# *FEMA P-58 Functional Recovery Module - Methodology and Use for Resilient Design*

SP3 Functional Recovery Webinar

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# Outline

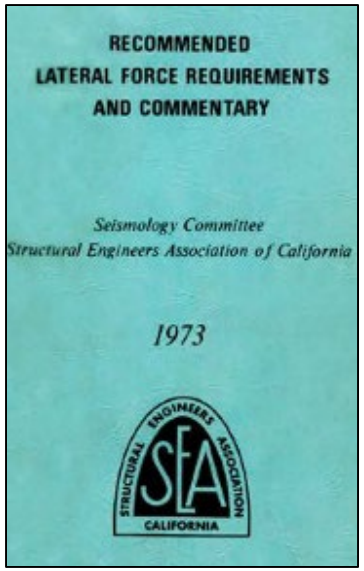
- What the FEMA P-58/ATC-138 methodology is:
  - Some historic context
  - Overview and development of the FEMA P-58 Methodology
  - Key FR concepts
  - Overview and development of the ATC-138 FR methodology
  - Challenges around defining and measuring functional recovery
- How FEMA P-58/ATC-138 can be used (and is being used) for Resilient Design for Functional Recovery.
- Time for Q&A (10-15 minutes)

# Historic Context

- Why are we talking about Resilient Design for Functional Recovery ?
  - We've been advancing performance expectations for decades
  - The expectation for functional performance is already there

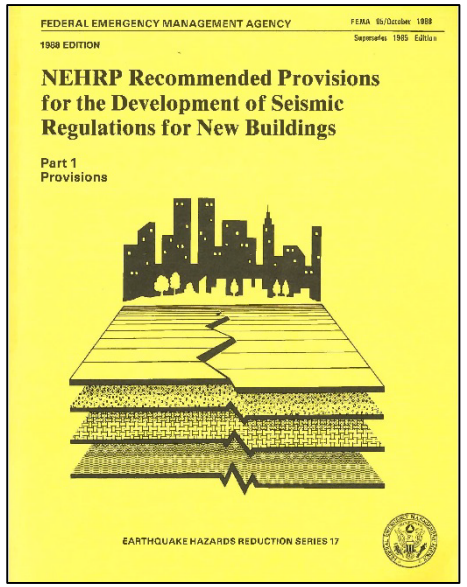
# Early Performance Statements

- SEAOC Blue Book:
  - Resist minor earthquakes without damage
  - Resist moderate earthquakes with some nonstructural damage
  - Resists major earthquakes with structural/nonstructural damage
  - Resist the most severe earthquakes without collapse



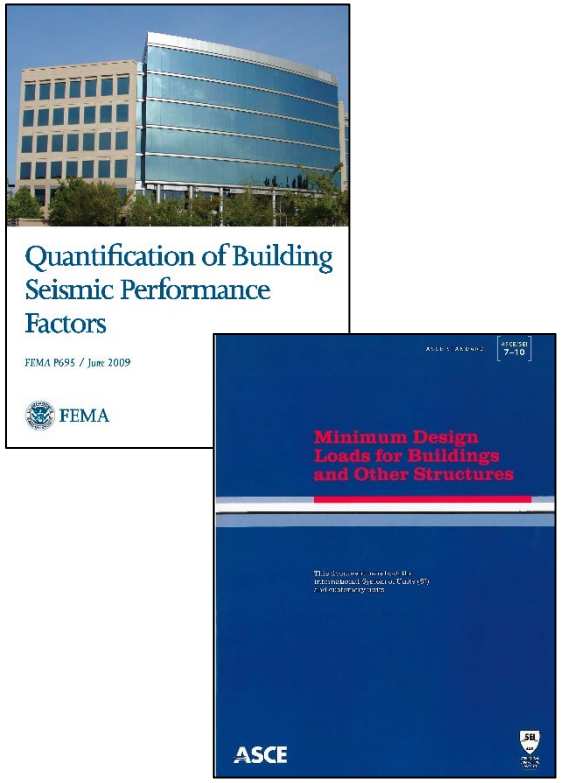
# Early Performance Statements

- 1988 NEHRP Provisions:
  - Minimize hazard to life
  - Increase expected performance of higher occupancy structures
  - Improve functional capability of essential facilities
  - (2009) Minimize repair costs, where practical to do so



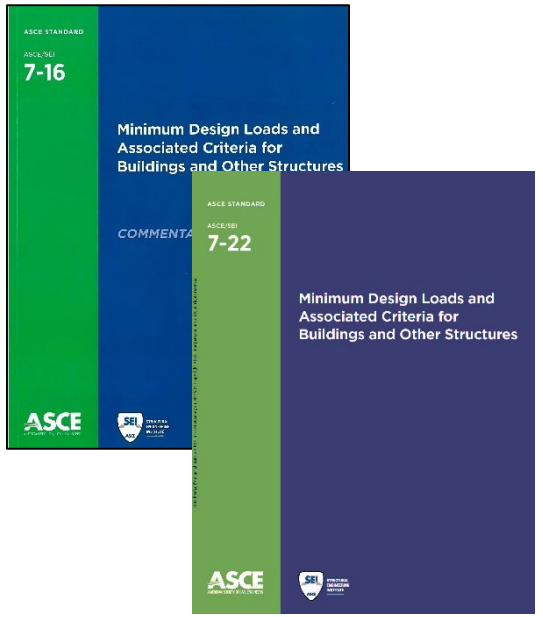
# Recent Performance Statements

- FEMA P-695:
  - 10% Probability of collapse given MCE shaking intensity
- ASCE 7-10 Commentary
  - Quantitative structural reliability criteria based on FEMA P-695



# Current Performance Statements

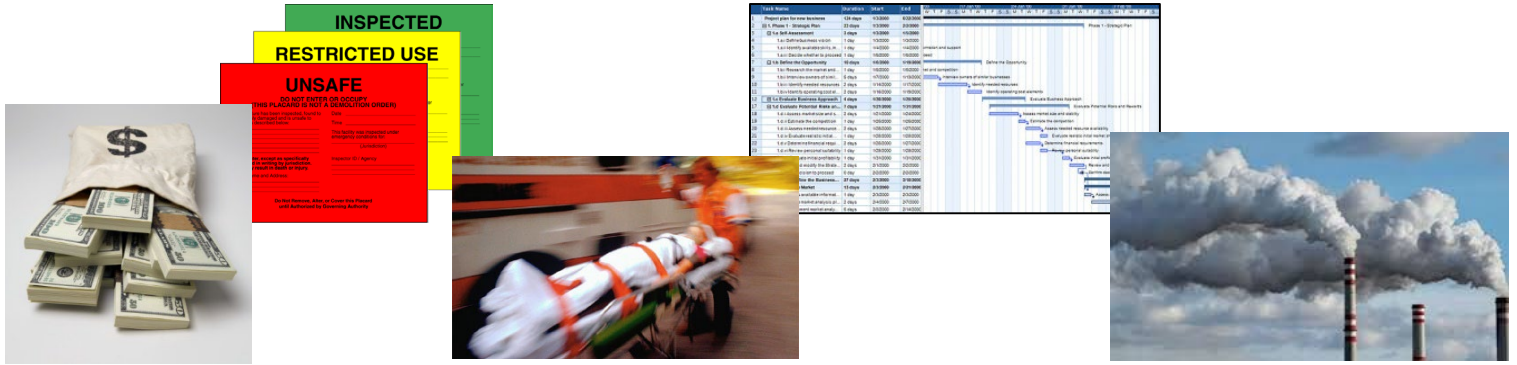
- ASCE 7-16 and ASCE 7-22 Provisions
  - PBSD must meet risk-based target reliability criteria specified in the standard
  - RC IV shall have reasonable probability of not preventing function immediately following a design event
  - Prescriptive provisions are deemed to comply




**1.3.3 Functionality** Structural systems and members and connections thereof assigned to Risk Category IV shall be designed with reasonable probability to have adequate structural strength and stiffness to limit deflections, lateral drift, or other deformations such that their behavior would not prevent function of the facility immediately following any of the design-level environmental hazard events specified in this standard.

# Evolution of Performance Statements

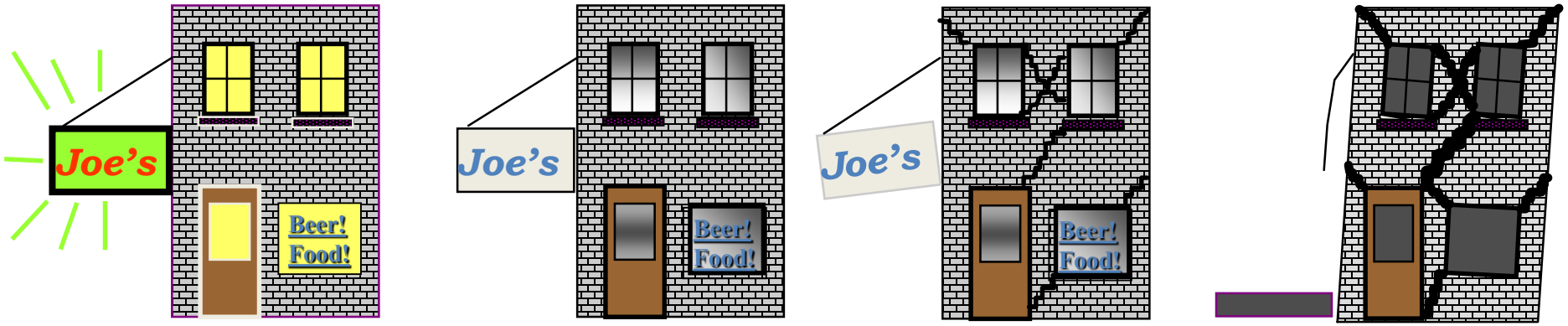
- Performance needs have been evolving beyond life safety
- Some performance statements have been intentionally aspirational (inserted before we knew how to calculate)
- FEMA P-58/ATC-138 performance metrics provide a quantitative link to our future aspirations



# FEMA P-58 (ATC-58 Project)

# ATC-58 Project Context

- FEMA 273 (1997) and Joe's Bar




*Operational* | *Immediate Occupancy* | *Life Safety* | *Collapse Prevention*

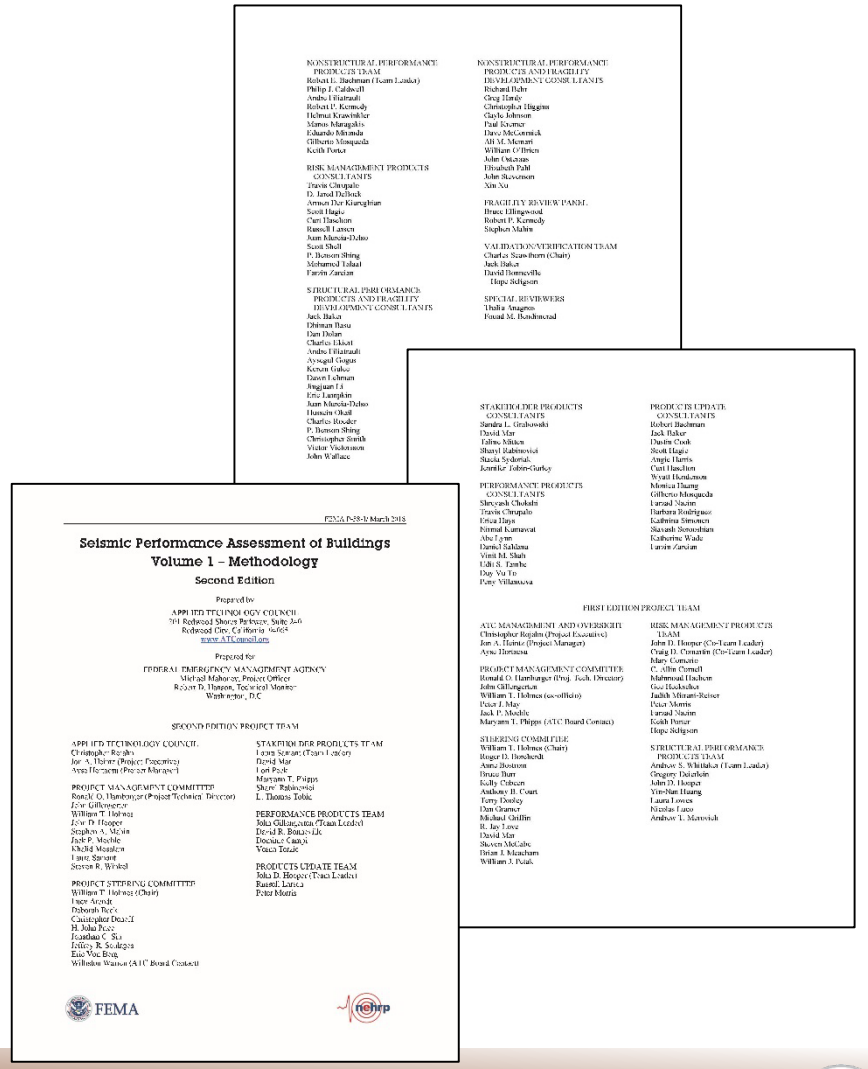
- What else could we need?

