

Applied Technology Council

Designing for Functionality - The Next Step in Performance-Based Seismic Design

SEAOSD Meeting
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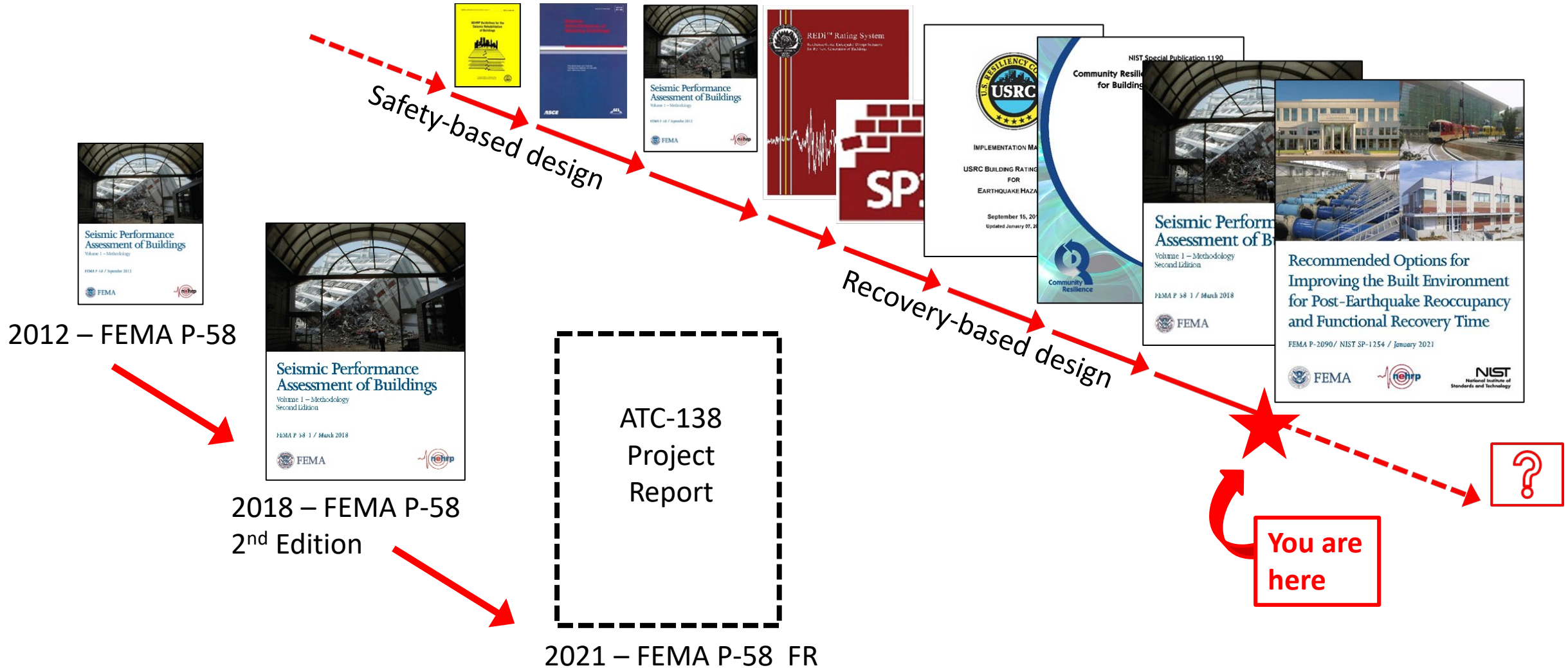
Outline

- Jon: Context, overview of FEMA P-58, and development of a method for assessing functional recovery
- Curt: Practical project examples and other use cases

