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Quantifying building sustainability and resilience

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Infrastructure Working Group
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Sustainability: we want our world to last



Ecological

These are interconnected systems



Social



Technical

Measuring performance of systems



Functional



Environmental



Economic



Social

Measuring absolute sustainability is difficult

We tend to measure trends:

Are we moving towards or away from sustainability?



Measuring performance of systems



Functional



Environmental



Economic



Social

We can measure performance during conditions that are:

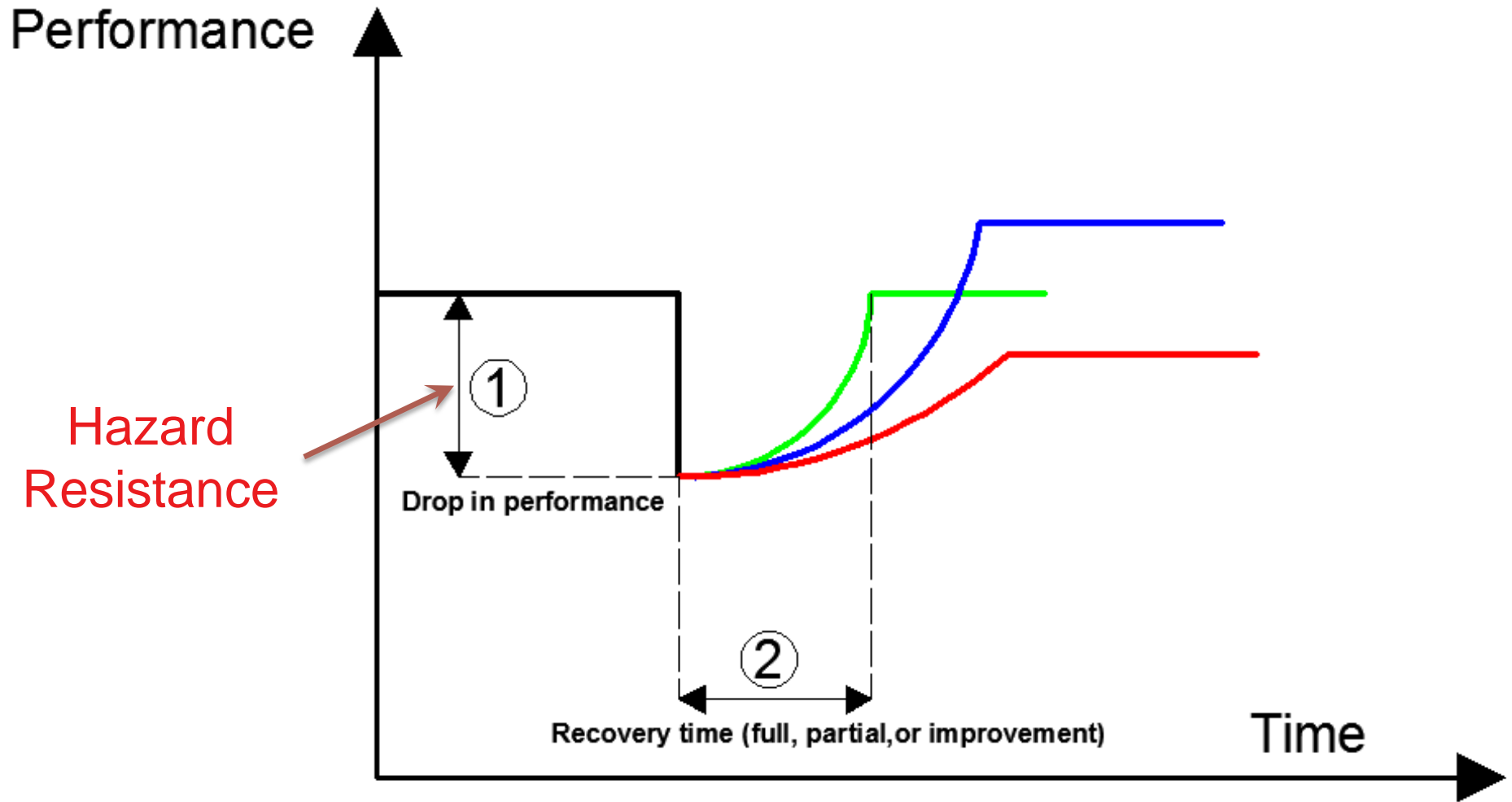
- Typical/intended
- Atypical/unintended



Resilience: a system's response to problems



Resilience: a system's response to problems



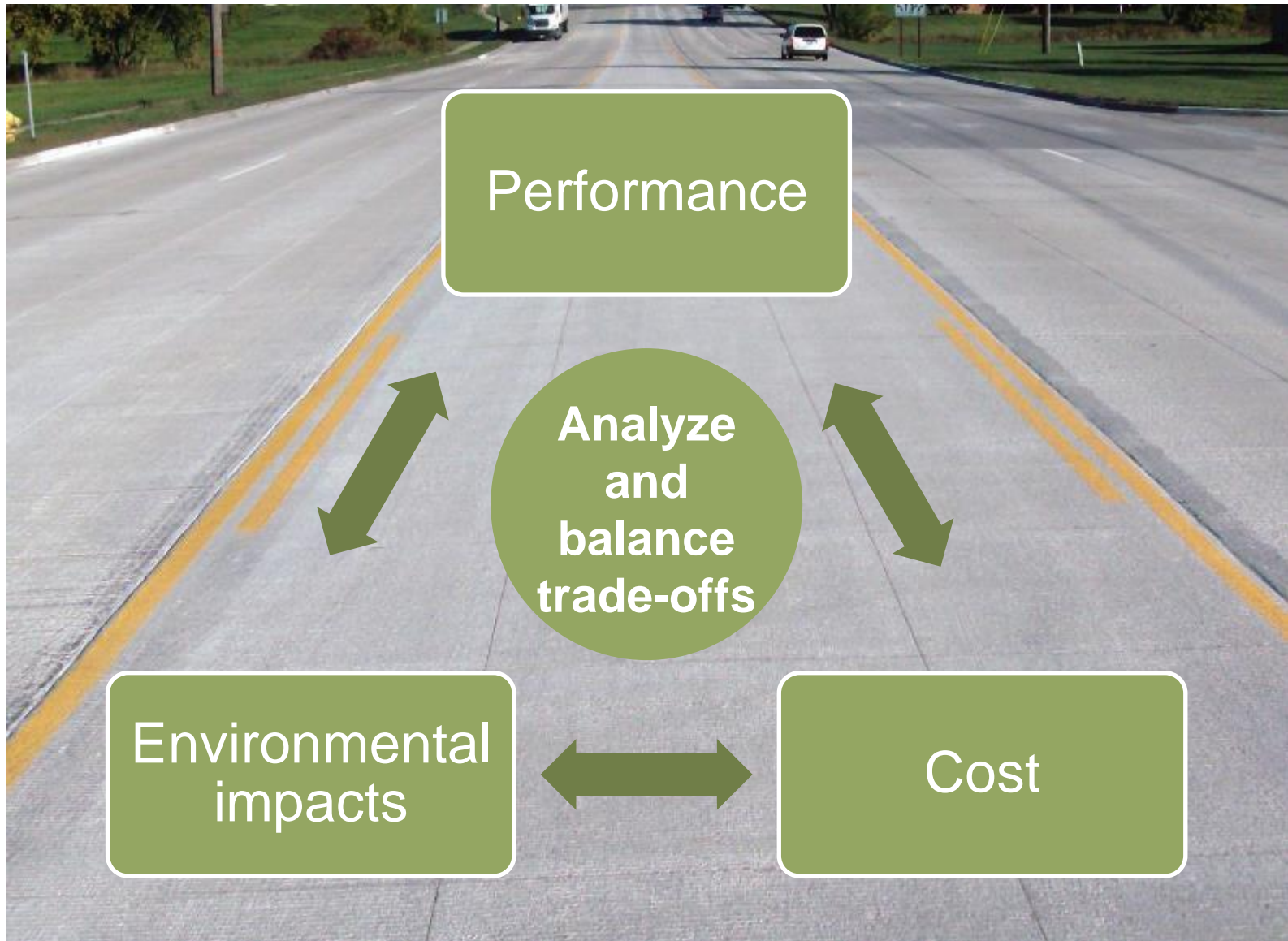
Buildings are integral to sustainability



*Quantifying
sustainability
performance
is essential
for progress*



Infrastructure & buildings decisions involve trade-offs



A life cycle perspective is key for sustainability and resilience decisions

Multiple mechanisms for reducing environmental impact and cost



Materials Production

- Use recycled content
- Reduce energy
- Improve performance

Design & Construction

- Use less (i.e., stronger) material
- Create longer-lasting designs

Use

- Reduce energy consumption
- Reduce heat island effects

End-of-Life

- Enable material recovery
- Plan for component reuse

Sustainable infrastructure achieved by:

Increasing performance

Design process

Analyze and balance trade-offs

Reducing environmental impacts

LCA

Reducing cost

LCCA



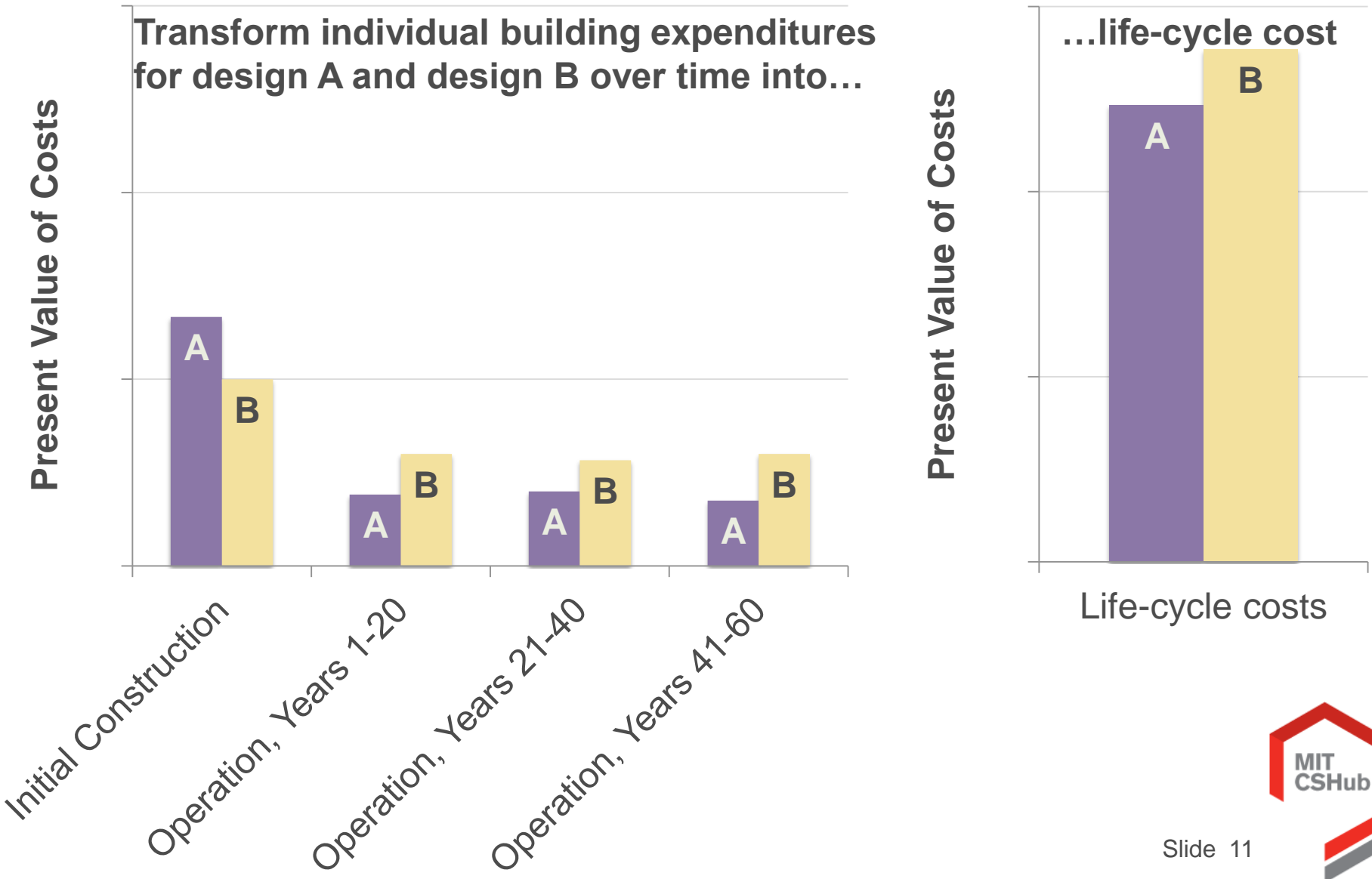
Which is preferred from a life cycle perspective?



Lower design standard	Higher design standard
Same location	
Same appearance	
Lower initial cost	Higher initial cost
Likely worse energy performance	Likely better energy performance
Worse hazard resistance	Better hazard resistance

Quantitative information is lacking on economic and environmental benefits of sustainable and resilient construction

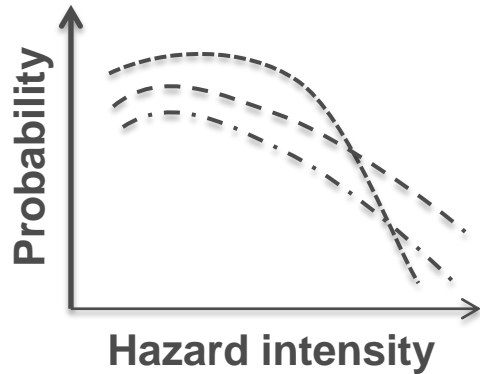
LCCA – Life-cycle cost analysis: Method for evaluating total costs of ownership



Life cycle cost analysis with hazard resistance

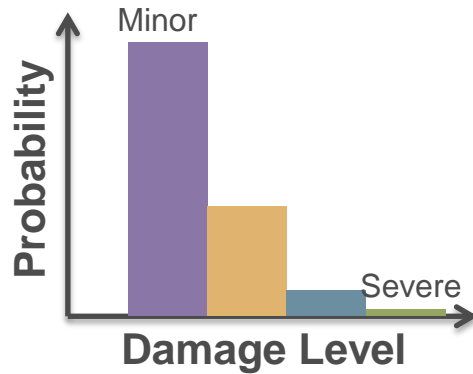
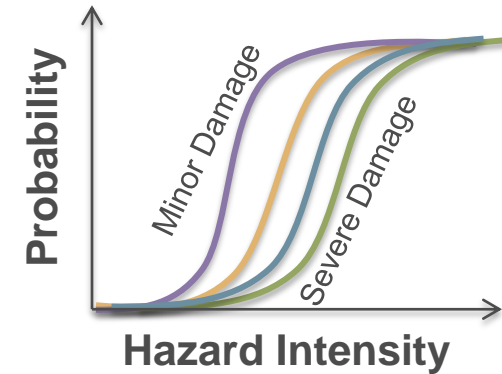