# ATC-58 Project Context

- Need for Next-Generation
  - Develop a framework to account for variability and uncertainty
  - Assess performance on a global rather than local level
  - Expand procedures to explicitly assess nonstructural performance
  - Revise discrete performance levels into measures that were more meaningful for decision-making
- ATC-58 Project was initiated in 2001

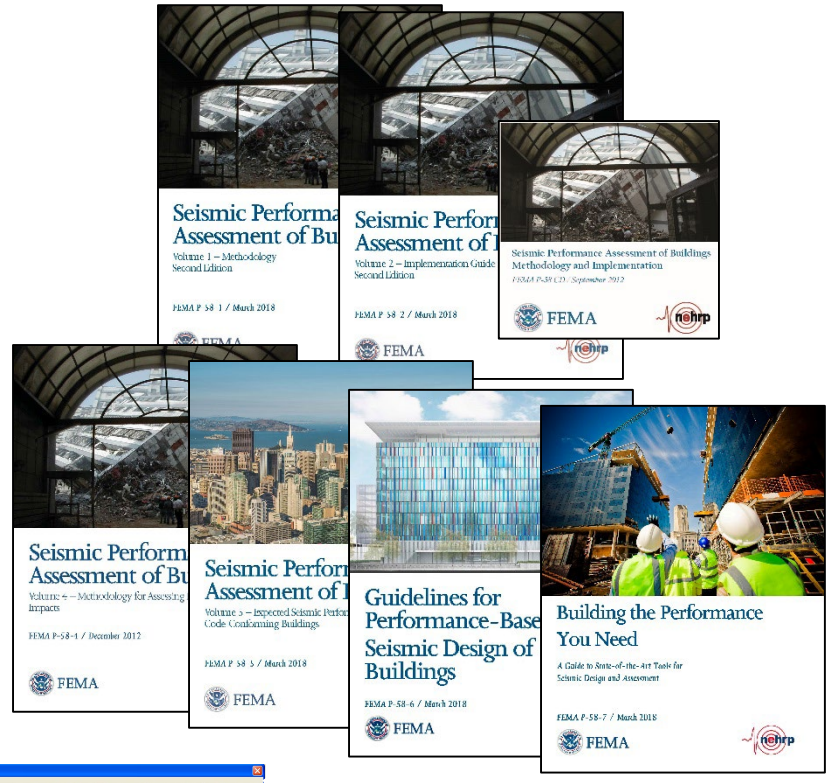
# ATC-58 Project Context

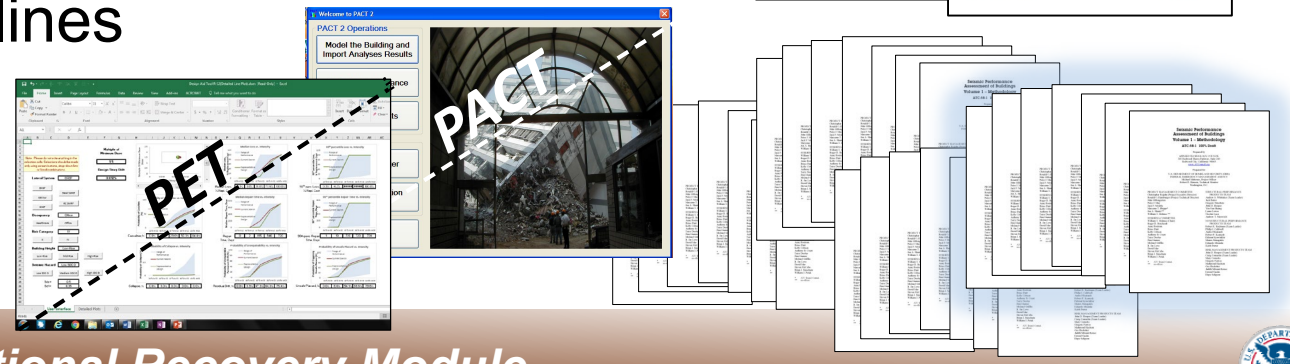
- Over 200 consultants across more than 20 teams over nearly 20 years
  - Project Management Committee
  - Project Steering Committee
  - Performance Products Team
  - Products Update Team
  - Stakeholder Products Team
  - Performance Working Group
  - Structural Performance Products
  - Nonstructural Performance Products
  - Risk Management Products
  - Validation/Verification Team
  - Fragility Review Panel
  - Fragility Development Consultants
  - Environmental Products Working Group



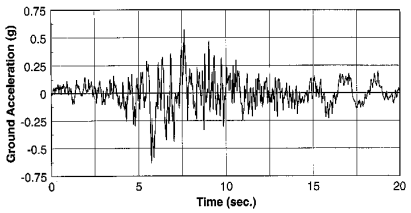
# FEMA P-58 Products

- FEMA P-58 *Seismic Performance Assessment of Buildings,* (2012, updated in 2018)
  - Volume 1, 2, and 3, Second Editions
  - Volume 4 – Environmental Impacts
  - Volume 5 – Expected Performance
  - Volume 6 – Engineering Guidelines
  - Volume 7 – Stakeholder Guidelines
  - Calc. Tools/Background Docs.

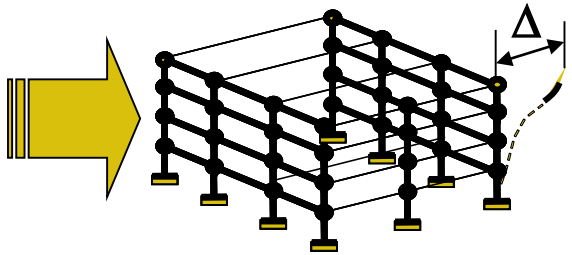


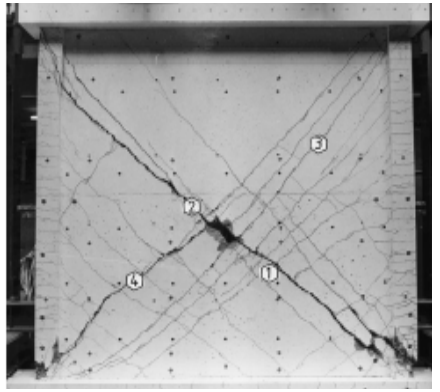
# FEMA P-58 Assessment Process



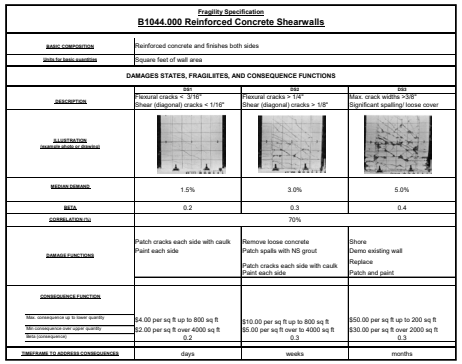

Ground Motion




Structural Response



Damage

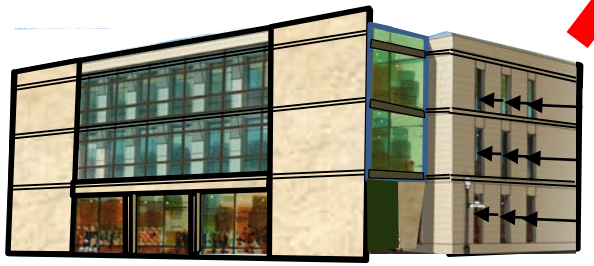


Fragility Specification

**B1044.000 Reinforced Concrete Shearwalls**

| | | | |
|---|---|---|---|
| BASIC COMPOSITION | Reinforced concrete and finishes both sides | | |
| Units for basic quantities | Square feet of wall area | | |
| DAMAGES STATES, FRAGILITIES, AND CONSEQUENCE FUNCTIONS | | | |
| DESCRIPTION | DS1: Flexural cracks < 3/16" Shear (diagonal) cracks < 1/16" | DS2: Flexural cracks > 1/4" Shear (diagonal) cracks > 1/8" | DS3: Max. crack widths >3/8" Significant spalling/ loose cover |
| ILLUSTRATION (Actual or Simulated) | | | |
| MEDIAN DEMAND | 1.5% | 3.0% | 5.0% |
| BETA | 0.2 | 0.3 | 0.4 |
| CORRELATION (%) | 70% | | |
| DAMAGE FUNCTIONS | Patch cracks each side with caulk<br>Paint each side | Remove loose concrete<br>Patch spalls with NS grout<br>Patch cracks each side with caulk<br>Paint each side | Shore<br>Demo existing wall<br>Replace<br>Patch and paint |
| CONSEQUENCE FUNCTION | | | |
| Max. consequence up to lower quantity | $4.00 per sq ft up to 600 sq ft | $10.00 per sq ft up to 800 sq ft | $50.00 per sq ft up to 200 sq ft |
| Min consequence over upper quantity | $2.00 per sq ft over 4000 sq ft | $5.00 per sq ft over to 4000 sq ft | $30.00 per sq ft over 2000 sq ft |
| Beta (consequence) | 0.2 | 0.3 | 0.3 |
| TIMEFRAME TO ADDRESS CONSEQUENCES | days | weeks | months |

*Fragility Spec*



*Building Performance Model*

Consequences

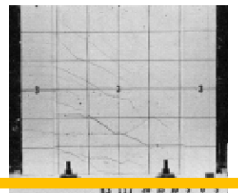
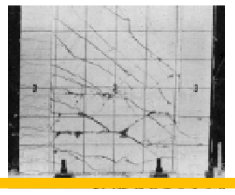
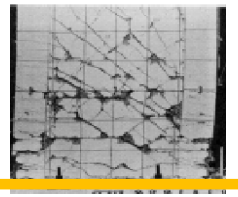
# Fragility Specifications

**Fragility Specification**

**B1044.000 Reinforced Concrete Shearwalls**

| | |
|---|---|
| **BASIC COMPOSITION** | Reinforced concrete and finishes both sides |
| **Units for basic quantities** | Square feet of wall area |

**DAMAGES STATES, FRAGILIITES, AND CONSEQUENCE FUNCTIONS**

| | DS1 | DS2 | DS3 |
|---|---|---|---|
| **DESCRIPTION** | Flexural cracks < 3/16"<br>Shear (diagonal) cracks < 1/16" | Flexural cracks > 1/4"<br>Shear (diagonal) cracks > 1/8" | Max. crack widths >3/8"<br>Significant spalling/ loose cover |
| **ILLUSTRATION (example photo or drawing)** |  |  |  |
| **MEDIAN DEMAND** | 1.5% | 3.0% | 5.0% |
| **BETA** | 0.2 | 0.3 | 0.4 |
| **CORRELATION (%)** | | 70% | |
| **DAMAGE FUNCTIONS** | Patch cracks each side with caulk<br>Paint each side | Remove loose concrete<br>Patch spalls with NS grout<br>Patch cracks each side with caulk<br>Paint each side | Shore<br>Demo existing wall<br>Replace<br>Patch and paint |
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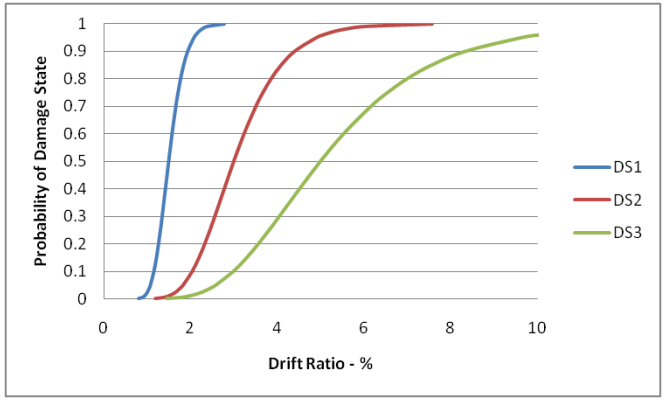
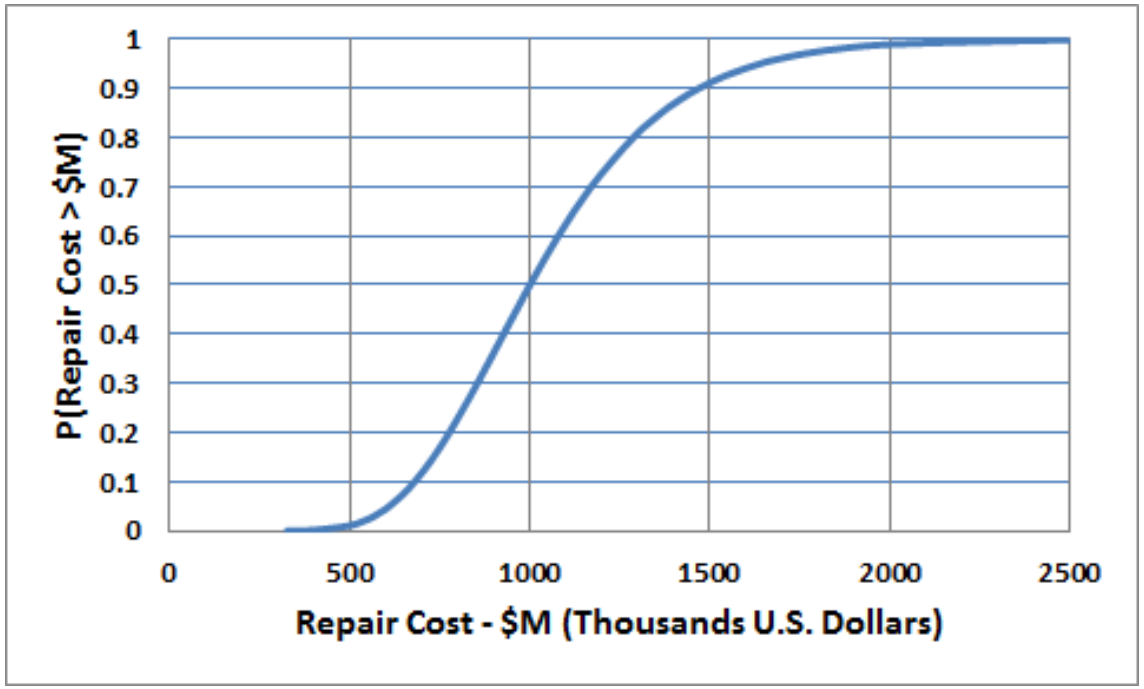


# FEMA P-58 Outputs

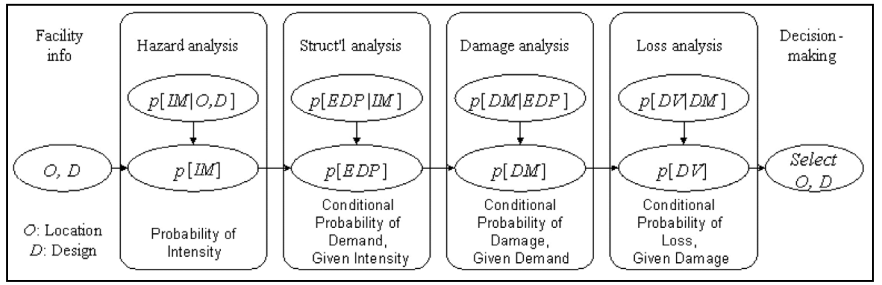
- Probable consequences and explicit consideration of uncertainty
  - Casualties
  - Repair costs
  - Repair time
  - Unsafe placarding
  - Environmental Impacts





# FEMA P-58 Technical Basis

- Theory based on the PEER PBEE Framework (Moehle and Deierlein, 2004)




- Practical application based on a modified Monte Carlo approach (Yang, et al. 2009)
- Fragility information based on
  - Latest available test data from researchers performing tests
  - Expert judgement where data did not exist

