outbreaks.' (CDC/ATSDR, 2018) The social vulnerability index value is determined by fifteen census data points in four categories: socioeconomic status, household composition, race, ethnicity, and language, and housing and transportation.

The three options for a resilience goal are distinct but related and were originally conceived of during the initial resilient and sustainable design research project.

Shelter In Place

One identified mode of building operation during and after a disaster event that has disrupted major services is to ‘shelter in place.’ The goal of shelter in place is to allow occupants of the building to safely remain there for the duration of the event. This means in the possibility of an electrical grid disruption, the building should have a system for running in a critical-loads or ‘low power’ mode, including emergency lighting, an elevator, refrigeration if necessary, and minimal heating, cooling, and ventilation systems. A possible disruption in municipal water service requires storage of potable water on site, greywater or rainwater capture and reuse, and onsite wastewater management. By ensuring occupants are safe and stable during a disaster event, resources can be directed to areas of greater need.

The shelter in place mode of operation is most appropriate for buildings that have stable occupant loads and consistent users. It may also be appropriate for buildings that cannot achieve net zero energy on site, but that have significant renewable capacity. Multifamily buildings are an example that meet both criteria, which lead to the previous study of a prototypical net-zero multifamily building designed for resilience. In a shelter in place scenario, three resilient outcomes are most crucial: habitable temperature and refuge; energy generation with storage and low power operations mode; and potable water distribution or access.

Disaster Hub

Another option for an operational mode during and after a disaster event is that of a ‘disaster hub.’ The goal of this mode is to protect any current occupants, and to be available to accept new occupants from the surrounding area for the duration of the event. This means occupancy, water use, and electrical loads may be higher than day-to-day operation, which requires these systems to be slightly oversized or able to expand to support this resilience goal.

The buildings most appropriate for this operational mode are those with the capacity for oversized renewable energy systems, those with open floor plans that can be reconfigured for shelter use, and those that are familiar to the nearby populations. Libraries, community centers, or recreation centers are all examples of buildings that fit this profile, and the previous study looked in detail at a high-performance library with resilient design modifications. This has the potential to create a distributed network of resilience hubs, located in buildings that already serve their communities.

The resilient operational goals are like those of the shelter in place mode - but at a different scale. The primary goals of the resilient library building include maintaining habitable temperature, low-power operation and energy storage, and rainwater and greywater capture and use / reuse. These goals are complicated by the consideration that a library building functioning as a hub building will have a higher occupancy than during normal use - active hours will be extended, occupancy will increase and demand more ventilation energy, and those seeking shelter may need to charge devices, heat food or water, or use medical devices. Therefore, based on modeling of the previously discussed prototype building, rather than a reduced critical load, the library building requires an increased critical load that can be supported by an oversized renewable system and battery storage. This research considered some project types as disaster hubs for their use during a disruption. Additional research should consider the integration of this

use with the daily use of these project types as “Resilience Hubs” that are a part of their community and develop ways to build resilience capacity in the social infrastructure of a place to complement the physical infrastructure (Baja, 2022).

Evacuate and Shut Down

Finally, for some buildings the appropriate resilient design response is to evacuate and shut down the building in a way that it is protected from significant damage during and after a disaster event. This may mean turning off or disconnecting systems, draining plumbing, and closing and blocking wall openings. There may be a need for some energy storage to maintain vital systems or communication equipment.

The buildings most appropriate for this resilient operation mode are those with limited capacity for renewable energy generation and storage, those that are in remote locations, and those with low or no regular occupancy. The resilient operational goals include maintain interior temperature safe for contents and resist physical damage without human intervention.

Design Strategies

The final tab of the Worksheet is the design strategy bank. This is a collection of resilient and sustainable design strategies sourced from various guides and standards. Each strategy is linked to the relevant hazards and building services. Related B3 guidelines are also noted, as well as the source of each strategy for further information. This tab displays a summary of the assessment, populated by inputs in previous steps. This summary includes the highest priority hazards, services most likely to be impacted, the resilience goal, and the services required for that goal. Users of the Worksheet filter the resilience strategies by hazards and services impacted to narrow the list to those best suited to the hazards and goal of the project. The strategy or strategies identified then form the basis of the implementation into the project. When appropriate, the project team should create and share a Resilient Design Features Guide for the project owner and project occupant’s reference. This guide should explain how resilient design was included in the project and any necessary operating or maintenance information. This guide is intended to ensure that resilient design features are utilized properly in a hazard event. Any on-going sustainability co-benefits should also be highlighted and explained in this guide.