Acknowledgements

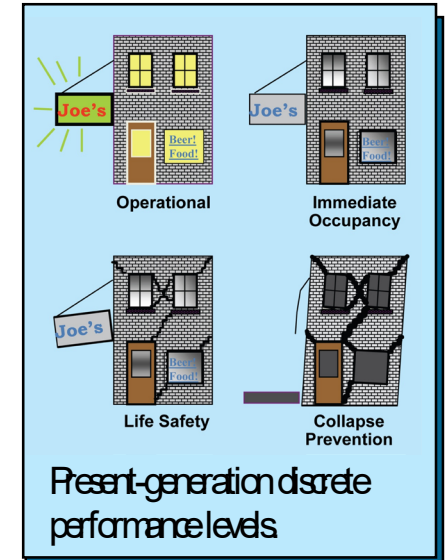
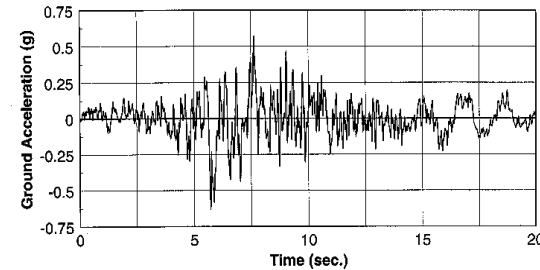
- Original FEMA P-58 development team
- FEMA-funded ATC-138 development team:
 - Ron Hamburger, Curt Haselton, John Hooper, Ryan Kersting, Abbie Liel, David Mar
- NIST-funded CU Boulder research team:
 - Abbie Liel, Dustin Cook
- Haselton-Baker Risk Group implementation team:
 - Curt Haselton, Jack Baker, Ed Almeter, Jared DeBock
Katie Wade

Evolution of Performance-Based Design


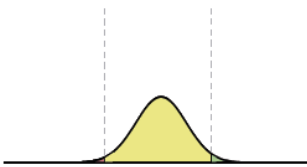
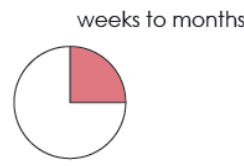





Key Concepts

- Performance-based design

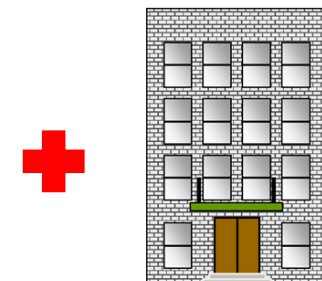
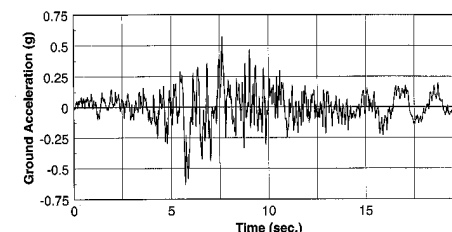
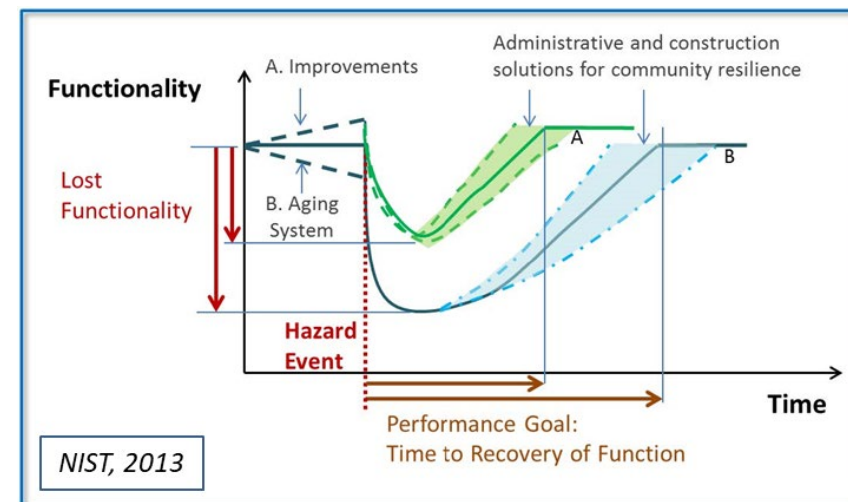


- Risk-based assessment (FEMA P-58)

Casualty Risks	Chance of Post-EQ Placard	Expected Building Downtime	Initial Building Cost	Repair Cost	Carbon Impacts of Repairs
					