# ATC-58 Project QA/QC

- Extensive quality assurance measures were undertaken to validate the basic methodology and products
  - Validation/Verification Team
  - Fragility Review Panel
  - Special Reviewers
  - Benchmark Performance Evaluations
    - Whack-A-Mole
    - Multi-year iterative process on 1000s of archetypes

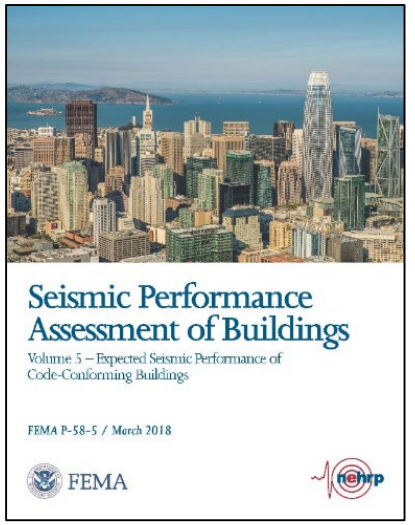
VALIDATION/VERIFICATION TEAM
Charles Scawthorn (Chair)
Jack Baker
David Bonneville
Hope Seligson

FRAGILITY REVIEW PANEL
Bruce Ellingwood
Robert P. Kennedy
Stephen Mahin

SPECIAL REVIEWERS
Thalia Anagnos
Fouad M. Bendimerad

# FEMA P-58 Summary Results

- FEMA P-58, Volume 5
  - Performance is NOT uniform across systems
  - You CAN control performance with design
  - Strength and stiffness are absolutely key
  - Risk Category IV design criteria improves performance



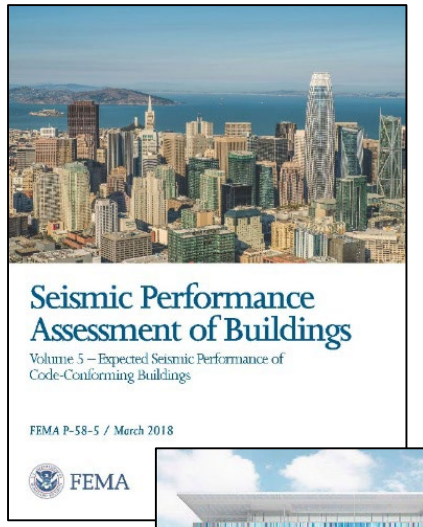
# FEMA P-58 Summary Results

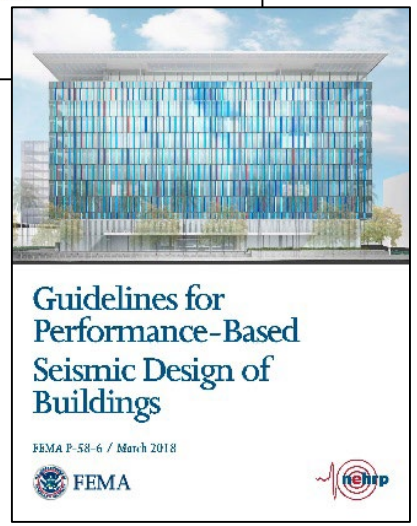
Table 6-1 Generalized Performance Expectations for Code-Conforming Buildings

| Performance Measure | Performance Expectation | |
|---|---|---|
| | Design EQ | MCE |
| **Risk Category II – Office** | | |
| Repair Cost | 10% | 30% |
| Repair Time | 45 days | 150 days |
| Casualty Rate | 1.0% | 2.0% |
| Probability of Unsafe Placard | 20% | 40% |
| Repairability | 95% | 80% |
| **Risk Category IV – Office (Emergency Operations Center)** | | |
| Repair Cost | 5% | 15% |
| Repair Time | 30 days | 75 days |
| Casualty Rate | 0.5% | 1.5% |
| Probability of Unsafe Placard | 10% | 25% |
| Repairability | 98% | 90% |

# FEMA P-58 Summary Results

- FEMA P-58, Volume 5
  - Trends made sense
  - Absolute losses judged to be reasonable
  - Relative losses could be used to tune designs to improve performance
- FEMA P-58, Volume 6
  - Guidance on short-circuiting the iterative process
  - Simplified demand estimation (isolated, damped systems)

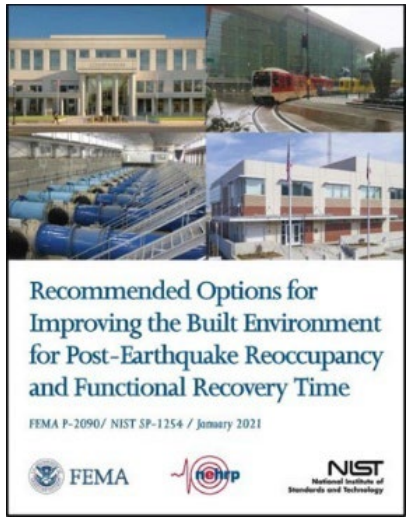


# *Functional Recovery (ATC-138 Project)*

# ATC-138 Project Context

- Ongoing FEMA contract for PBSD Support
- Pivoted to functional recovery with the publication of FEMA P-2090/NIST SP-1254
- Research by Liel and Cook (CU Boulder) and Koliou (Texas A&M) under a NIST-funded grant became the basis for extending the FEMA P-58 methodology



# ATC-138 Project Context

- Project Team

APPLIED TECHNOLOGY COUNCIL
Jon A. Heintz (Project Manager)

PROJECT MANAGEMENT COMMITTEE
Ronald O. Hamburger (Project Technical Director)
Curt Haselton
John D. Hooper
Ryan A. Kersting
Abbie Liel
David Mar

WORKING GROUP MEMBERS
Ed Almeter
Jack Baker
Dustin Cook
Laxman Dahal
D. Jared DeBock
Aaron Malatesta
Katherine Wade

FUNCTIONAL RECOVERY REVIEW COMMITTEE
Ronald O. Hamburger
Curt Haselton
Jon A. Heintz
John D. Hooper
Abbie Liel
David Mar

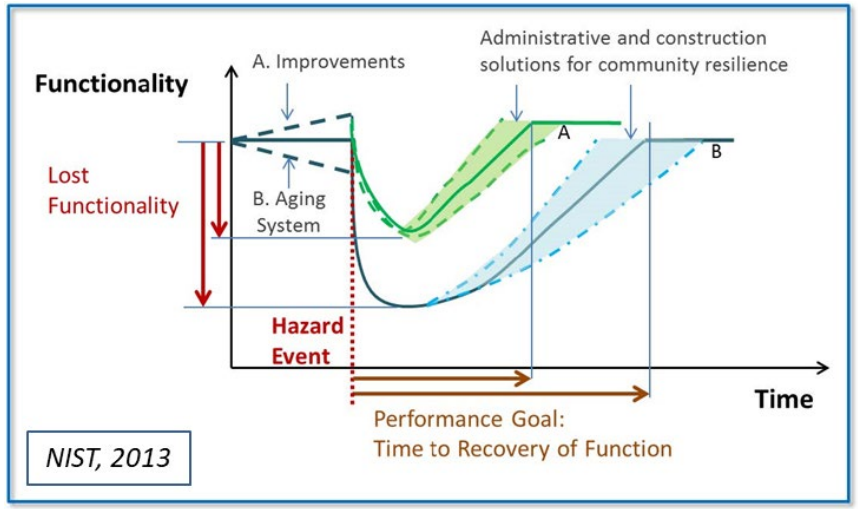
PROJECT REVIEW PANEL
Jeffrey Keileh
Peter Morris
Jonathan C. Siu
Mike Tzortzis
Steven R. Winkel
Russell Wissink

# ATC-138 Project Status

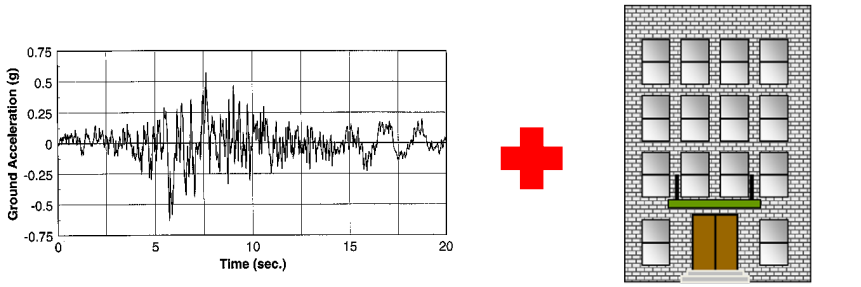
- Vetted the method developed by Liel and Cook
- Adjusted and expanded the functional criteria and embedded assumptions
- Improved fragility formulations for nonstructural components and distributed systems
- Released a working beta version in 2021
- Currently benchmarking results (Whack-A-Mole)

# Key Concepts

- Resilience versus Functional Recovery
  - Community Resilience is the goal




  - Functional Recovery is the performance-based design objective for achieving that goal



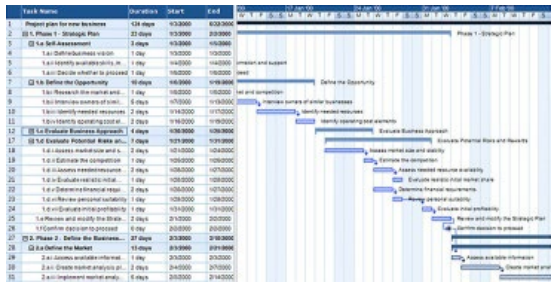

Functional Recovery

# Key Concepts

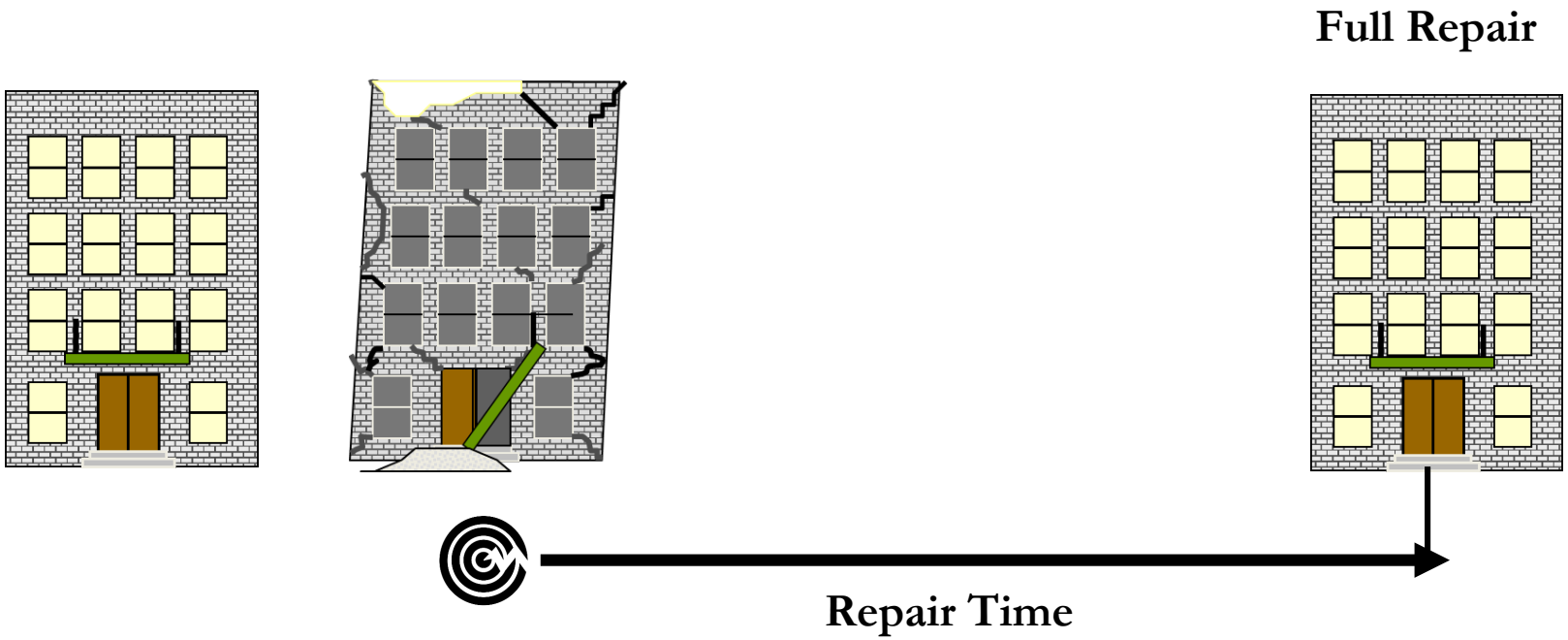
- Functional Recovery definition
  - Recovery to “basic function”
  - More than reoccupancy, but less than full functionality

*(from FEMA P-2090/NIST SP-1254)*

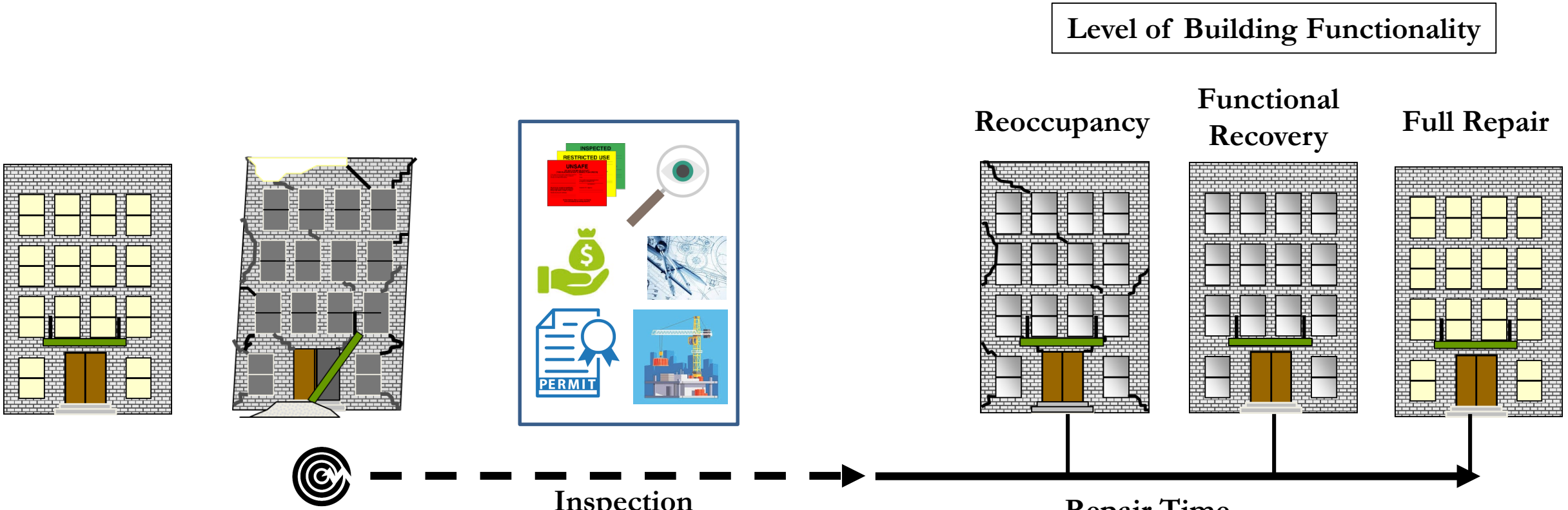
- Repair time versus downtime
  - Time to conduct repairs
  - Consideration of impeding factors