Probabilistic Hazard Repair Estimation

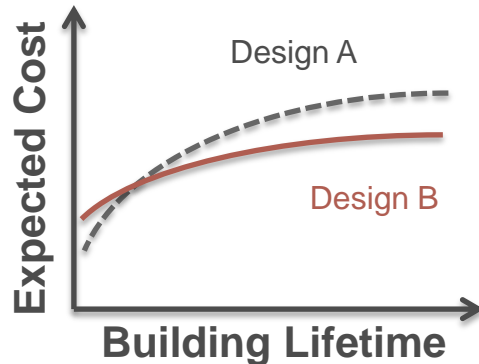


Hazard Curves

Fragility Curves



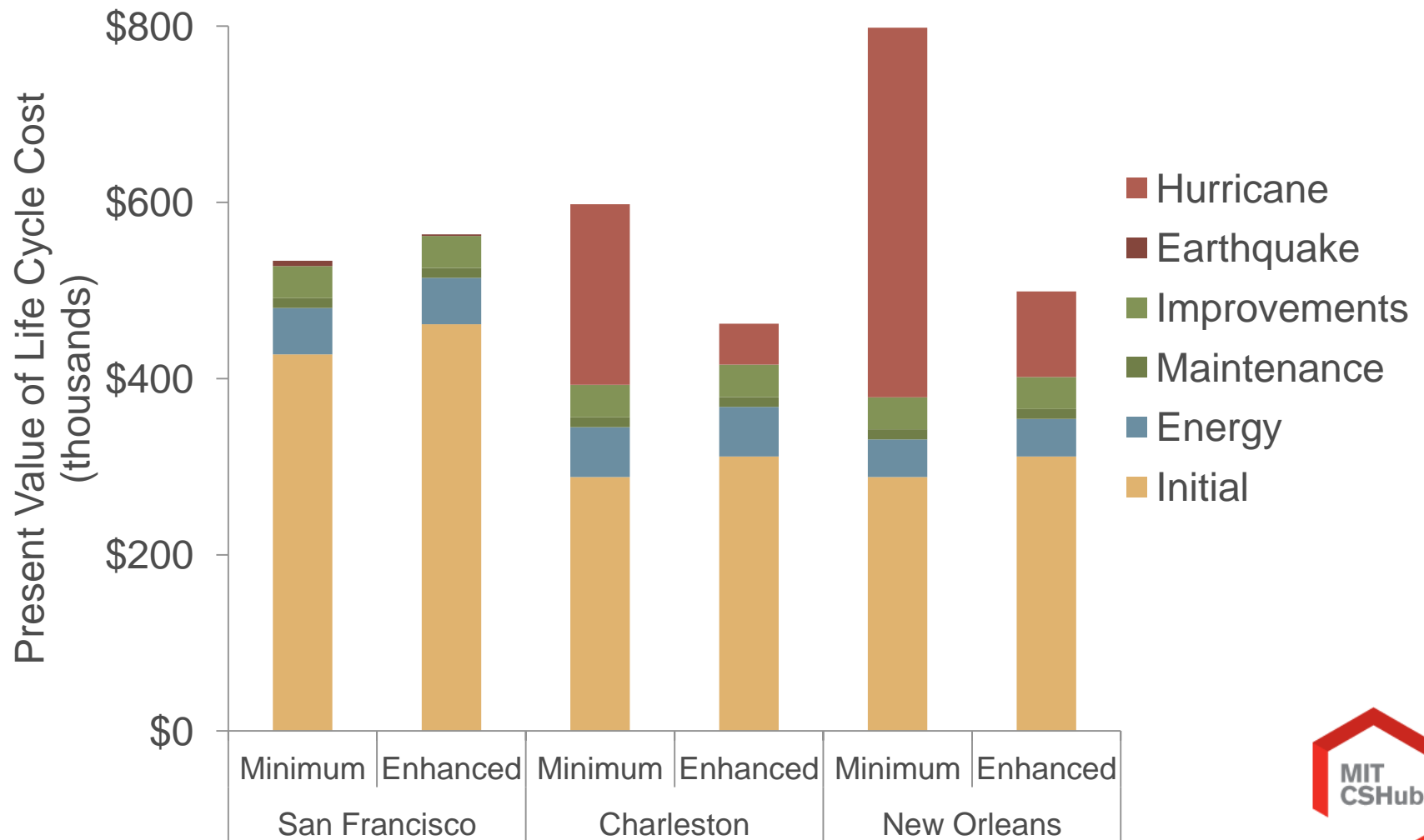
Damage model



Life Cycle Cost Analysis

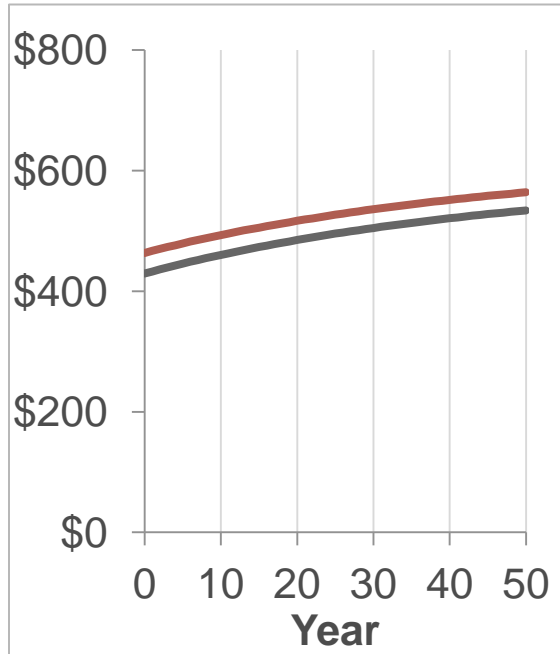
Key finding: life cycle perspective is important