Key Concepts

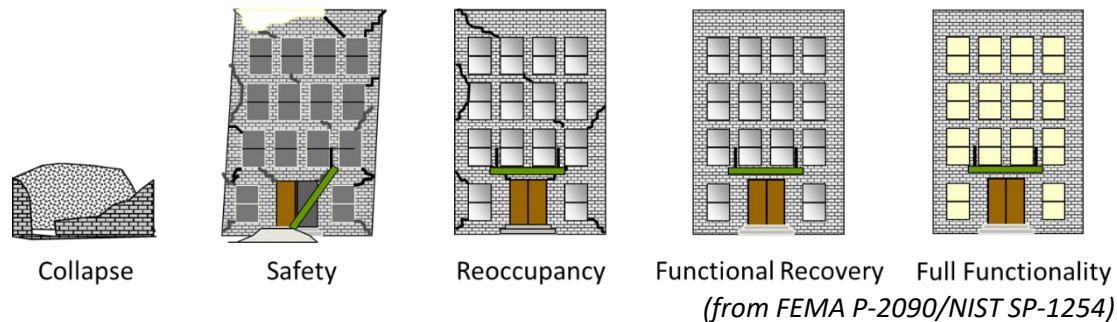
- Resilience versus Functional Recovery
 - Community Resilience is the goal
 - Functional Recovery is the performance-based design objective for achieving that goal



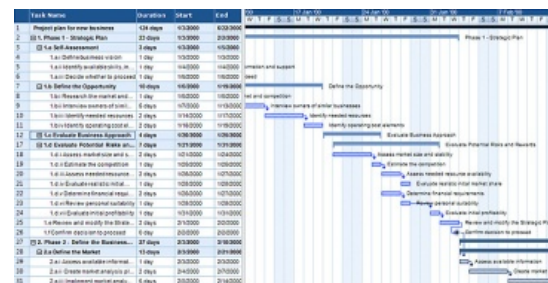
Functional Recovery

Key Concepts

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



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



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?

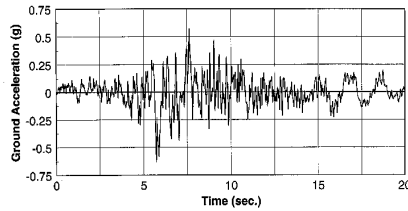


FEMA P-58 (ATC-58 Project)

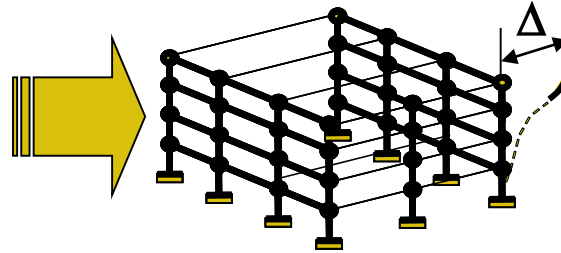
- FEMA P-58 *Seismic Performance Assessment of Buildings, Second Edition* (2018)
 - Volume 1, 2, and 3, Second Editions
 - Volume 4 – Environmental Impacts
 - Volume 5 – Expected Performance
 - Volume 6 – Engineering Guidelines
 - Volume 7 – Stakeholder Guidelines
 - Background Documents
 - Calculation Tools