# What FEMA P-58 provides



# What is needed



# Key Questions

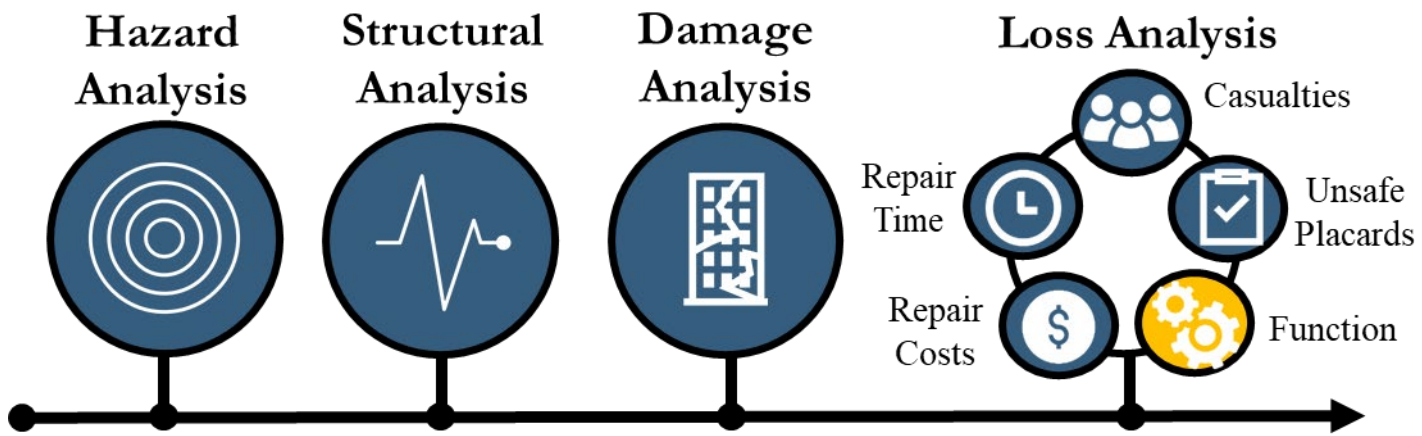
- What is basic function?
- How long can we live without it?
- At what hazard level?

- What damage impairs function?
- For how long?
- Can we tune designs to achieve desired recovery times?

# *Extension of FEMA P-58 (ATC-138 Project)*

## *Abbie Liel*

# Extension of FEMA P-58 (ATC-138 Project)



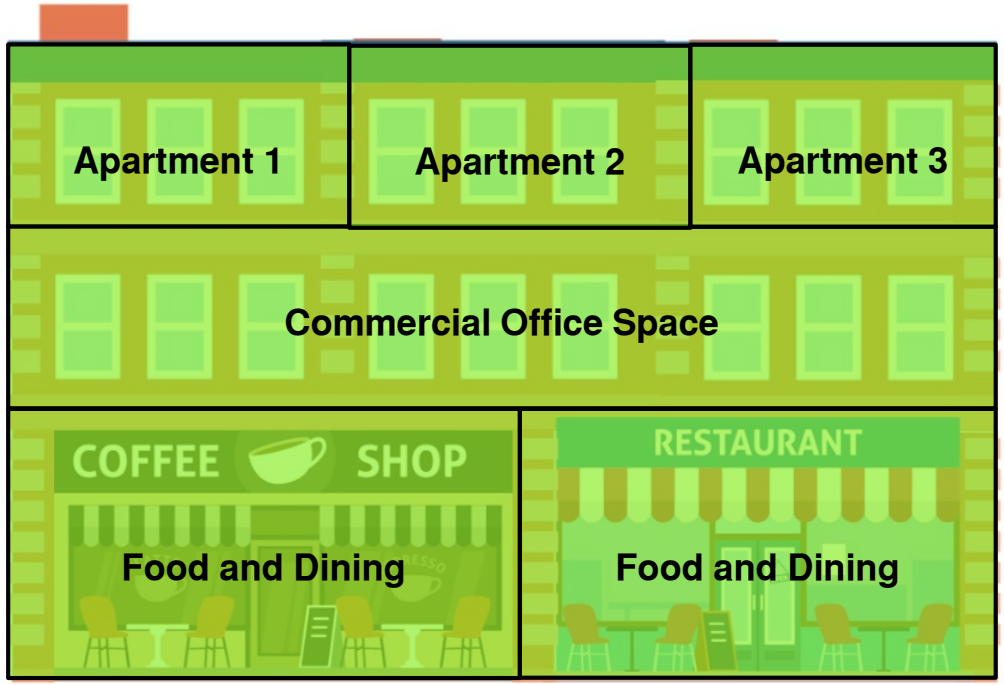

*(courtesy of A. Liel, D. Cook )*

- Extending FEMA P-58 to Assess Function required:
  - Update of unsafe placard (red-tag) logic
  - Fault tree logic for functional impacts of damage
  - Update of repair scheduling
  - Assessment of impeding times

# Building Performance Models


- Building Performance models must be adjusted to match the level of detail needed for assessment
- Fragility Specifications must include damage and consequences related to function

# Building Performance Models




FEMA P-58 PGs:

- Components at each level in each direction

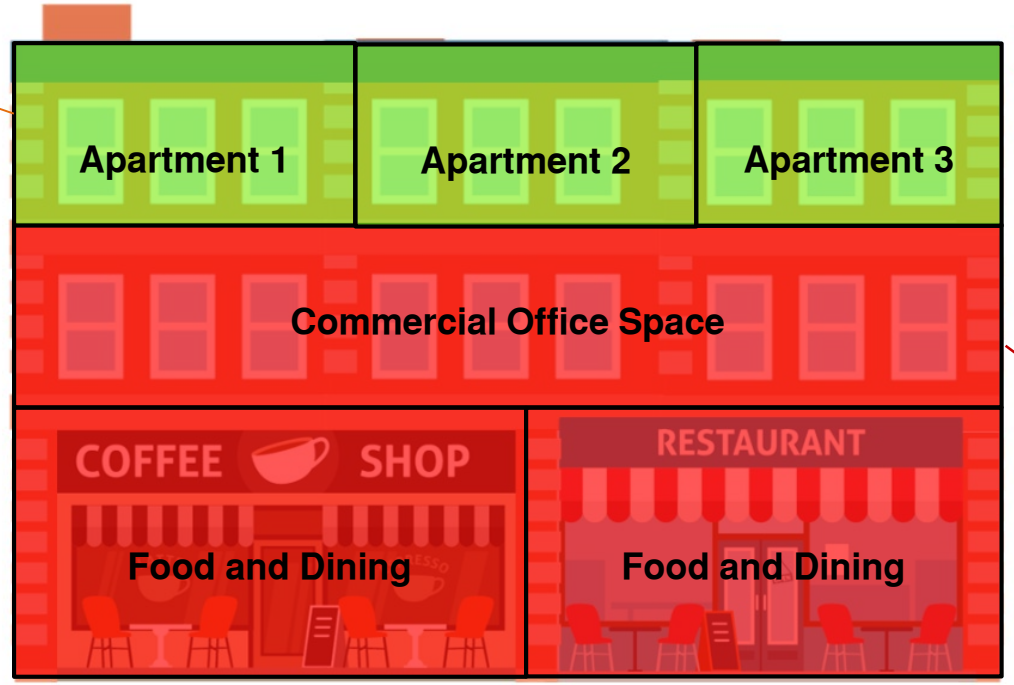
ATC-138 PGs:

- Components at each level in each direction, in each tenant unit

# Measure of Performance

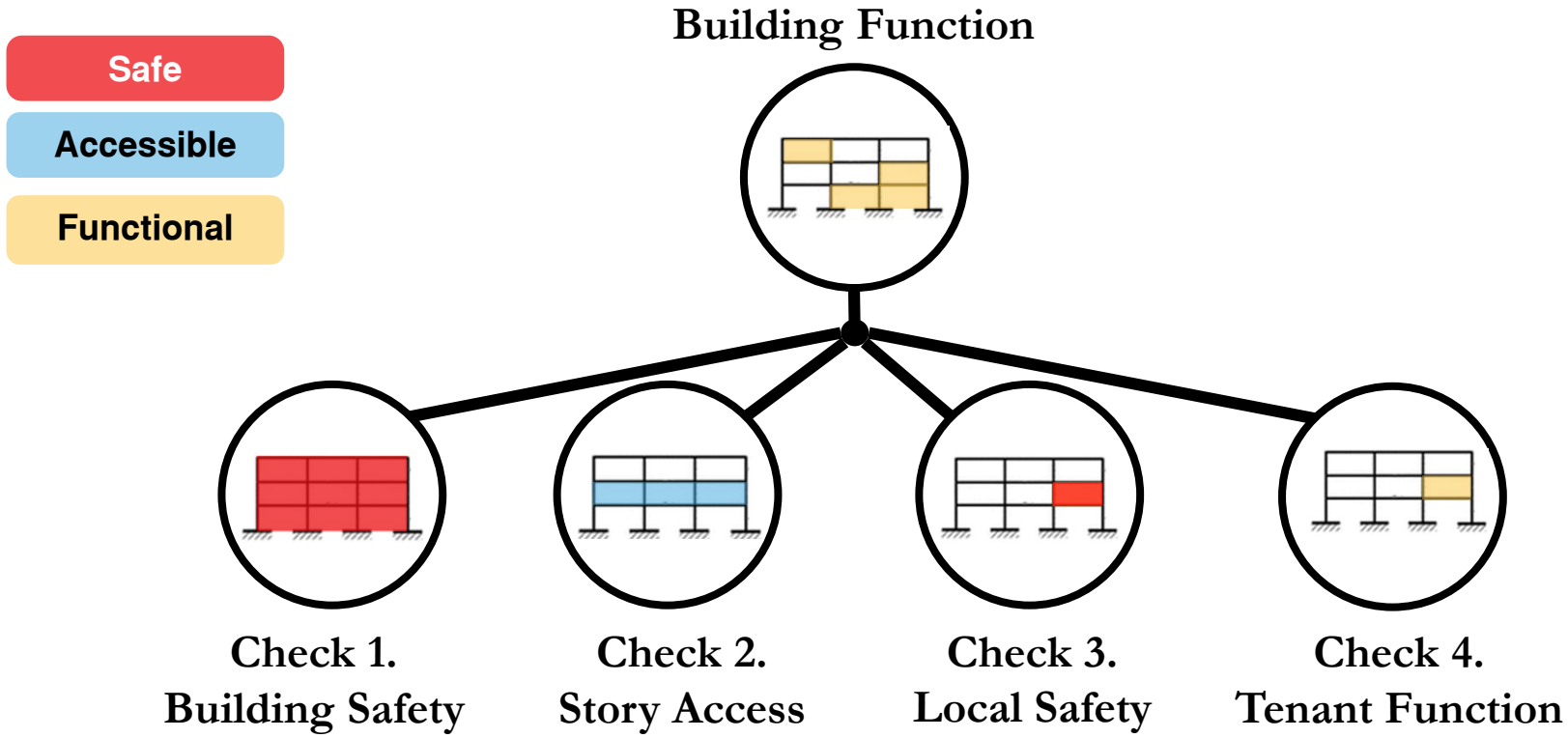
**Level of Performance**
**X% of the building floor area**

Recovery level of the building at **any day** before or after the earthquake. Defined as **percent of the floor area** that meets the **tenants' basic functional needs**.