LCC varies by location, discount rate, and hazard resistance

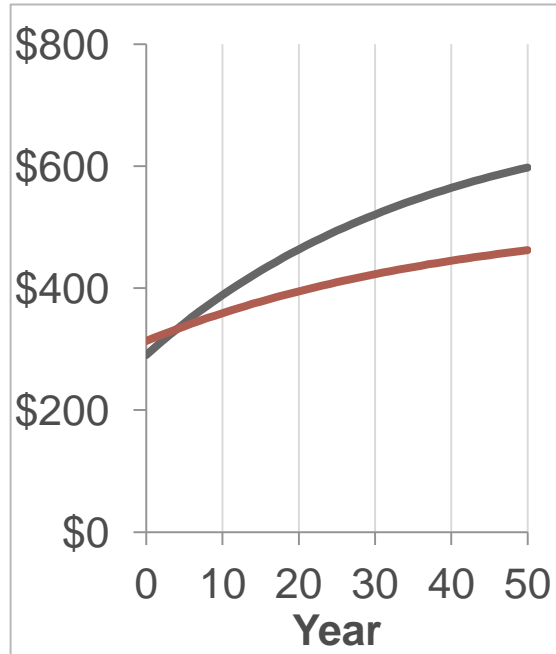


Probabilistic LCCA approach enables expected payback period

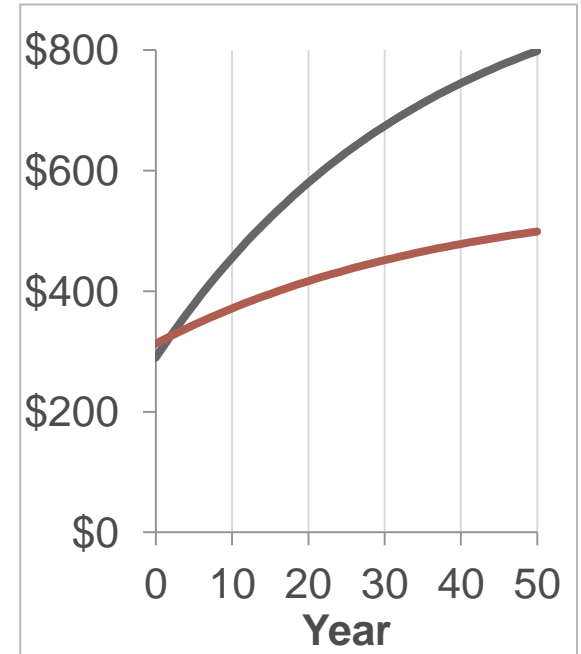
San Francisco, CA
No Payback



Charleston, SC
5 year payback



New Orleans, LA
2 year payback

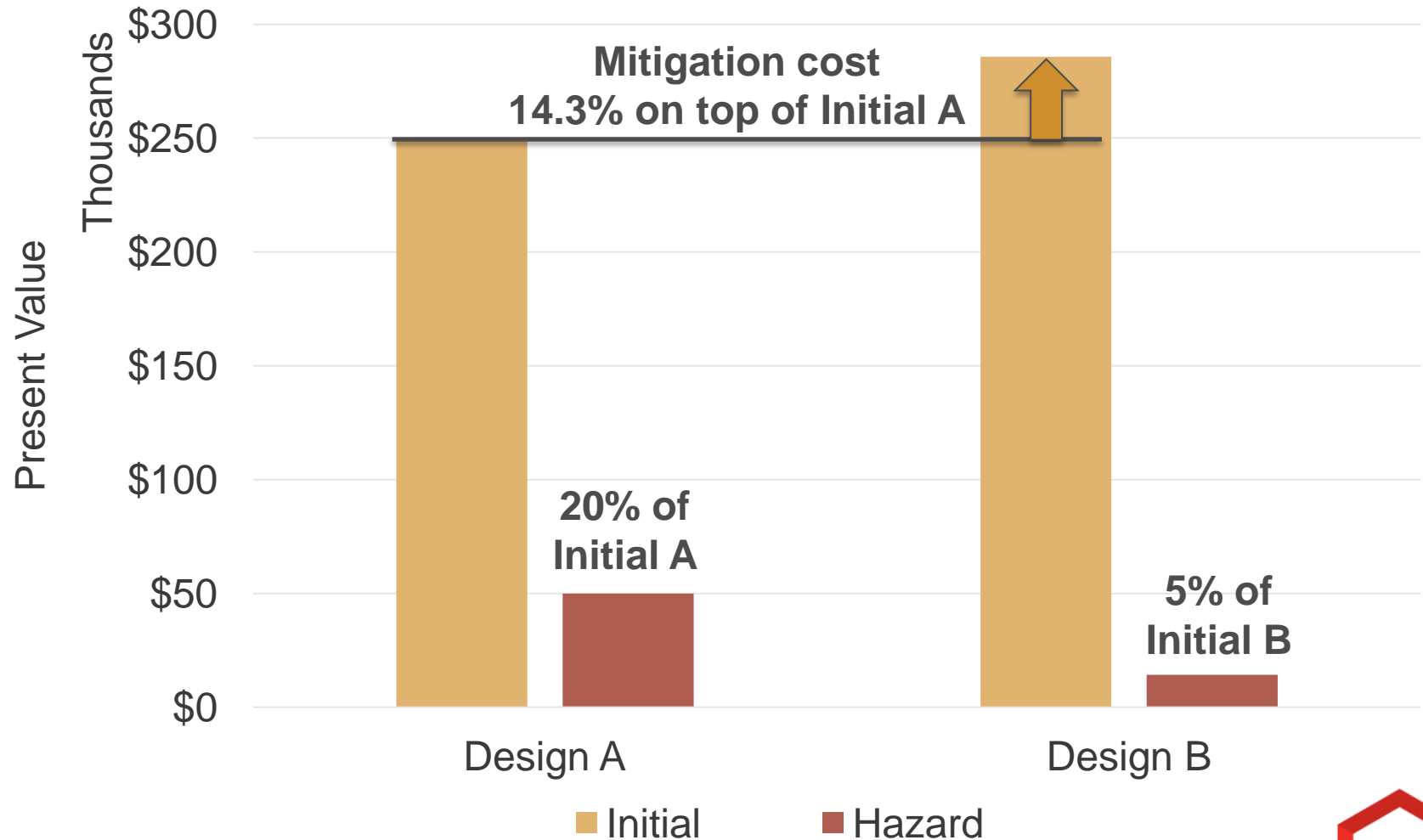


Enhanced resistance design

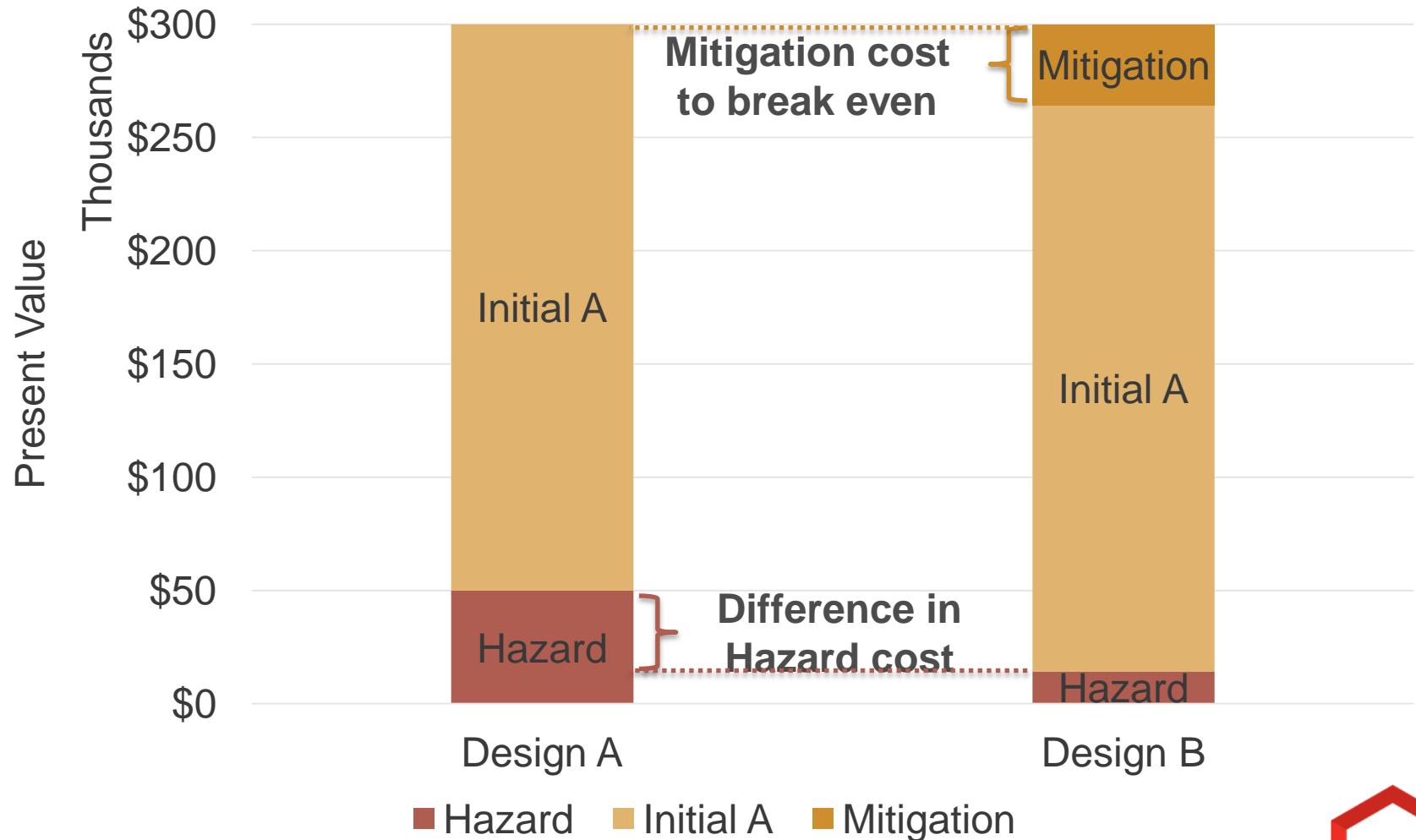
Minimum resistance design



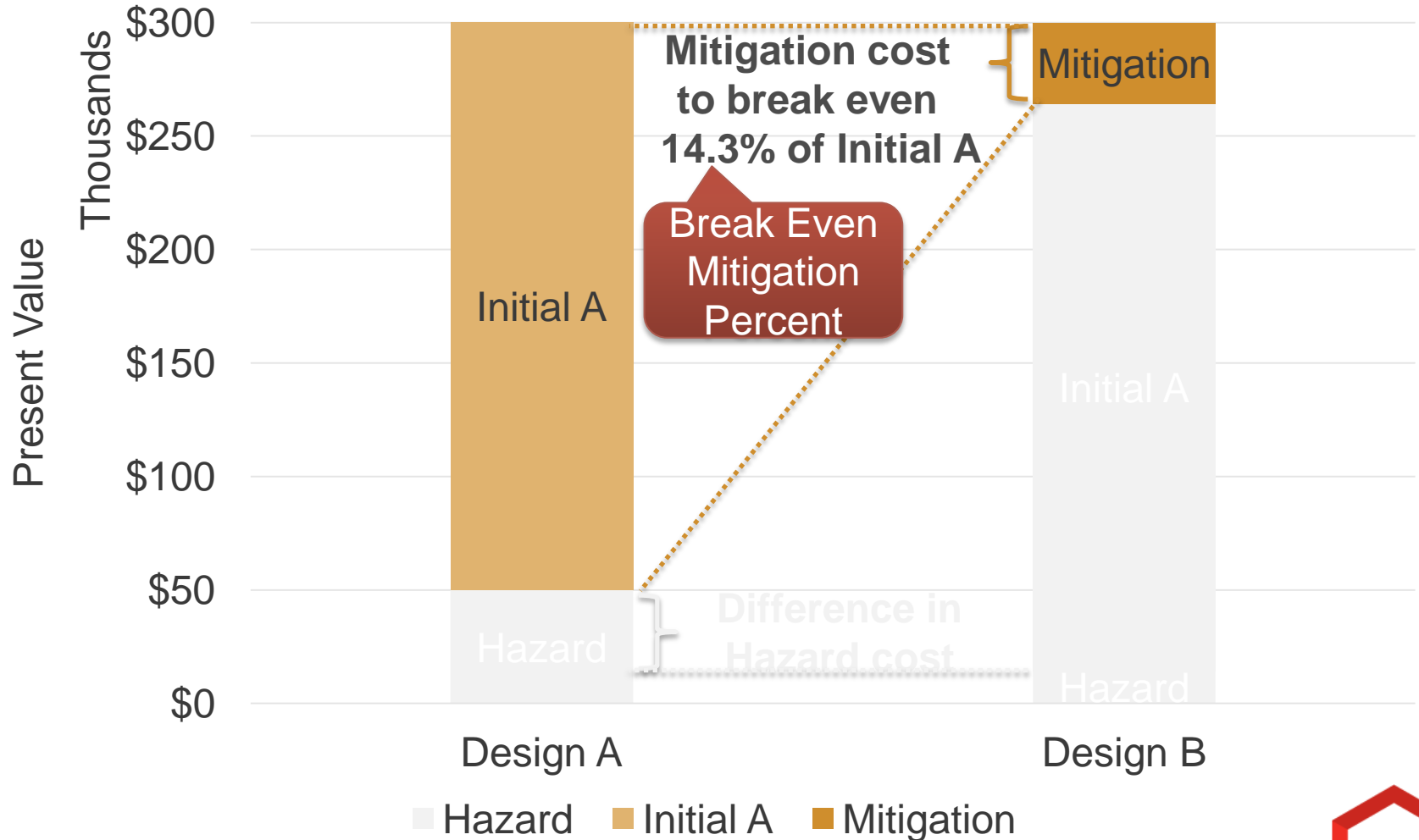
If \$250k to build standard house, how much more would you pay for hazard resistance?



How much mitigation can you afford in order to break-even across life cycle?