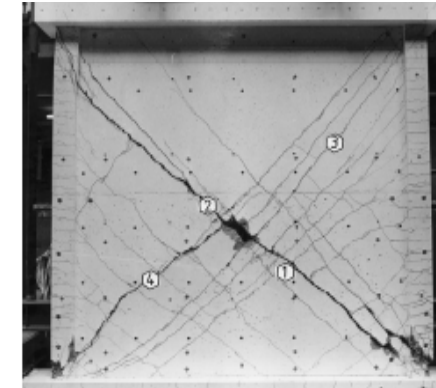
FEMA P-58 Assessment Process



Ground Motion



Structural Response



Damage

Fragility Specification B1044.000 Reinforced Concrete Shearwalls			
ANAL. CONSTRUCTION	Reinforced concrete and finishes both sides		
DESIGN BASIS ASSUMPTION	Square foot of wall area		
DAMAGES STATES, FRAGILITIES, AND CONSEQUENCE FUNCTIONS			
DAMAGE STATE	10%	50%	90%
DESCRIPTION	Reinforced cracks < 1/16" Shear (diagonal) cracks < 1/16"	Reinforced cracks < 1/8" Shear (diagonal) cracks < 1/8"	Max. crack width > 1/8" Significant spalling/ loose cover
ILLUSTRATION			
VELOCITY EXPOSURE	1.5%	3.0%	5.0%
SEISM	0.2	0.3	0.4
CONSEQUENCE	70%		
DAMAGE FUNCTION	Patch cracks each side with caulk Paint each side	Remove loose concrete Patch spalls with NS grout Patch cracks each side with caulk Paint each side	Shore Demo existing wall Reinforce Patch and paint
CONSEQUENCE FUNCTION			
Min. replacement of 10 inch quantity	\$4.00 per sq ft up to 800 sq ft	\$10.00 per sq ft up to 800 sq ft	\$50.00 per sq ft up to 200 sq ft
Min. replacement per sq inch quantity	\$2.00 per sq ft over 4000 sq ft	\$5.00 per sq ft over 4000 sq ft	\$30.00 per sq ft over 2000 sq ft
Min. replacement	0.2	0.3	0.3
APPLICABLE TO BUSINESS CONSEQUENCES	days	weeks	months