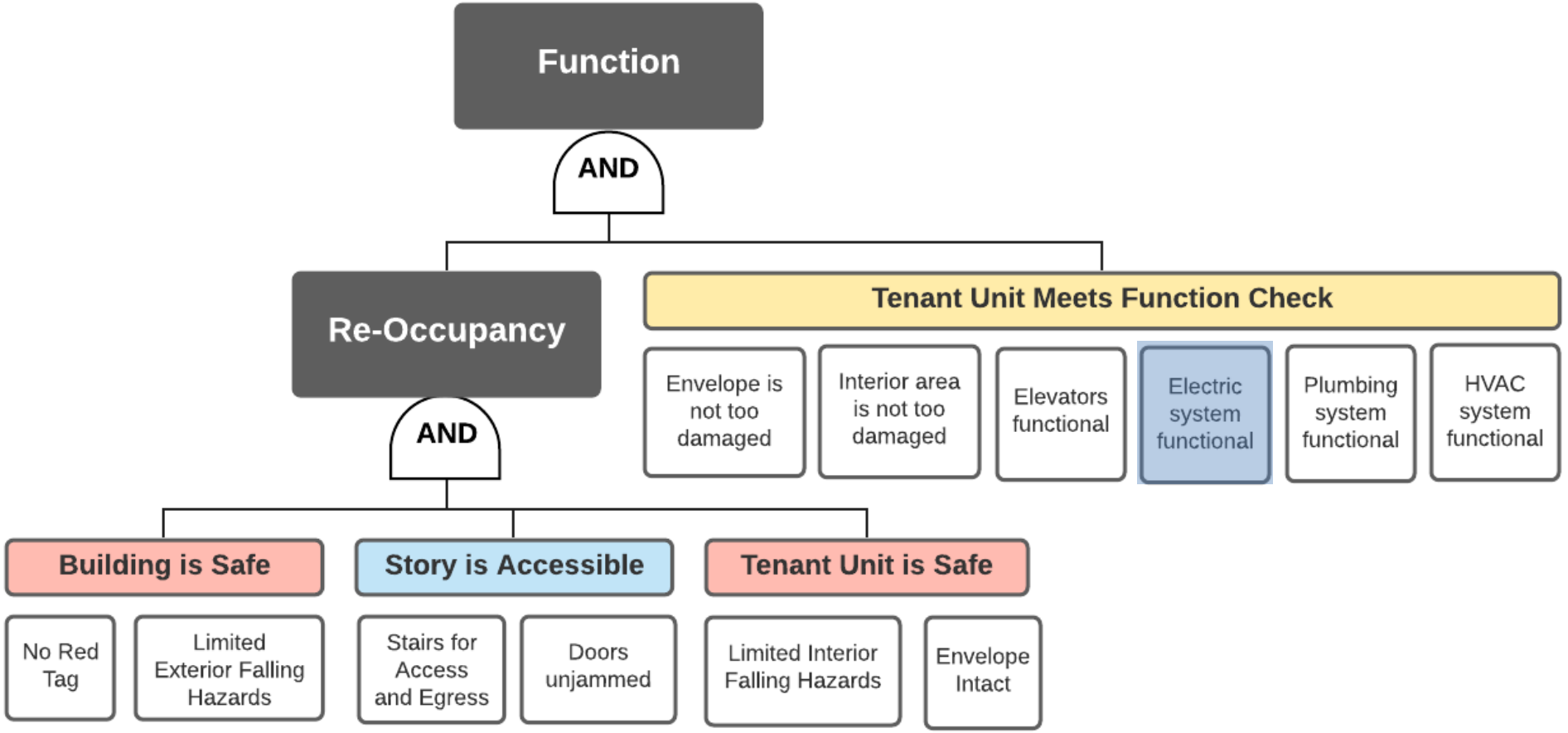



**Performance State**
**This tenant unit is/is-not functional**

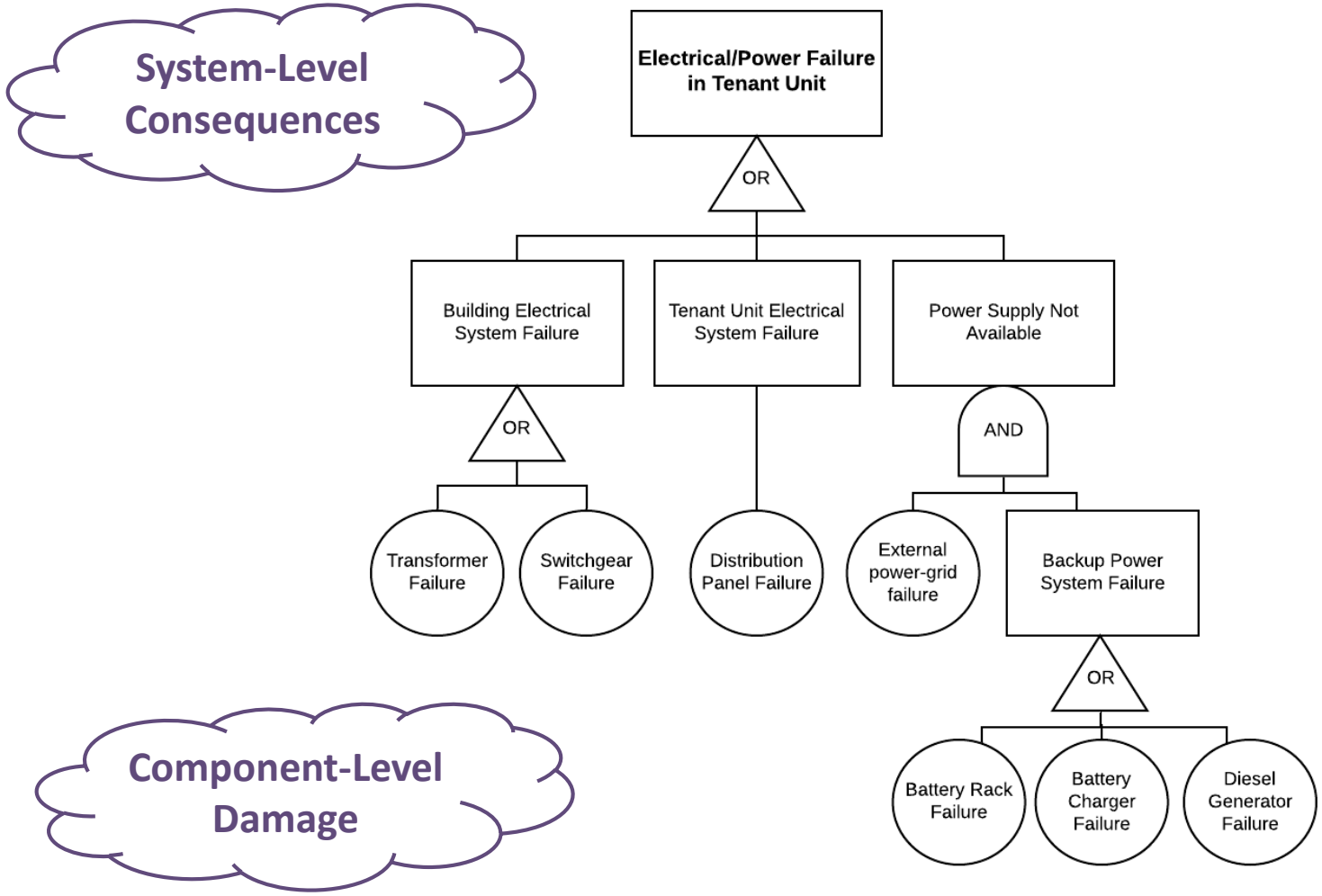
# Assessment of Function



# Basic Fault Tree Logic



# Mapping Damage to Function - Electrical



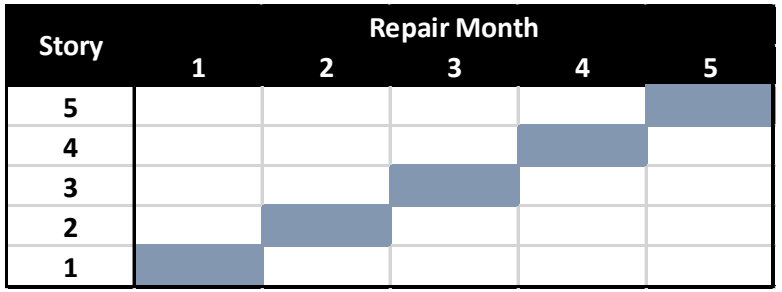

Hard Questions:

- What damage impairs function of a system?
- How much damage results in a red-tag?
- How much damage is locally safe/unsafe?
- What access is needed for reoccupancy?
- What systems are needed for basic function?

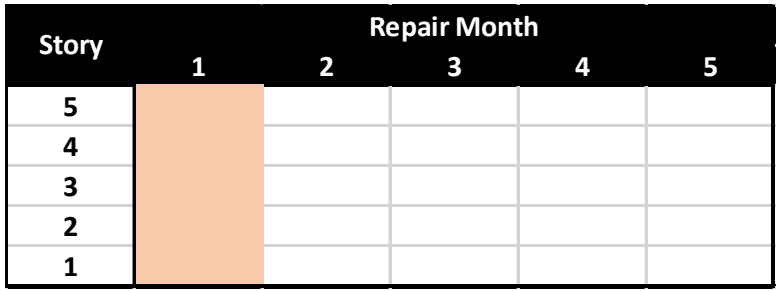
# Repairs and Repair Scheduling

- FEMA P-58 Repair Times
  - Series (lower bound)
  - Parallel (upper bound)
- More sophisticated scheduling was needed
  - Prioritization of repair schedule
  - Consideration of impeding factors

**Series**

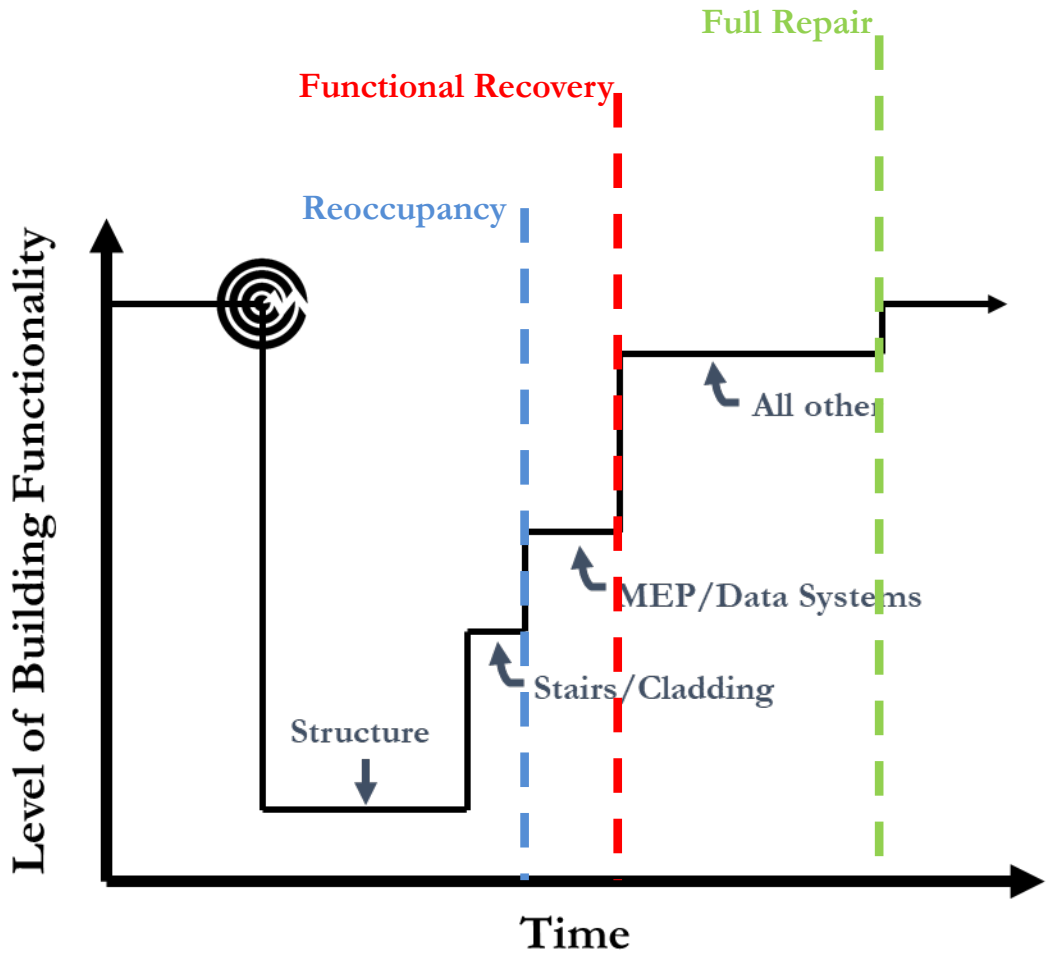



**Parallel**

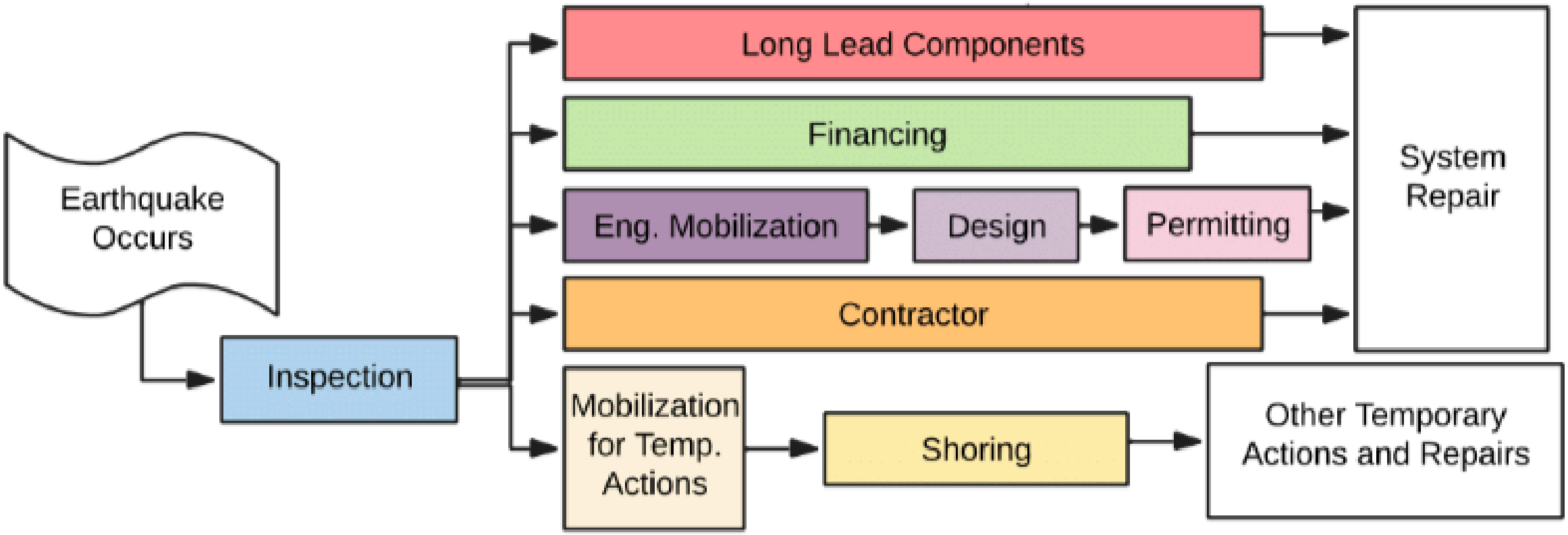


# Repair Sequencing

1. Safety repairs
2. Access repairs (stairs, doors, elevators) necessary for occupancy
3. Other repairs necessary for occupancy
   (fire protection, HVAC, lighting, exterior envelope containment)
4. Other repairs necessary for function (data, tenant special equipment)
5. Nice to have repairs (patch and paint)



# Impeding Factors and Repair Scheduling




- ATC-138 includes default assumptions for impeding times based on architect, contractor, and building official input

# Temporary Actions and Repairs

| Temporary Repair Class | Scheduling Priority | Crew Size | Mobilization Time[1] |
|---|---|---|---|
| Janitorial/general | 5 | 10 | 1 day |
| Basic carpenters/laborers | 4 | 5 | 2 or 28 days |
| Skilled laborers | 3 | 2-5 | 5 or 28 days |
| Skilled labor for shoring | 1 | 3 | 5 or 28 days |
| Specialized laborer or equipment | 2 | 1-4 | 7 or 28 days |