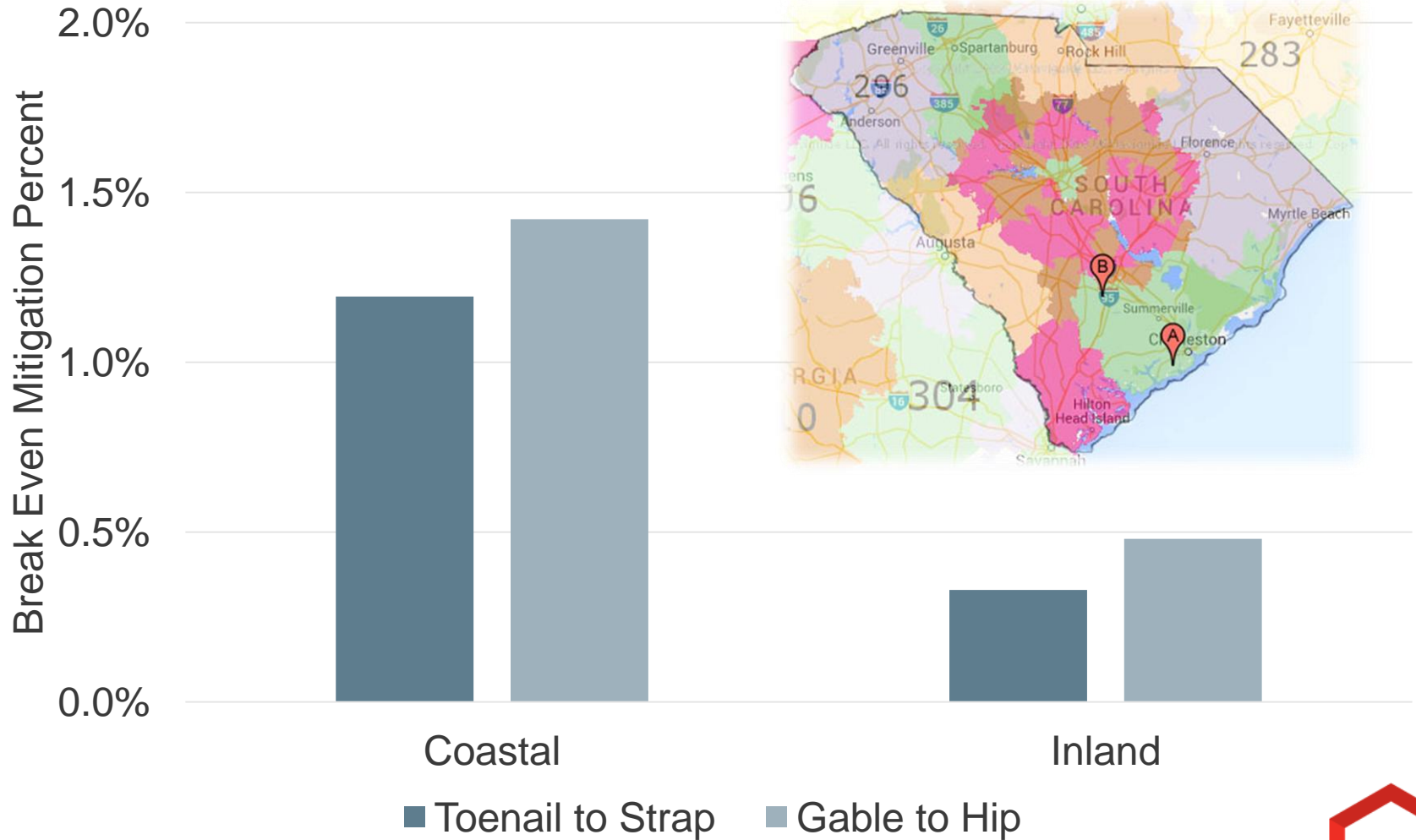


How much mitigation can you afford in order to break-even across life cycle?



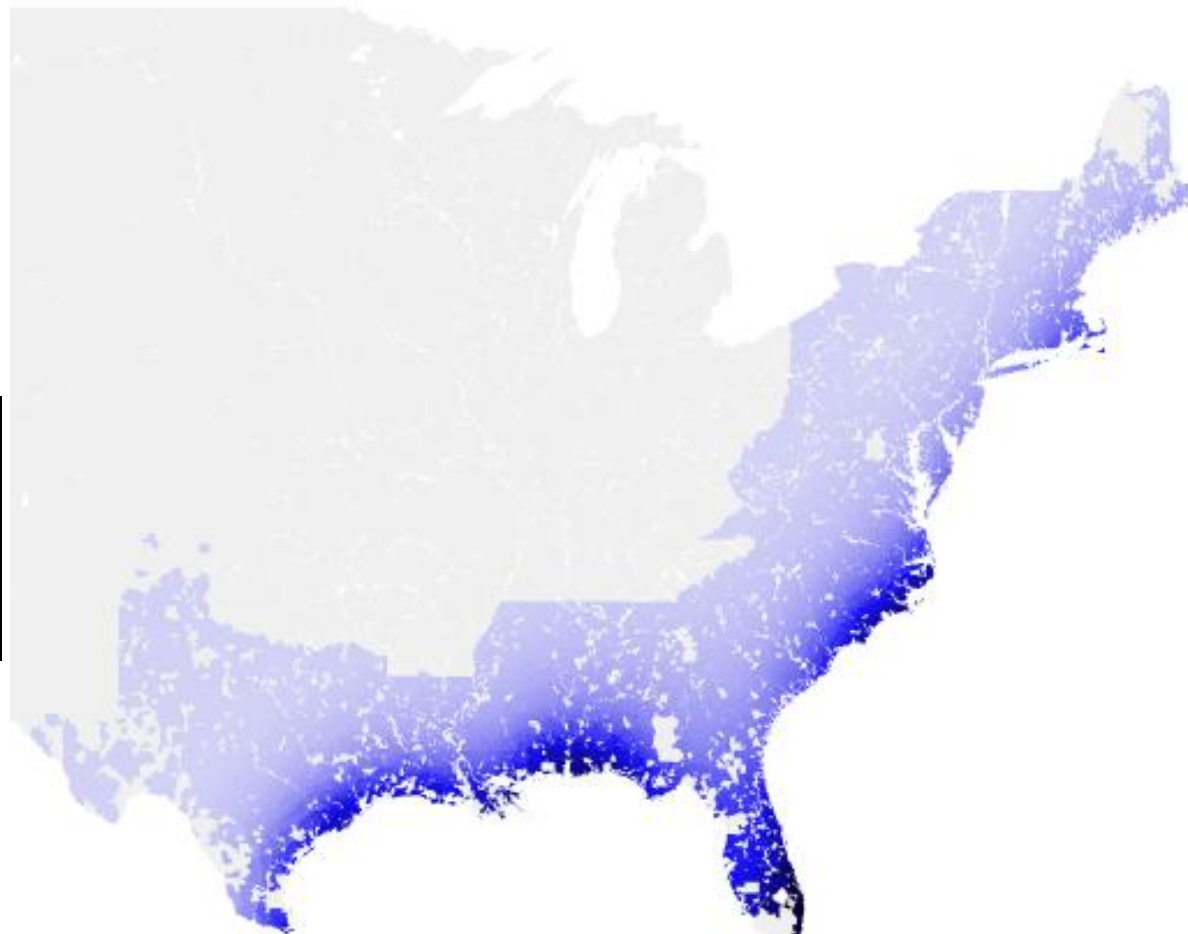
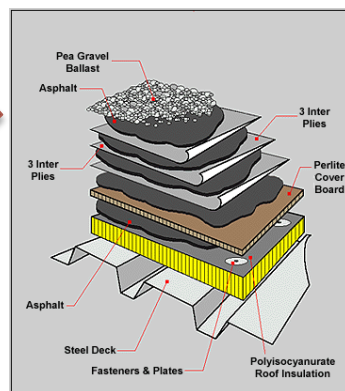
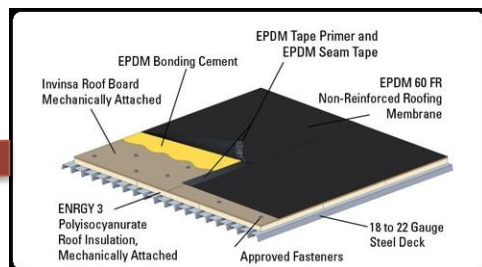
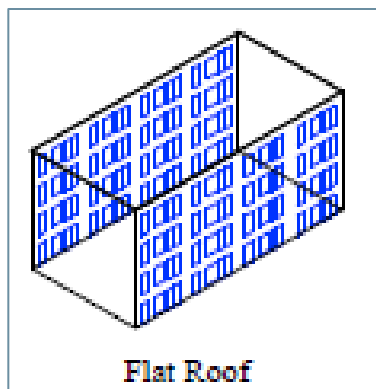
Example: South Carolina wood frame home