Sources for the resilience strategy bank include: Urban Sustainability Directors Network – Guide to Developing Resilience Hubs, the ReLi guidelines and LEED pilot credits from USGBC, Enterprise Green Communities Strategies for Multifamily Resilience, this Green Building and Climate Resilience publication from the University of Michigan, and the Fortified standards - a voluntary program administered by the Insurance Institute for Business and Home Safety that includes design details and material requirements. As with the hazard assessment, this portion of the Worksheet will be updated and expanded as new sources and strategies become available.

Expanding Resilience in the B3 Guidelines

In addition to the creation of a new guideline and associated worksheet, some existing sustainable design guidelines within Minnesota’s B3 program can be expanded to enhance both resilience and sustainability of the project. These additional measures are explained below:

Energy and Atmosphere - Future Weather Modeling

Using the SB2030 As-Designed tool, project teams will perform an annual energy model of the project with provided future-looking weather file to assess how changes in climate will impact the expected energy use of the building over its expected service life. Future weather may impact HVAC sizing, overall energy demand, or other performance aspects. Project teams are asked to incorporate findings from this analysis into current building design, if relevant. Initially, the project teams will use WeatherShift files developed by IES, however additional research and effort, and therefore funding, are required to develop the data and process to integrate future weather files into the design process. At the state level, the state climatology office is working to create a dynamically downscaled set of data for use in capital project planning from the global scale climate change data. While this work is progressing, there is a need to understand the overall challenges of planning for a changing climate with predictions of various levels of accuracy and precision as (Rastogi and Kahn, 2022) have outlined.

Indoor Environmental Quality - Passive Survivability

Project teams are asked to demonstrate with energy modeling that a building will passively maintain thermally safe conditions during a power outage that last four days during representative extreme summer and winter time conditions. Additional research is needed in this area to develop common metrics and/or methods for defining what constitutes a passively survivable space/facility.

Materials and Waste – Impact Resistant and Pest Control

When building in areas with a high risk of hail, windstorm, or tornados, based on the B3 Resilience Worksheet, project teams are asked to specify and install window and door assemblies that meet the appropriate performance level identified in ASTM E1996-Standard Specification for Performance of Exterior Windows, Curtain Walls, Doors, and Impact Protective Systems Impacted by Windborne Debris in Hurricanes. Similarly, when building in areas with a high risk of civil disobedience or other risks, based on the B3 Resilience Worksheet, project team as asked to specify and install window and door assemblies that meet the appropriate performance level identified in ASTM E2395-Standard Specification for Voluntary Security Performance of Window and Door Assemblies with Glazing Impact. Finally, project teams are asked to consider expanding termite range when specifying materials and detailing foundation systems.

Challenges and Constraints

Authority

Twenty years ago, the Minnesota Department of Administration was required to create a set of sustainable building design guidelines for all new state buildings. These guidelines evolved into the Minnesota Sustainable Building Guidelines (B3) that is now in its third version. The

Center for Sustainable Building Research (CSBR) at the University of Minnesota develops and manages the guidelines and provides support to project teams. CSBR developed a set of recommended guidelines to integrate the findings from the study ‘Resilient Adaptation of Sustainable Buildings’ (Graves, Weber, and Kutschke 2018) into the B3 system. Current Minnesota statute supports creating guidelines for sustainability in the building sector, however it does not allow guidelines that target resilience only. As a result, some of the recommendations for resilience also contribute to the sustainability of a project such as energy efficient building envelopes and solar power. However, some recommendations such as coupling battery storage with solar power does not provide a direct sustainability benefit, despite its resilience advantage. Therefore, efforts have started to modify the state statute to add “resilience” to the set of building design guidelines for all new and major renovations of state buildings.