Ex: Spilled contents, sweeping

Ex: Boarding up windows, picking up suspended ceilings

Ex: Shoring for HVAC, shoring for limited structural damage

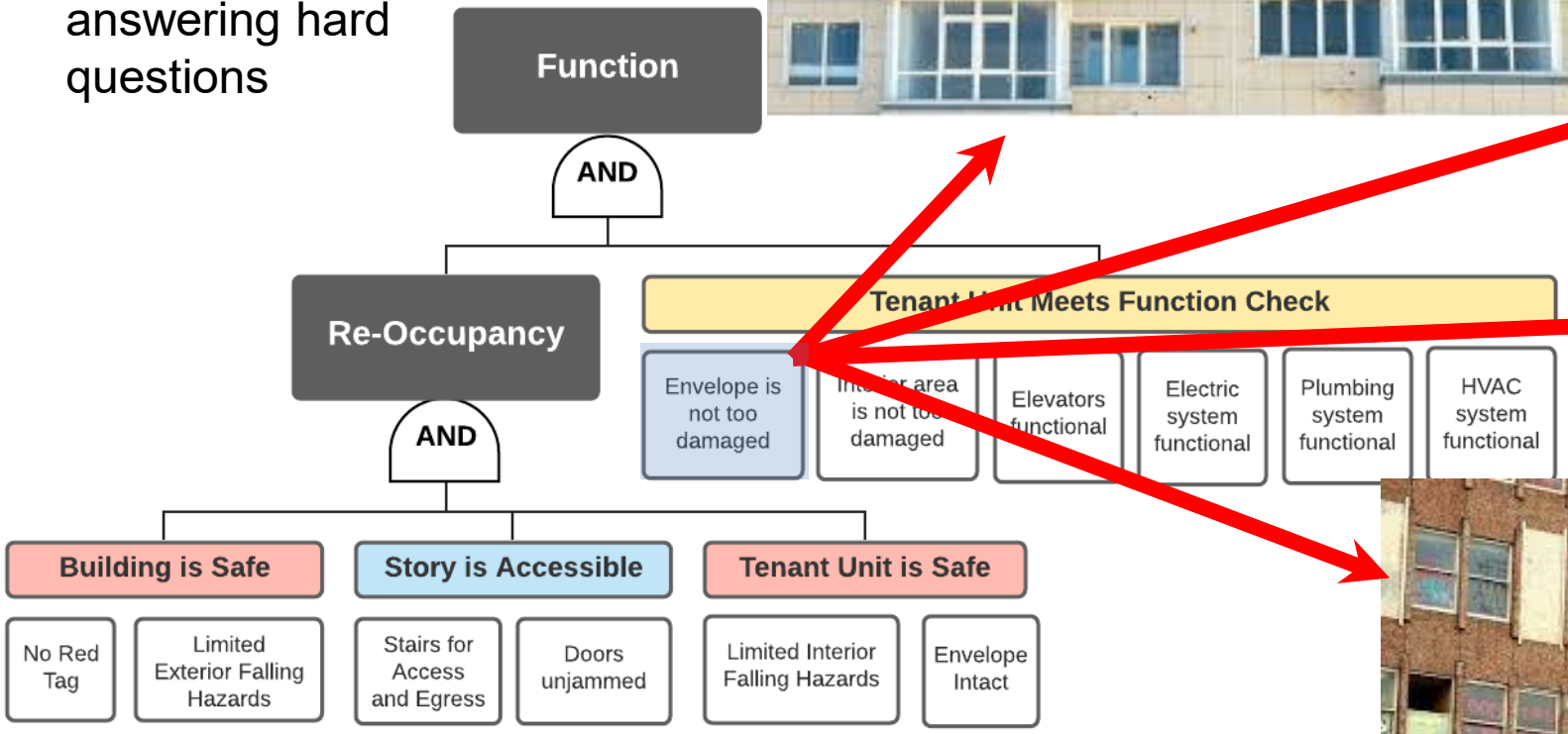
Ex: Parapet removal

More Hard Questions:

- What temporary actions restore function?

# Challenges

- Basic Function implies less than full function
- Developing the methodology required answering hard questions



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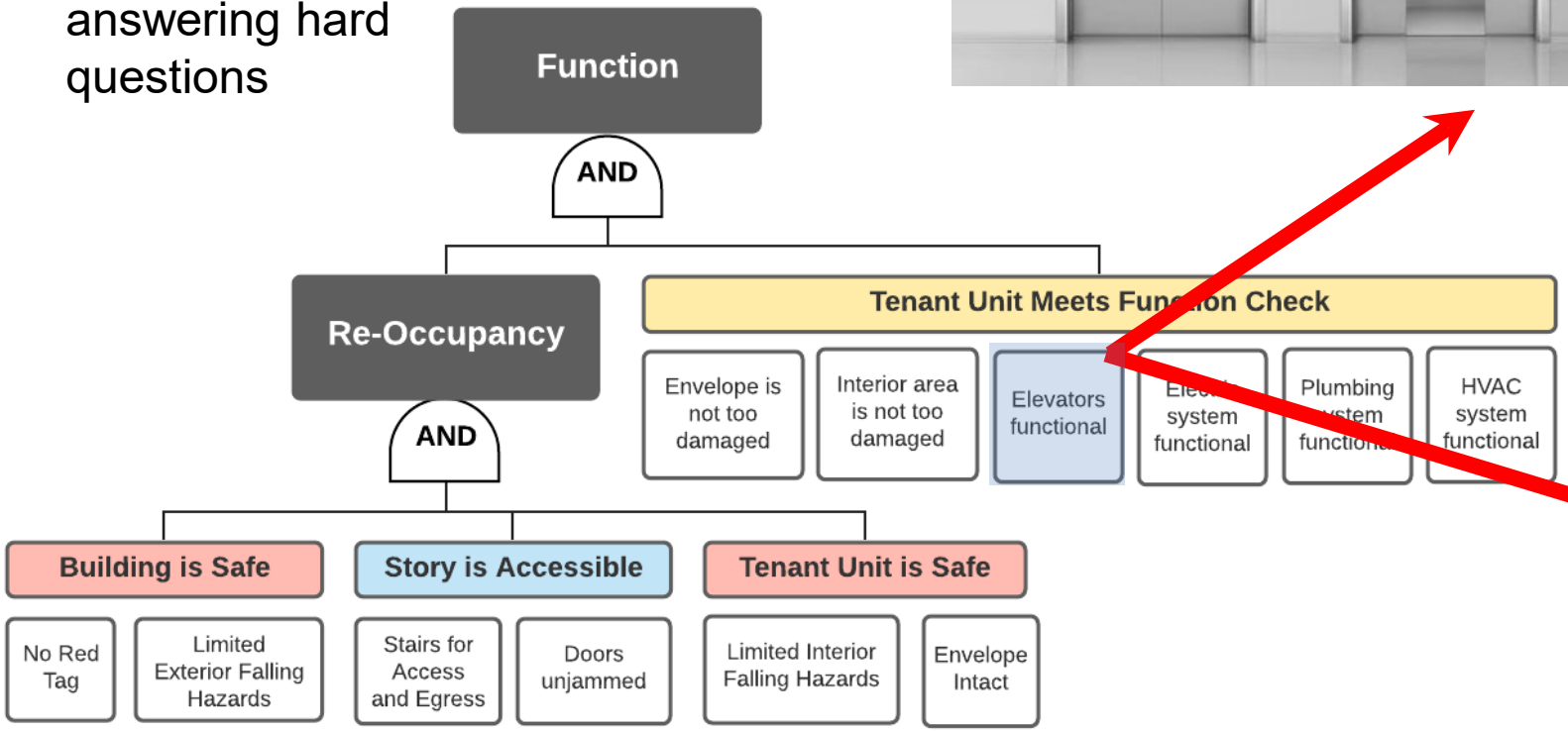


# Challenges

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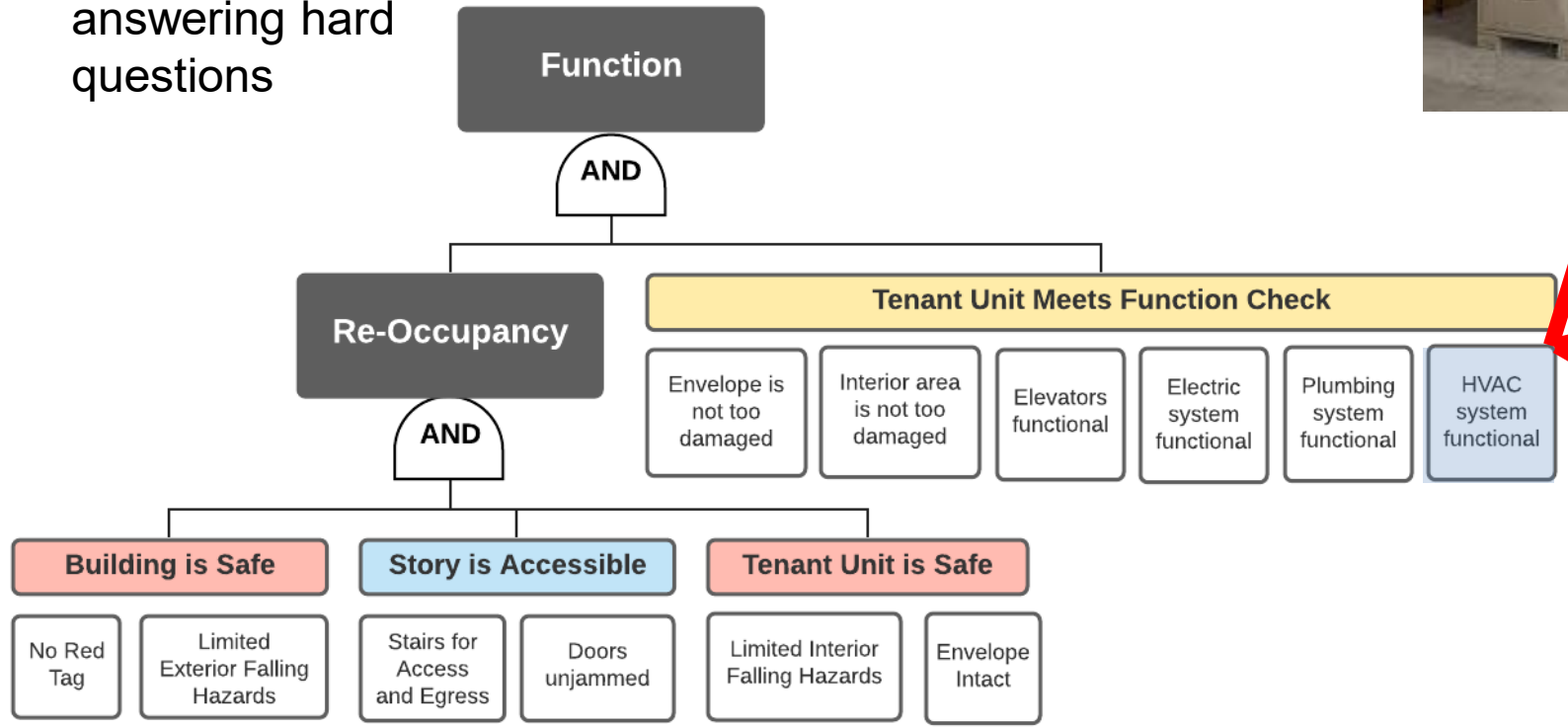



# Initial Concepts of Basic Function

- Challenges:
  - What is included (structural, nonstructural, contents)?
    - "Core and shell plus"
    - "Plus" is not fully defined
  - Zero damage state is not realistic
    - Trying to allow for some level of damage
    - Functional systems are still required for functionality

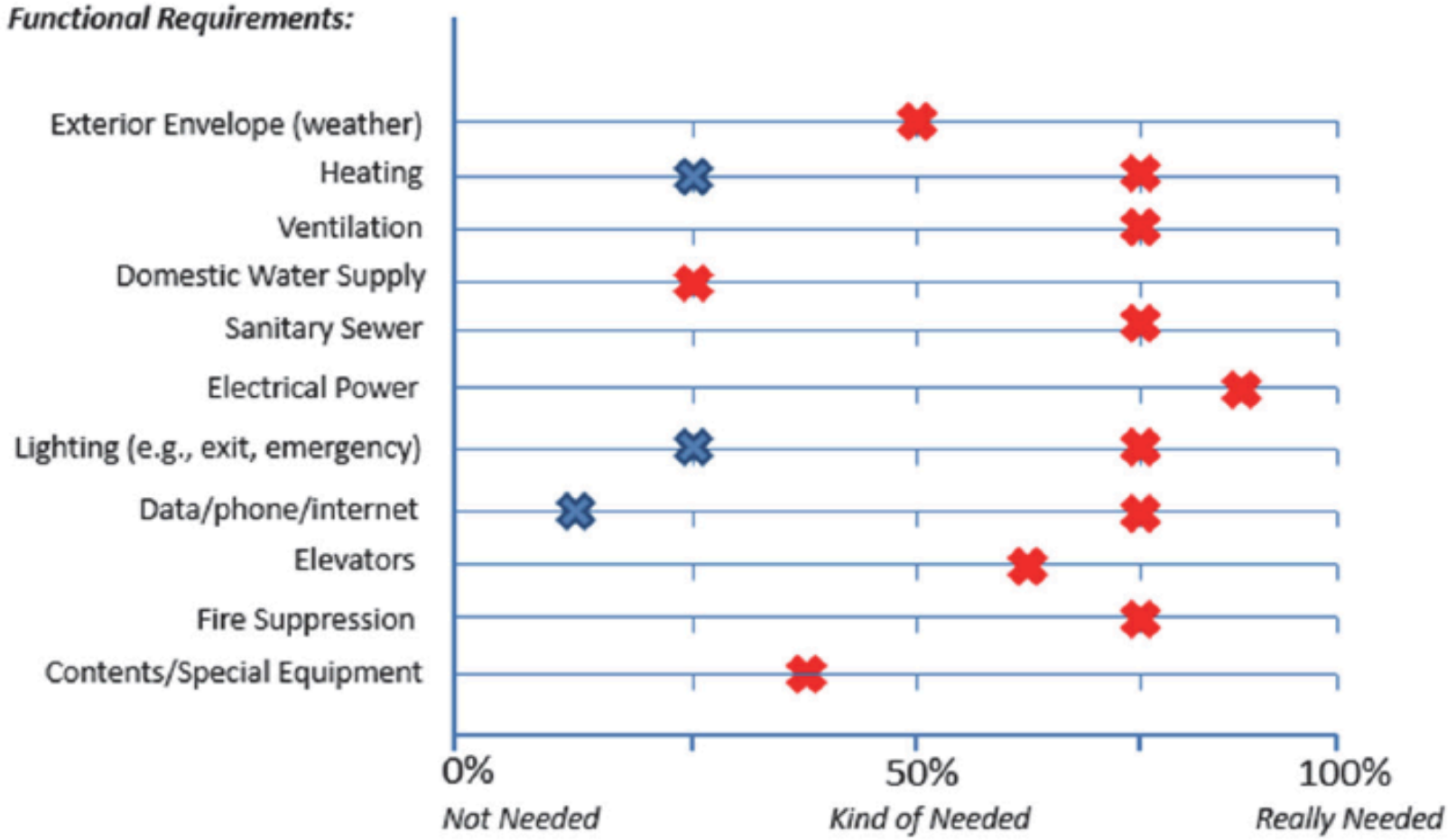
# Initial Concepts of Basic Function

- Challenges:
  - What does it mean to allow temporary measures/workarounds?
    - Represents “tolerance” for inconvenience
    - But not considered an acceptable “design target” for functionality
  - What reduction in functionality is reasonable?
    - There are few systems we can live without
    - There are few differences between occupancies, resulting in few permutations of different criteria for functionality