Comparing mitigation options



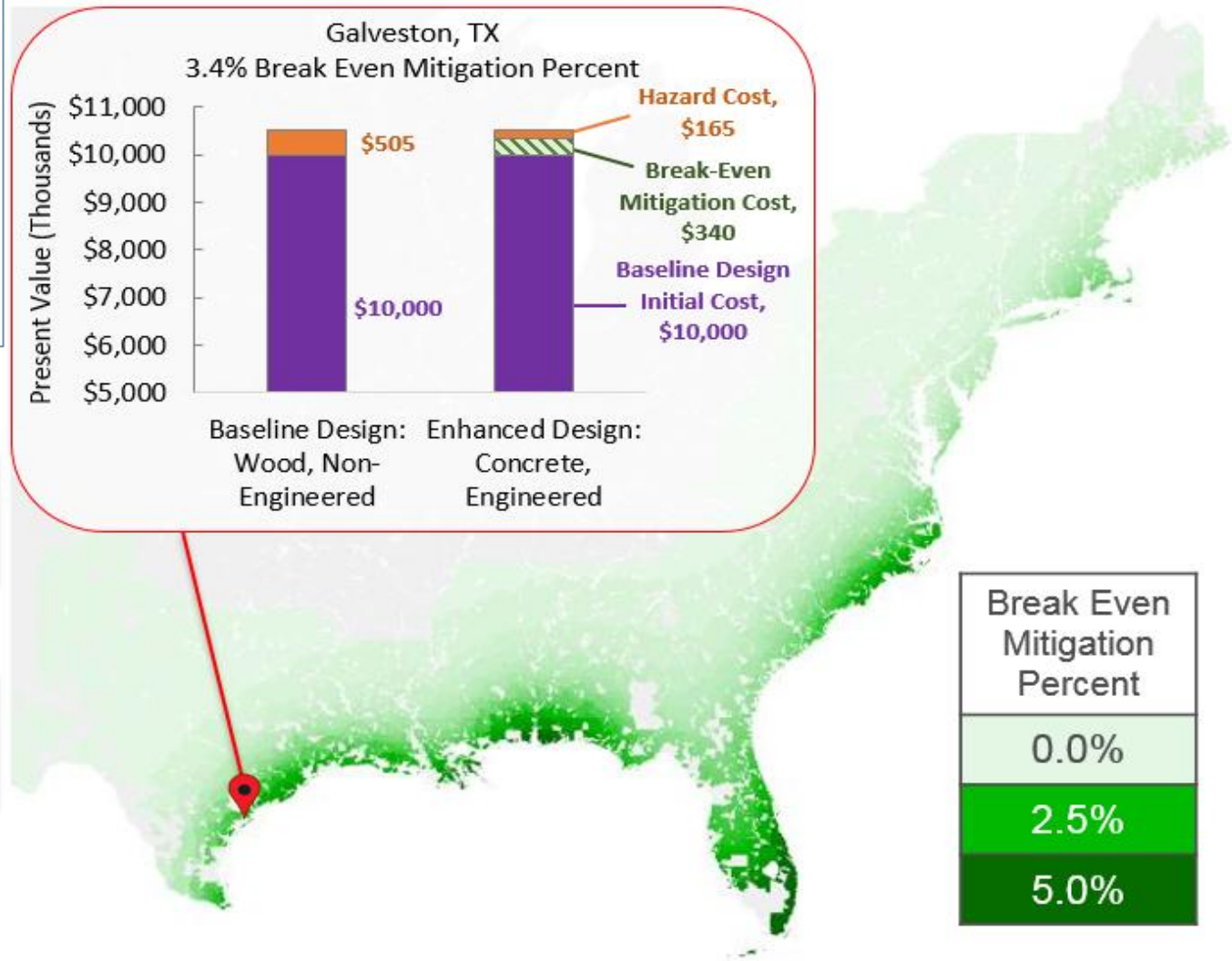
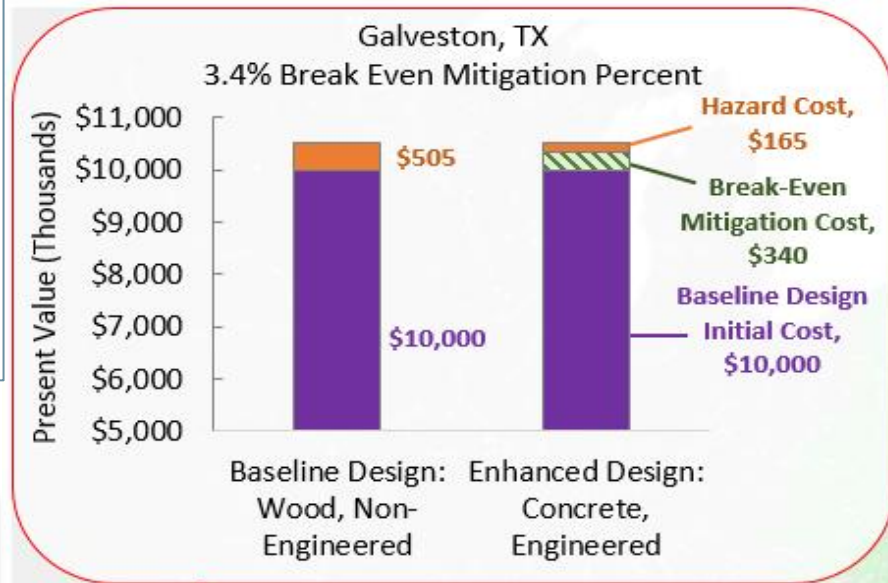
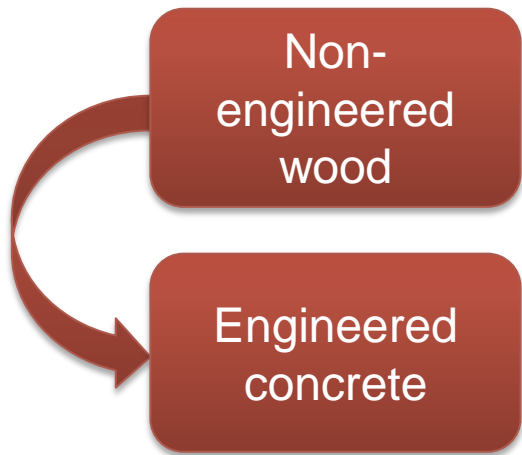
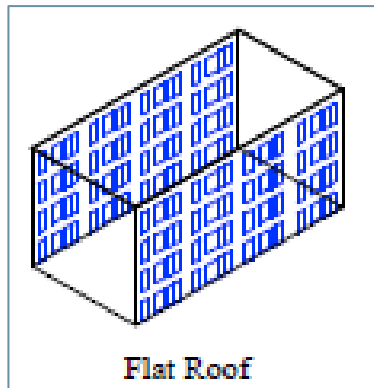
Example: Mid-rise non-engineered masonry

Break Even Mitigation Percent for enhanced roof



Example: Mid-rise change in structure

Non-engineered wood to Engineered concrete

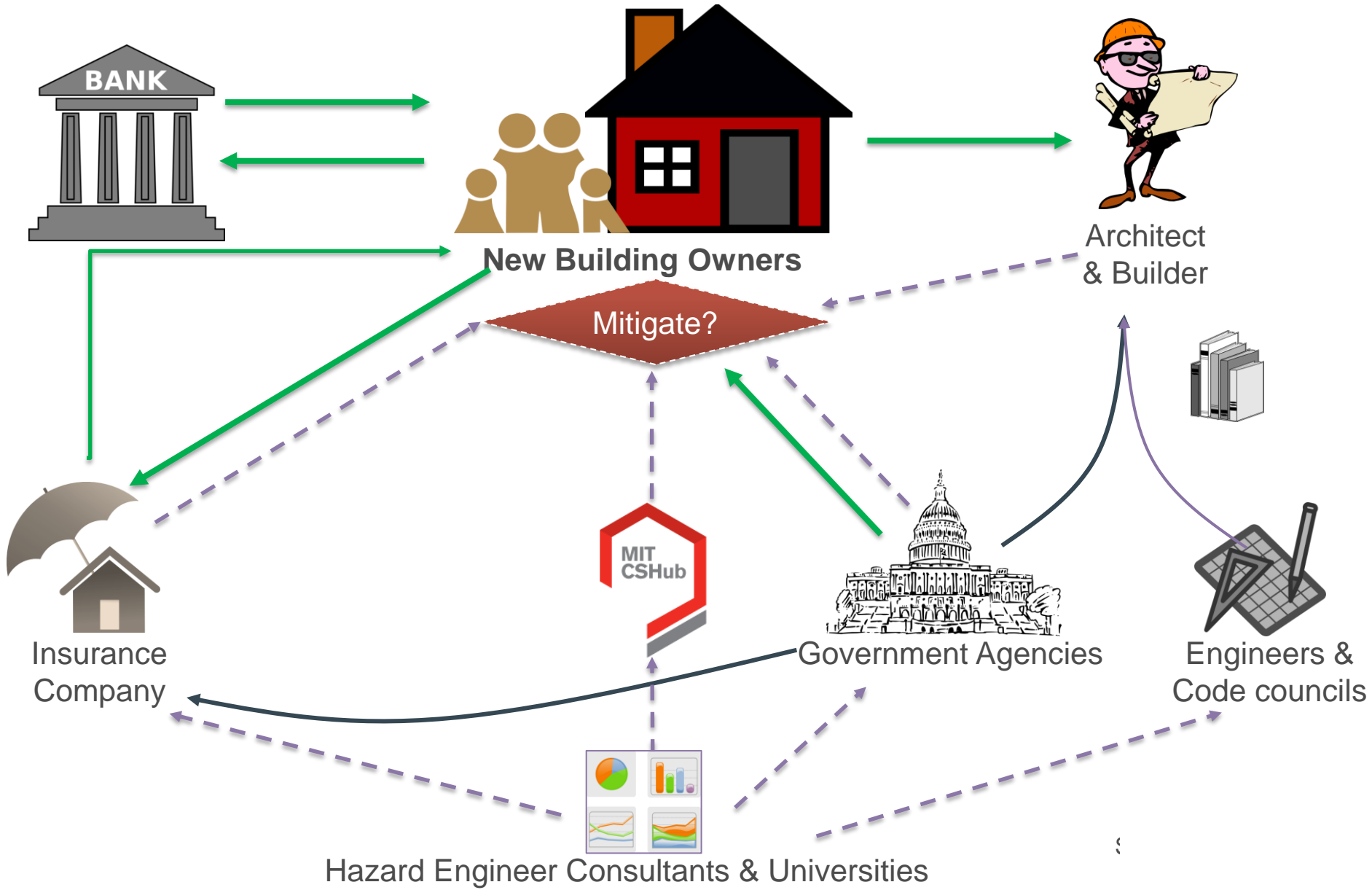


Mitigation decisions involve many stakeholders

Money 

Info 

Regulate 



CSHub contribution: quantifying sustainability and resilience performance

Sustainable infrastructure achieved by:

Increasing performance

Design process

Analyze and balance trade-offs

Reducing environmental impacts

LCA

Reducing cost

LCCA



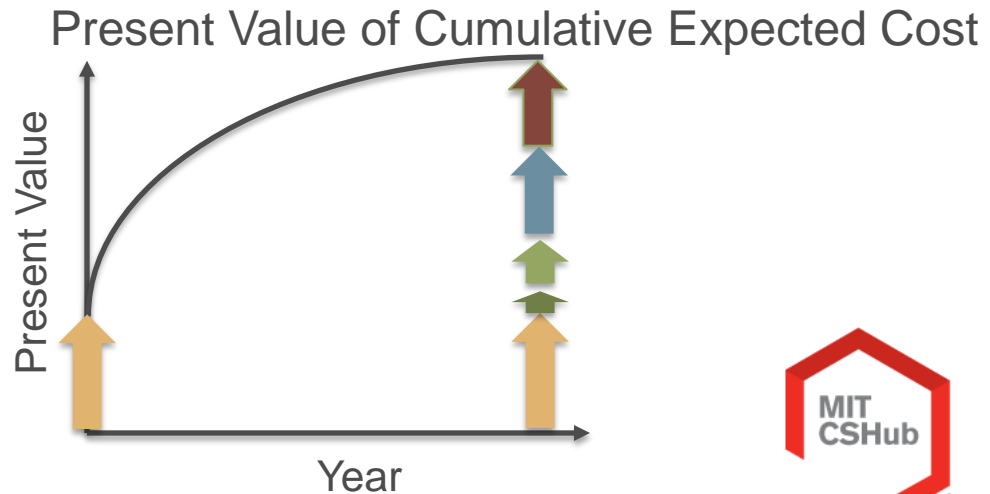
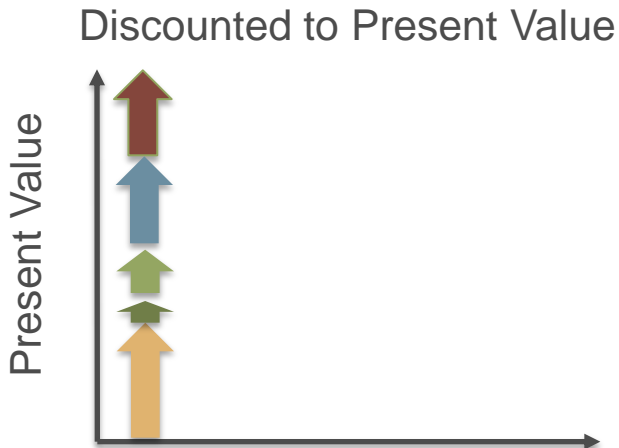
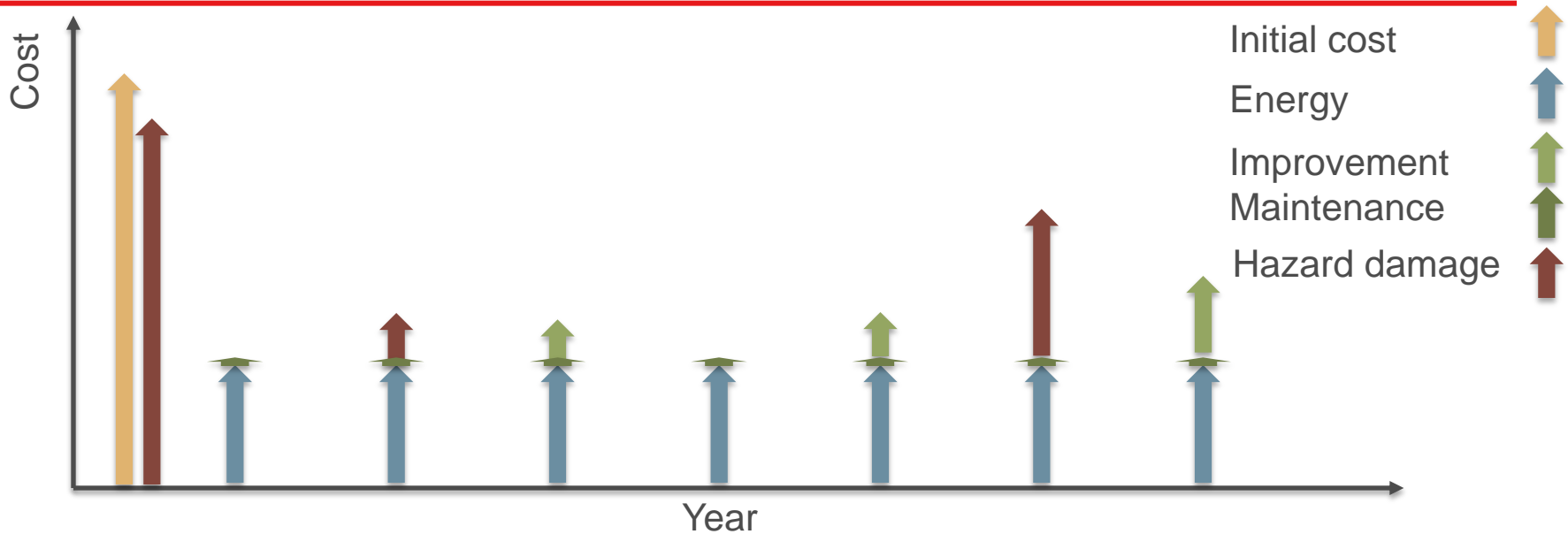
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More information available at:

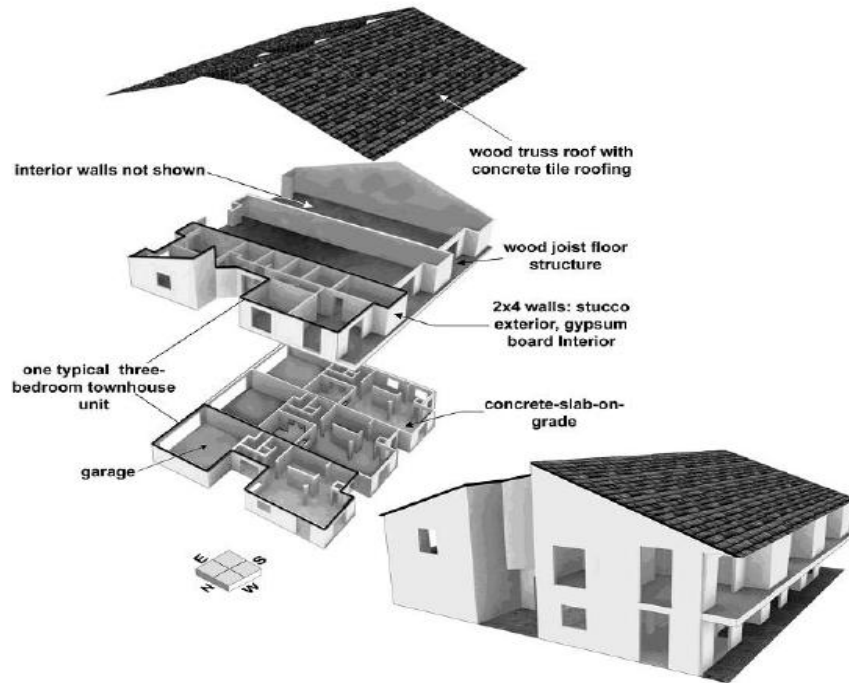
<http://cshub.mit.edu/>
cshub@mit.edu

Back-up Slides

Cost representations across life cycle



Case study: Single family wood frame



CUREE-Caltech Woodframe Project

Two level of resistance:

- Minimum code compliant
- Enhanced

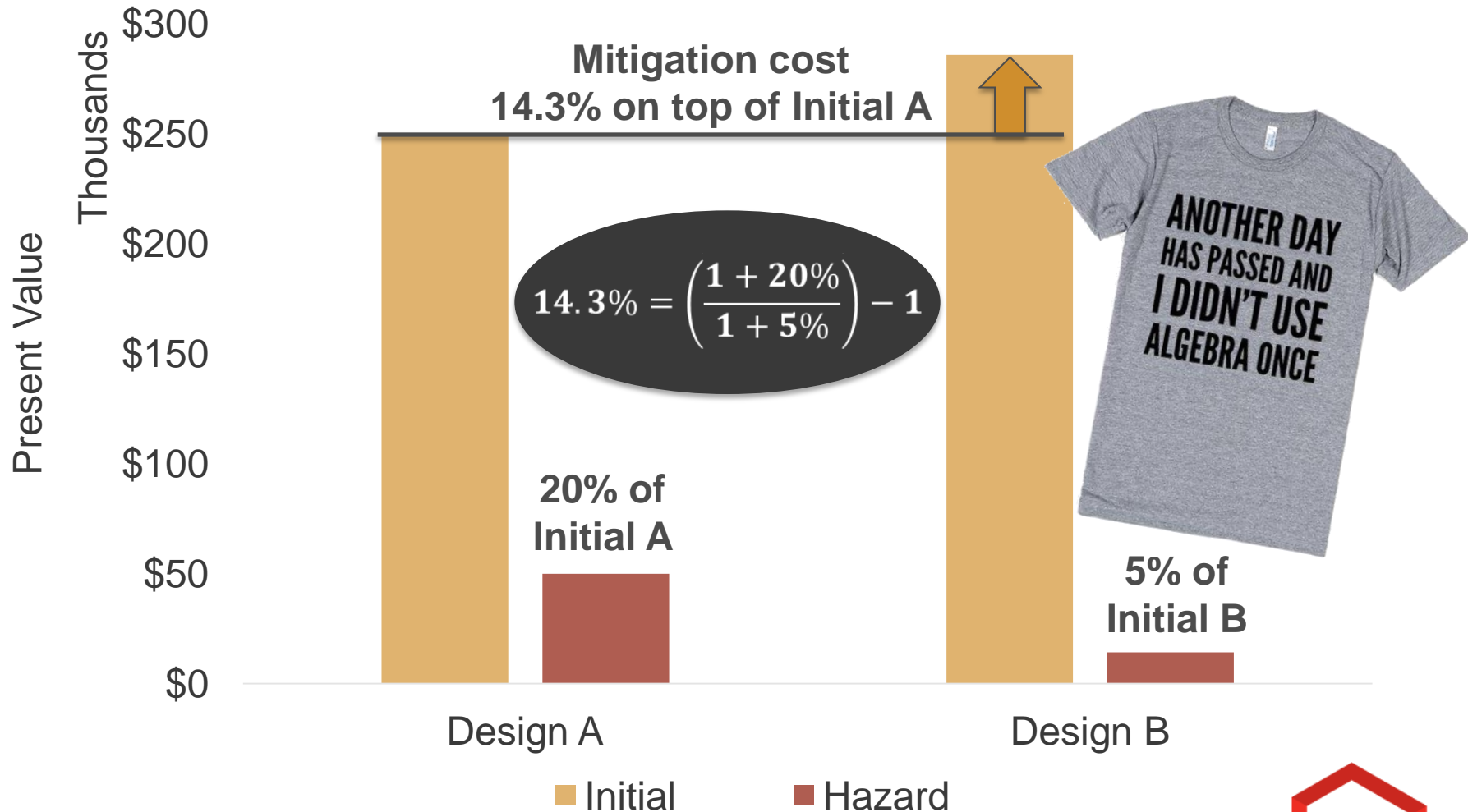
Seismic enhancements:

- reduce nailing spacing in the shear walls

Hurricane enhancements:

- Increasing the resistance of roof shingle
- Stronger nails for roof panels
- Annealed glass thickeners
- Stronger hurricane clip for roof to wall connection

How to calculate Break Even Mitigation Percent



FEMA Benefit Cost Analysis tool

Benefit Cost Analysis 5.2.1

Home

Home (Ctrl+H) Projects (Ctrl+P) Structures (Ctrl+S) Print (Ctrl+R) Export BCA (Ctrl+E) Import/Export (Ctrl+I) Backup/Restore (Ctrl+B) About (Ctrl+A)

Configure Actions Data Database About

Quick Start Area

Create New Project

Create New Structure

Add Structures to Project

Start New Mitigation

Export BCA

BCA Tool Quick Start

The BCA Tool provides access to resources and automated functions needed to complete a successful Benefit-Cost Analysis for hazard mitigation grant programs.

The diagram to the left displays the process used to successfully complete a Benefit-Cost Analysis.

To begin your project, click on the functional icons in the process diagram to the left. Each icon provides quick access to that functional area from the home screen. The functionality within the menu on the top (aka ribbon) and the navigation tree in the left pane are available throughout the tool.

View the [Quick Start Tutorial Movie](#) for an overview of how to Create a Project. The video walks you through the process of creating a project in the tool. You can also click on the icon for a link to context-sensitive help, or the icon for a Flash-based movie tutorial.

Legend

- Help Documentation
- Movie Tutorial

Compare life-cycle cost of hazards

The screenshot displays the 'Benefit Cost Analysis 5.2.1' software interface. The main window title is 'Benefit Cost Analysis 5.2.1'. The interface includes a ribbon with tabs for 'Home', 'Projects', 'Structures', 'Print', 'Export BCA', 'Import/Export', 'Backup/Restore', and 'About'. The ribbon contains various icons and labels for these functions, such as 'Home (Ctrl+H)', 'Projects (Ctrl+P)', 'Structures (Ctrl+S)', 'Print (Ctrl+R)', 'Export BCA (Ctrl+E)', 'Import/Export (Ctrl+I)', 'Backup/Restore (Ctrl+B)', and 'About (Ctrl+A)'. Below the ribbon, the project information is displayed: 'PROJECT: Custom ASCE wind, Risk cat II, contour 115, STRUCTURE: Copy of SFD: WSF1', 'MITIGATION TYPE: Hurricane Wind - Load Path', and 'STRUCTURE BCR: 0'. The main area is titled 'Hurricane Wind - Building Properties' and contains two columns of settings: 'Properties Before Mitigation' and 'Properties After Mitigation'. The 'Properties Before Mitigation' column includes: 'Select type of construction *' (Wood), 'Select type of building *' (WSF1-Wood, Single Family, One Story), 'Shutters *' (No), 'Garage, Houses w/out Shutters *' (None), 'Roof Shape I *' (Hip), 'Secondary Water Resistance *' (No), 'Roof-Wall Connection *' (Toe-nail), and 'Roof Deck Attachment II *' (6d @ 6"/12"). The 'Properties After Mitigation' column includes: 'Shutters *' (Yes), 'Garage, Houses with Shutters *' (None), 'Roof Shape I *' (Gable), 'Secondary Water Resistance *' (No), 'Roof-Wall Connection *' (Strap), and 'Roof Deck Attachment II *' (8d @ 6"/6").

Home

Home (Ctrl+H) Projects (Ctrl+P) Structures (Ctrl+S) Configure

Print (Ctrl+R) Export BCA (Ctrl+E) Actions

Import/Export (Ctrl+I) Data

Backup/Restore (Ctrl+B) Database

About (Ctrl+A) About

PROJECT: Custom ASCE wind, Risk cat II, contour 115, STRUCTURE: Copy of SFD: WSF1
MITIGATION TYPE: Hurricane Wind - Load Path
STRUCTURE BCR: 0

Save and Go Back Save and Continue

Hurricane Wind - Building Properties

Select type of construction * Wood

Select type of building * WSF1-Wood, Single Family, One Story

Properties Before Mitigation

Shutters * No

Garage, Houses w/out Shutters * None

Roof Shape I * Hip

Secondary Water Resistance * No

Roof-Wall Connection * Toe-nail

Roof Deck Attachment II * 6d @ 6"/12"

Properties After Mitigation

Shutters * Yes

Garage, Houses with Shutters * None

Roof Shape I * Gable

Secondary Water Resistance * No

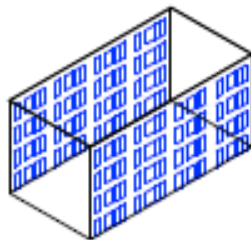
Roof-Wall Connection * Strap

Roof Deck Attachment II * 8d @ 6"/6"

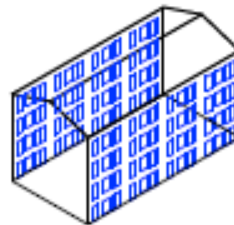
Embedded FEMA buildings types

- Manufactured home
- Wood & masonry single family
- Wood, masonry, concrete multi-family
 - Engineered / non-engineered
- Strip mall
- Industrial/warehouse/factory
- “Commercial”

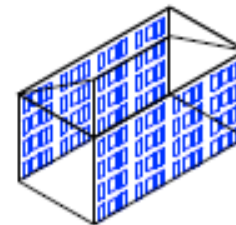
Three-Story Buildings – 80'×40' Plan, 30' Eave Height



Flat Roof



Gable Roof



Hip Roof

Four-Story Buildings – 80'×40' Plan, 40' Eave Height

Hurricane mitigation examples

- Shutters
- Roof:
 - Type: Gable vs Hip vs Flat
 - Cover: Built-up vs EPDM
 - Roof-wall connection: Toe-nail vs strap
 - Spacing of nails in roof-deck attachment
- Masonry reinforced
- Window area (Low, Med, High)