Budget and Cost Implications

Resilience guidelines would operate similarly to sustainability guidelines in that requirements would not necessarily need to have a direct payback because the benefits could be to human or environmental health. This is different than the energy and carbon guidelines that have traditionally been required to have a cost-effective payback (12 years or less) to be required. As with sustainability guidelines, cost needs to be tracked for resilience measures not only for the impact to capital costs, but also to research potential benefits and returns. Some possible approaches to evaluating cost at the early stage include establishing a percentage of the total project budget to dedicate to resilience, considering the total value of a completed project and repair / replacement value, or an estimate of possible damages. This part of the resilience assessment is crucial to consider early and will be a frequent question for project teams. Additionally, when resilient design guidelines are fully incorporated and required in the B3 system, it will be crucial to track and analyze budget information and record outcomes in the event of a service disruption. This information will be utilized to continue to refine guidelines to ensure intent and impact are in line with the program and State goals.

Next Steps and Future Research

Other state work integration

An Executive Order issued in December of 2019 created the Climate Change Subcabinet and the Governor’s Advisory Council on Climate Change to Promote Coordinated Climate Change Mitigation and Resilience Strategies in the State of Minnesota. The stated goals for this group, which includes executives from fifteen state agencies, departments, and boards, include:

- Identify policies and strategies that will put Minnesota on track to meet or exceed greenhouse gas reduction goals and achieve 100% clean energy by 2050
- Identify policies and strategies that will enhance the climate resiliency of Minnesota’s natural resources, working lands, and communities and assist state agencies, businesses, and local communities to prepare for climate change impacts that cannot be avoided or mitigated
- Engage with Minnesotans on these complex issues

- Promote equitable policy solutions that can reduce disparities in Minnesota, ensure a just transition for impacted workers and communities, and encourage green economic development.

During the first years of work, this subcabinet has met to establish interagency collaboration, determine appropriate staff support, review the ongoing climate change mitigation and resilience work of state agencies and boards, determine near-term policies to consider in upcoming legislative sessions, and to build a vision for public engagement. As work continues, it will be crucial for the B3 guidelines and approach to support and enhance the approach of this subcabinet. This group may also be important in creating mandates and authority for resilient design measures.

IPCC 6

The recently released Sixth Intergovernmental Panel on Climate Change Report, ‘Climate Change 2022 – Impacts, Adaptation and Vulnerability’ draws attention to the social implications of climate change, resilience, and adaptation. The report specifically mentions the danger of maladaptation, which refers to actions that may lead to increased risk of adverse climate-related outcomes, including via increased GHG emissions, shifted or increased vulnerability to climate change, more inequitable outcomes, or diminished welfare now or in the future. The report provides key adaptation options for human settlements, while also warning of the potential for maladaptation and the limits of adaptation. Key adaptations include:

- A mix of interventions ranging from infrastructure, nature-based, socio-cultural, and institutional including vulnerability reducing measures, avoidance, hard and soft infrastructure protection, accommodation, advance, and staged, managed retreat.
- Disaster risk management and risk sharing
- Green infrastructure and ecosystem services, sustainable urban water management
- Maladaptation and limits to adaptation risks include:
- Short term, fragmented, non-inclusive governance planning and implementation
- Inflexible infrastructure that cannot be adjusted, stranded assets, or stranded communities
- As global warming increases, limits to adaptation will be reached in more systems including water security, agricultural production, and human health.

Continuing work on the B3 guidelines for resilience and sustainable design must include the consideration of the potential for maladaptation and recognize the limits of adaptation. It is also of vital importance to evaluate social impacts of the guidelines and the actual projects built to meet them. Additional review of the new IPCC report should provide guidance in these areas.

Future Research

Systems responding to disruptions go through the “Adaptive Cycle” (Gunderson and Holling, 2002) to find a new state of equilibrium. We are in a period of rapid release and change in response to a complexity of changes and challenges. Additional research is required to reorganize and integrate resilience effectively into green building programs. Reconciling the

relationships and conflicts between resilience and sustainability are the core of the future research (Bohm, 2022). Other major areas of future research are:

- Resilient Design Modeling: Downscaling climate data
- Applying resilient energy design modeling to projects
- Reconsidering site and water guidelines with future climate data
- Determining the optimal scale for resilience and sustainability improvements in systems
- Cost and benefit analysis of resilience and sustainability at various scales

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