Image: BBC, NZ

# What is Basic Intended Function?

## Group 1-B; Assigned Occupancy: Commercial




| *Temporary Workarounds (e.g., board up windows):* |
|---|
| Board up windows; cover with tarps |
| Seasonal and regional; AC (blue) |
| Operable windows |
| Bottled water |
| Portable toilets |
| Emergency generators/batteries |
| Portable lights; regular lighting (blue) |
| Servers critical; phone/internet (blue) |
| Only one needed |
| Fire watch |
| |

# Tolerance for Inconvenience (Loss of Use)

| Systems | Funct. Bin 1 | Funct. Bin 2 | Funct. Bin 3 | Funct. Bin 4 | Funct. Bin 5 | Funct. Bin 6 |
|---|---|---|---|---|---|---|
| Envelope | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Interior Area | ✓ | ✓ | ✓ | ✓ | ✓ | |
| Access (stairs vs. elevators) | ✓ | ✓ | ✓ | ✓ | ✓ | |
| Plumbing | ✓ | ✓ | ✓ | | | |
| Electrical | ✓ | ✓ | ✓ | ✓ | | |
| HVAC | ✓ | ✓ | | | | |
| Data | ✓ | | | | | |

# Fault Trees Interpret Basic Function

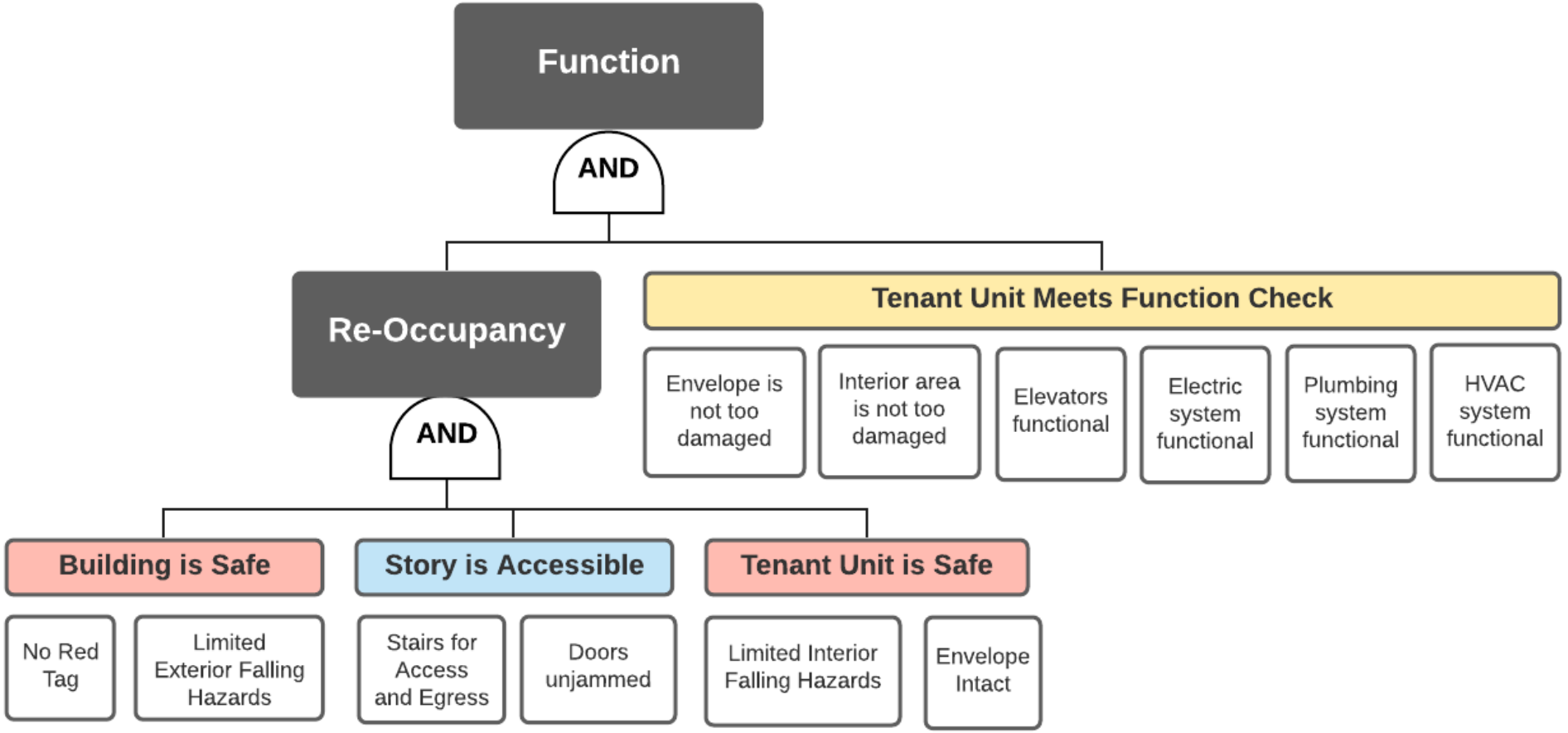


Table 1 Requ. for Reoccupancy and Functional Recovery, Including Default Acceptance Criteria

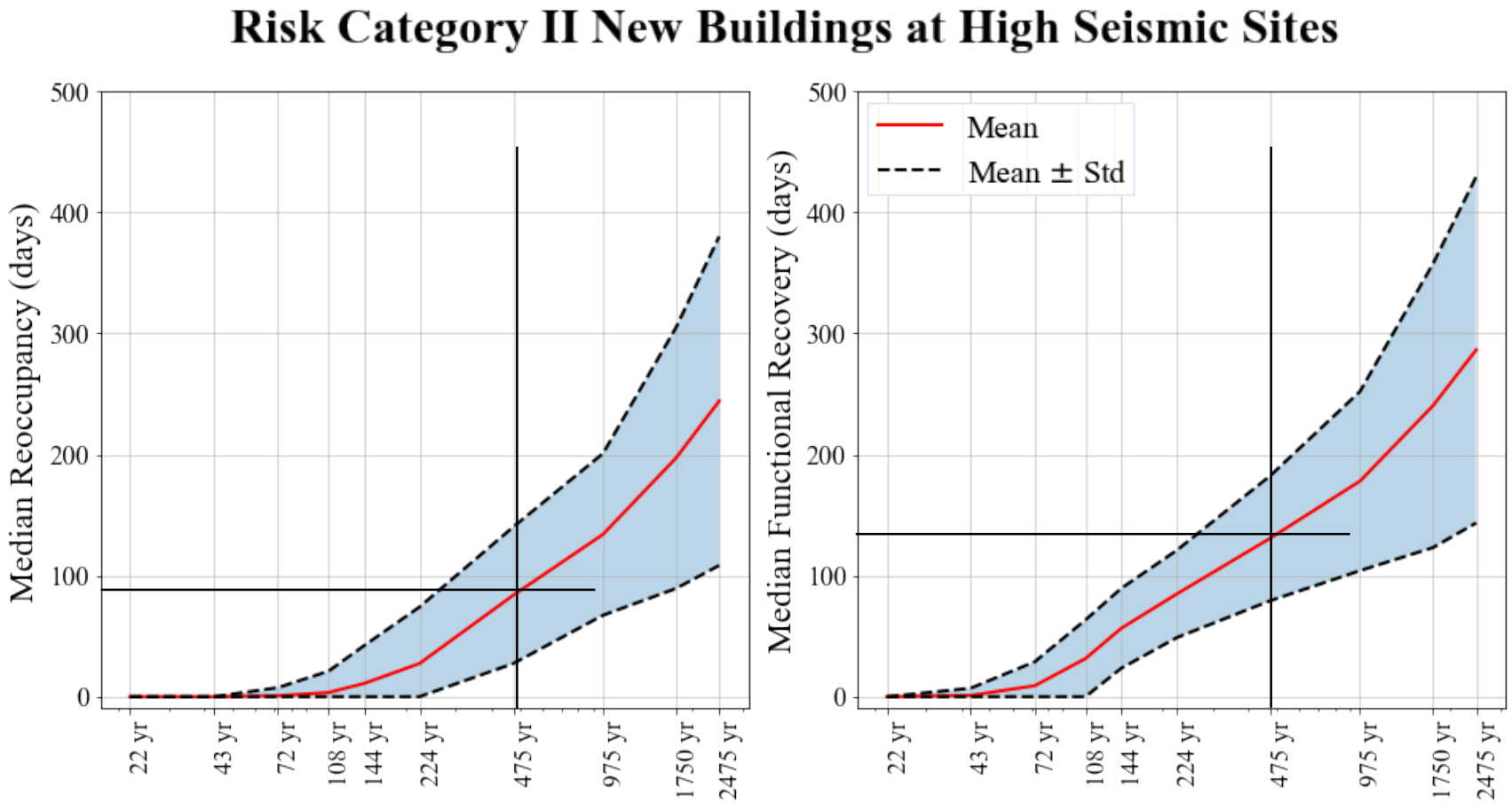
| Recovery Stage | Requirement | System | Logic | Acceptance Criteria including Defaults for Commercial Office (and Residential) |
|---|---|---|---|---|
| **Re-Occupancy:** Building Area is Occupiable | Building is Safe | Structural (damage limited, no red tag) | Structural damage must be limit so building is not red-tagged (check on moderate damage not being too widespread) | < 50% of components at a story/direction can have a SC1[1] or greater damage state |
| | | | Structural damage must be limit so building is not red-tagged (check on damage that reduces lateral strength of the building) | < 25% of components at a story/direction can have a SC2[1] or greater type damage |
| | | | Structural damage must be limit so building is not red-tagged (check on damage that compromises vertical load carrying capacity) | < 10% of components at a story/direction can have a SC3[1] or greater damage state |
| | | | Structural damage must be limit so building is not red-tagged (check on damage that is likely to cause progressive collapse) | No components can have a SC4[1] damage state |
| | | Building Envelope (cladding) | Falling hazards over exit doors must be limited | Tenant unit has at least 50% of the buildings design egress, and at least two safe exit points |
| | | Fire Protection | Fire suppression systems needed if fire watch not possible/allowed, fire separations needed, gas breaks not permitted | Fire suppression system is functional, fire separations intact, and no gas line breaks[2] (fire watch is user-input) |
| | | Hazardous Materials | No component damage that causes release of hazardous material that affects the whole building | Fails if any component damage state occurs that is flagged as releasing hazardous material to full building |
| | Story is Accessible | Stairs | Story where tenant unit is located must have door/stair access and safe egress | > 50% of story stairs are safe, at least two vertical paths of exit (stairs) are maintained, these stairwells have working doors |
| | | Exit Doors | Sufficient exit doors much be operational (i.e. not jammed). | Tenant unit has at least 50% of the buildings design egress, and at least two safe exit points |
| | Tenant Unit is Safe | Interior Components | Interior components (structural and non-structural) do not present a falling hazard | < 10% tenant area damaged with falling hazards |
| | | Building Envelope | Damage to building envelope does not present risk to occupant safety (no major holes in the enclosure that occupants can fall out) | < 10% tenant area with heavily damaged envelope |
| | | Hazardous Materials | No component damage that causes release of hazardous material in the local tenant unit | Fails if any component damage state occurs that is flagged as releasing hazardous material to tenant unit |
| | | Multiple Building Systems | Reoccupancy requirements met for the local jurisdiction (e.g. water, sanitary waste, power, heating, ventilation, etc.) | Not required when using the analysis method defaults[2] (user can select to enforce these various requirements) |

| Recovery Stage | Requirement | System | Logic | Acceptance Criteria including Defaults for Commercial Office (and Residential) |
|---|---|---|---|---|
| Functional Recovery: Building Area is Functional | Tenant Unit is Occupiable | All | Tenant unit must meet the occupancy requirements above (i.e. a tenant unit cannot be functional without also being occupiable) | Tenant unit is occupiable (according to requirements in the above previous section of this table) |
| | Envelope is not too Damaged | Building Envelope | Cladding is not damaged enough to significantly compromise environmental seal, temporary repairs to cladding are not too broad to substantially reduce light exposure | < 50% of the perimeter of the tenant space is affected (with < 75% used as default for residential) |
| | | Roof Enclosure | Roof does not leak too much to make top story non-functional | < 10% of structural roof damage and < 25% of weatherproofing roof damage (only top story is non-functional if criteria are not met) |
| | Interior Area is not too Damaged | Interior Components | Tenant unit is not too badly damaged in terms of local interior falling hazards (structural and non-structural) and/or interior partitions being is very high damage states (i.e. tenants uncomfortable to use space) | < 25% of the interior space is affected (with < 50% used as default for residential) |
| | Elevators are Functional | Elevators | A sufficient number of elevators must be functional for tenant unit space higher up in the building to be functional | Tenant units above 3rd story (5th story for residential) need >=1 elevator operational per 1000 occupants[2,3] |
| | Plumbing Systems are Functional | Plumbing: Potable Water | Plumbing potable water system may need to be functional for tenant unit (excludes check of off-site water, not in footprint) | System is functional and provides water to tenant unit[2] (user inputs if this is required, defaults to required) |
| | | Plumbing: Sanitary | Plumbing sanitary waste system may need to be functional for tenant unit (excludes check of off-site sewer, not in footprint) | System is functional and provides service to tenant unit[2] (user inputs if this is required, defaults to required) |
| | Electrical System is Functional | Electrical | Electrical systems may need to be functional for tenant unit (excludes check of off-site power, since not in building footprint) | System is functional and provides power to tenant unit[2] (user inputs if this is required, defaults to required) |
| | Heating and Ventilation Systems are Functional | HVAC: Ventilation | HVAC ventilation system may need to be functional for tenant unit | System is functional and provides ventilation to tenant unit[2] (user inputs if this is required, defaults to required) |
| | | HVAC: Heating | HVAC heating system may need to be functional for tenant unit | System is functional and provides heating to tenant unit[2] (user inputs if this is required, defaults to required) |
| | | HVAC: Cooling | HVAC cooling system may need to be functional for tenant unit | System is functional and provides cooling to tenant unit[2] (user inputs if this is required, defaults to required) |
| | | HVAC: Exhaust | HVAC exhaust system may need to be functional for tenant unit | System is functional and provides exhaust from tenant unit[2] (user inputs if this is required, defaults to required) |
| | Data Systems are Functional | Data Systems | Data system may need to be functional for tenant unit | System is functional and provides exhaust from tenant unit[2] (user inputs if this is required, defaults to required) |
| | Tenant-Specific Contents | Contents | Functionality of some tenant-specific content may be required for function | Defaults do not require function of content[2] (user can add content fragilities and flag as needed for function) |

# Initial Concepts of Basic Function

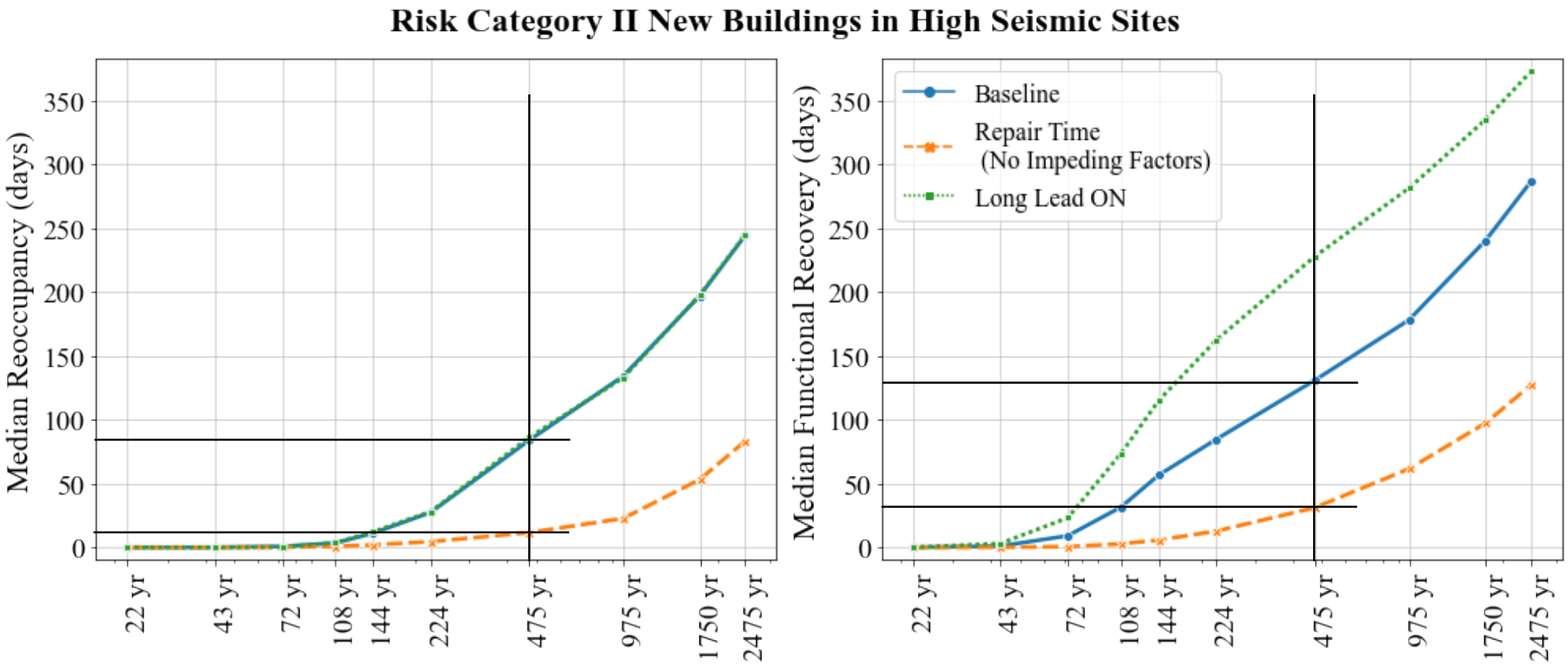
- ATC-138 has addressed commercial office and residential occupancies
- Planning more testing on additional occupancies
  - Hospital, EOC, Retail, Warehouse, High-rise Residential
- We are developing reoccupancy/functional criteria for these occupancies by extrapolation
  - Initial conversations have resulted in only small differences

# ATC-138 Results – Recovery Time

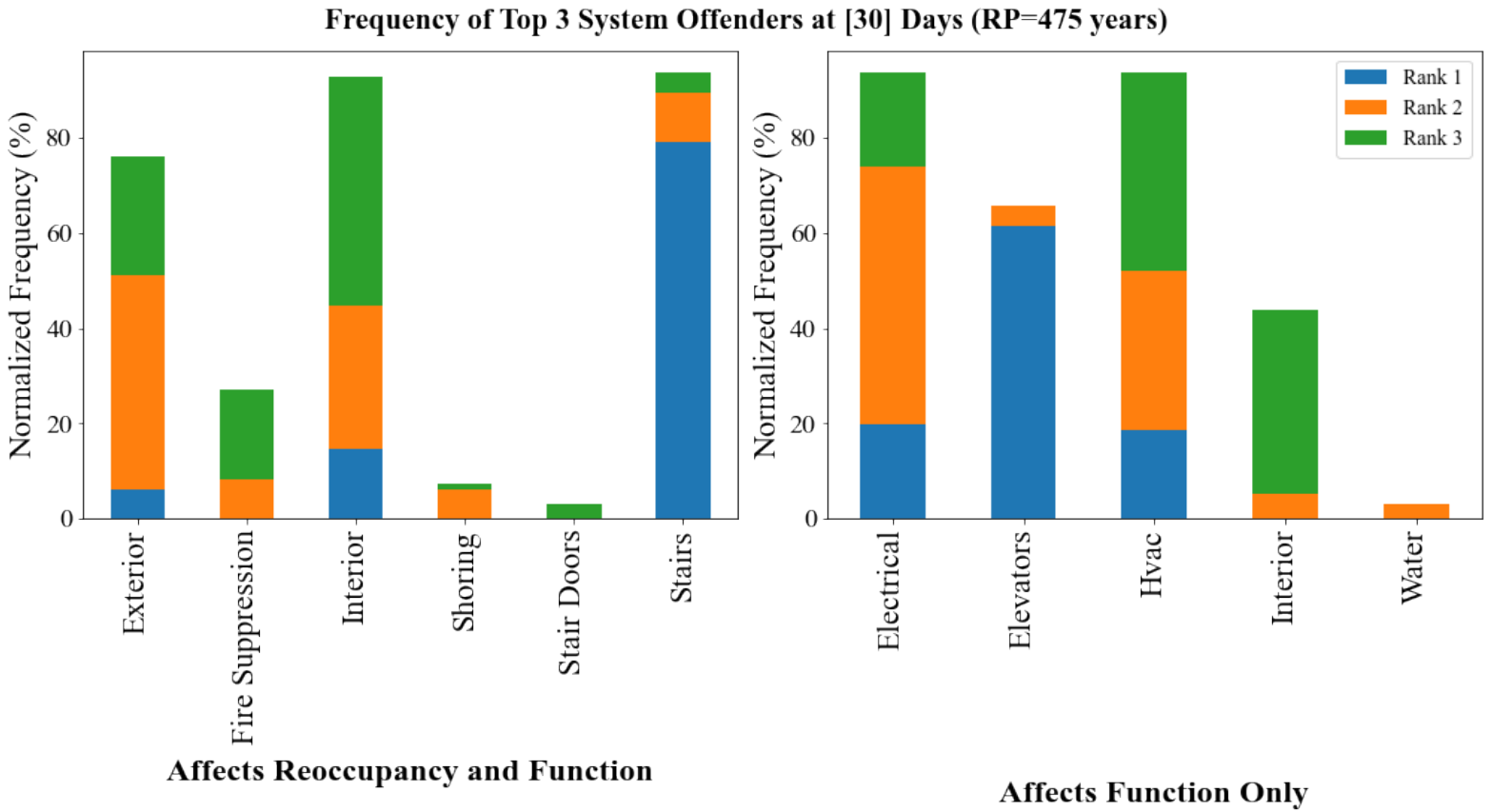


# ATC-138 Results – Impeding Factors

**Take Away:** Impeding factors and long-lead items significantly increase recovery times



# ATC-138 Results – Frequent Offenders




## Reoccupancy offenders (ordered):

- Structural lateral/gravity elements (red tag)
- Stairs when no seismic joint (C2011)
- Curtain/exterior walls (falling) (B2022/B1071)
- HVAC components (falling) (C3041)
- Pendant lighting (C3034.002)

## Functional Recovery (ordered):

- Electrical distribution panel (D5012)
- Elevators (D1014)
- HVAC components – ducting, drops, VAV boxes (D3041)
- Air handling units (D3052)
- Cooling tower (D3031)
- Exterior walls (B1071)

# Applications

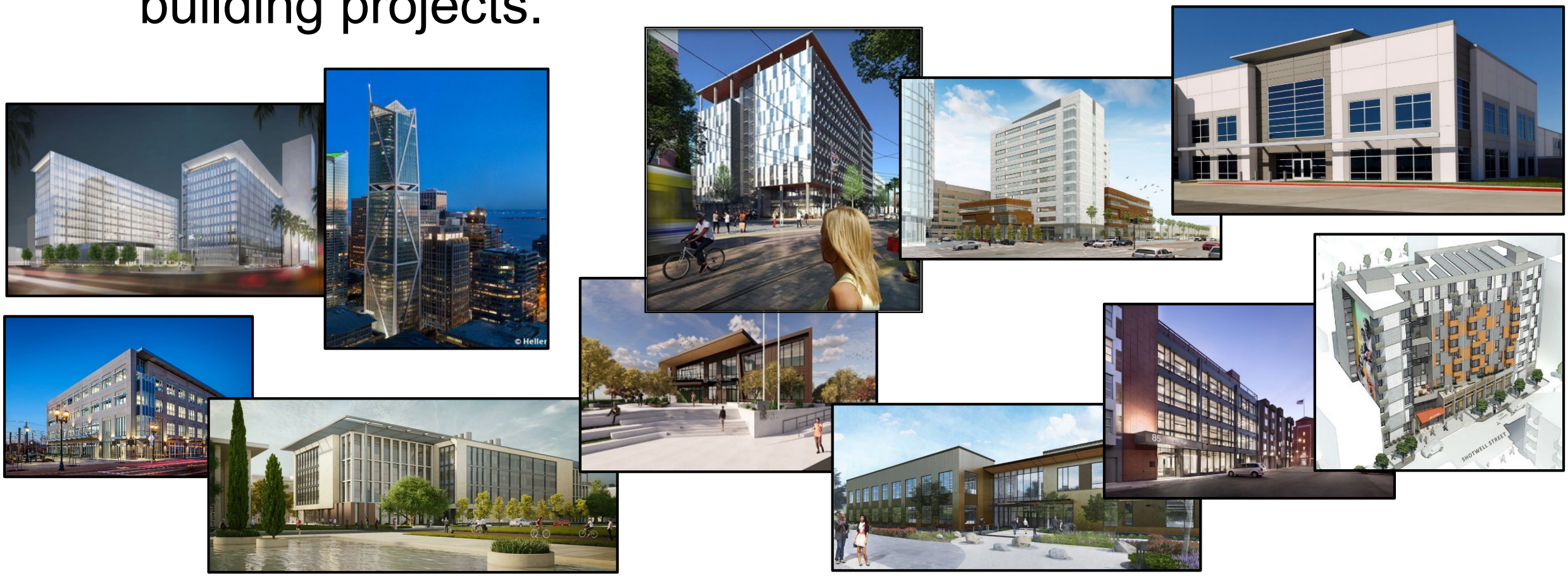
- FEMA P-58/ATC-138 now provides vetted, quantitative information to:
  - Design buildings to improve functional performance
  - Consider relative system performance
  - Define functional performance
  - Determine appropriate performance targets
  - Provide cost-benefit data

# Use for Resilient Design

- The FEMA P-58/ATC-138
  - estimates functional recovery times for a building or possible building design
  - is detailed enough to quantify how design changes affect function recovery time outcomes
  - can be used to iteratively design a building to meet a recovery time goal

# Use for Resilient Design

- This is being done electively now on individual building projects.



# Use for Resilient Design

- The typical resilient design process used is:
  - ✓ **Step #1: Select Structural System -** Select trial system, assess code-minimum performance, iterate as needed.
  - ✓ **Step #2: Identify Problem Components -** Identify systems/components with functionality issues in the trial design.
  - ✓ **Step #3: Design Components for Function -** Design all problem components to remain functional, using component-level design targets.
    - Including structural and non-structural.
    - Including drift-sensitive and acceleration-sensitive.
  - ✓ **Step #4: Confirm Design Goals are Met -** Run the full building performance model again to ensure that building-level recovery time goals are met.

# Summary and Conclusions

- The ATC-138 Project has developed a working (beta) version of a methodology that:
  - Maps component damage states to building function through a series of fault trees
  - Summarizes specific component damage states affecting building function (to aid design)
  - Quantifies time to recovery of function
  - Represents the best available information at this time

# *Thank you!*


Christchurch, New Zealand
Image: The Guardian