Fragility Spec

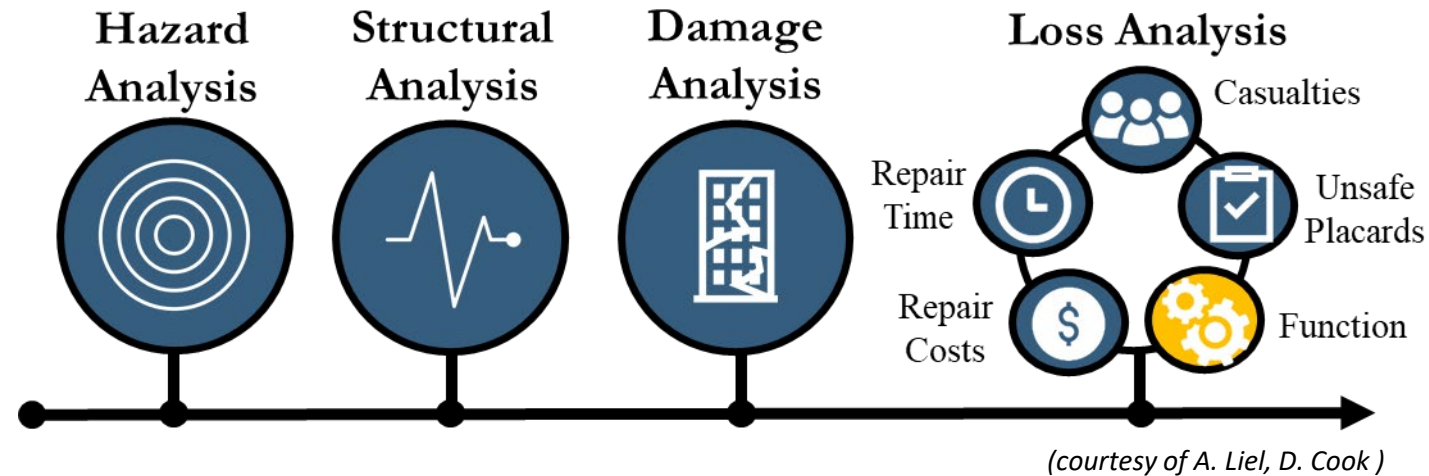


Building Performance Model



Consequences

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



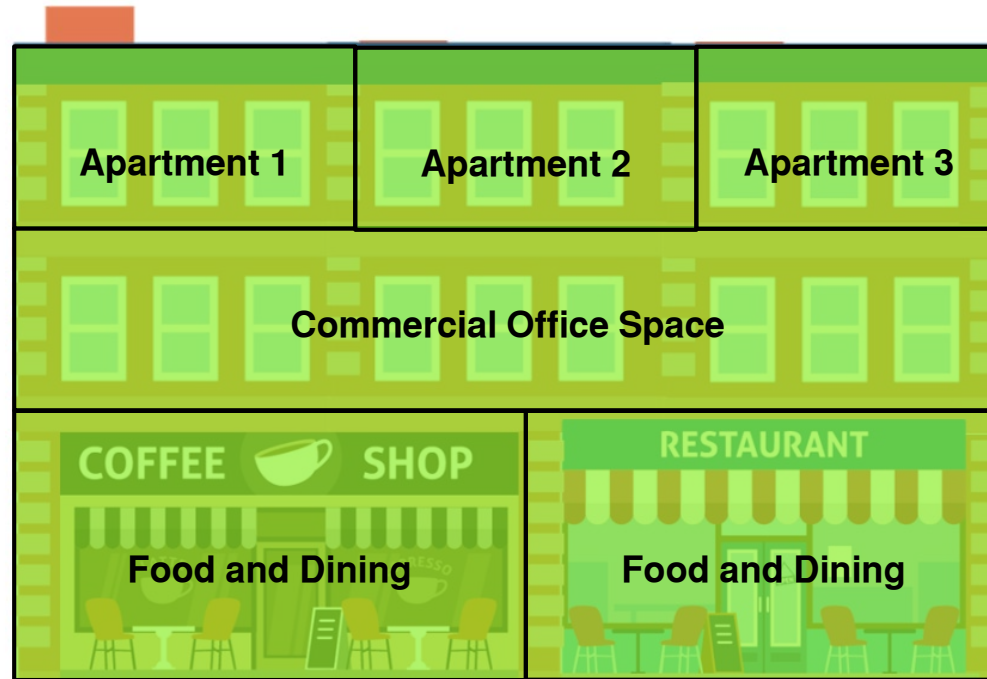
- Assessment of Function requires:
 - Update of Unsafe Placard (Red-Tag) logic
 - Update of Repair Time scheduling
 - Assessment of Impeding Times
 - Fault tree logic for functional impacts of damage

Unit of Analysis: Tenant Unit



(courtesy of A. Liel, D. Cook)

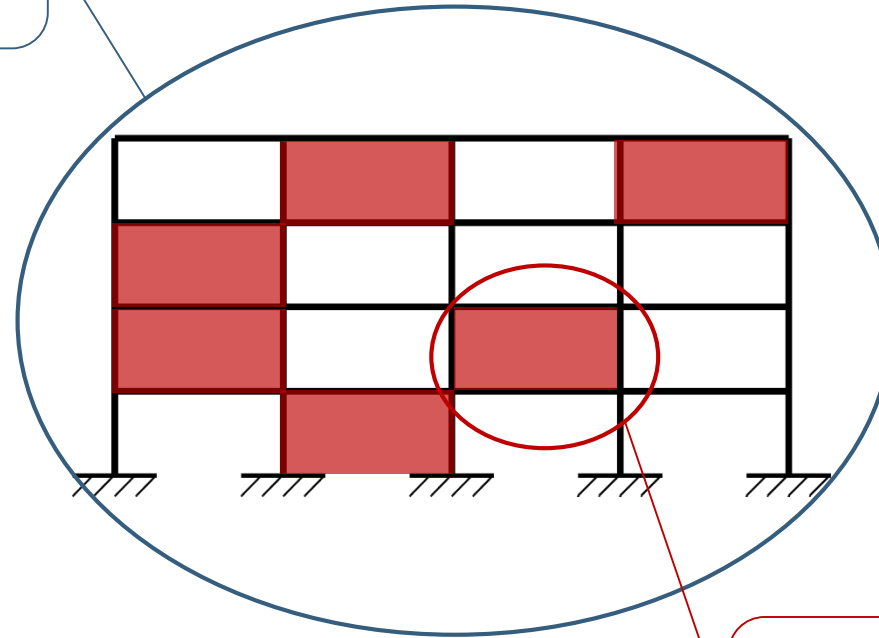
Unit of Analysis: Tenant Unit



(courtesy of A. Liel, D. Cook)

Measure of Performance

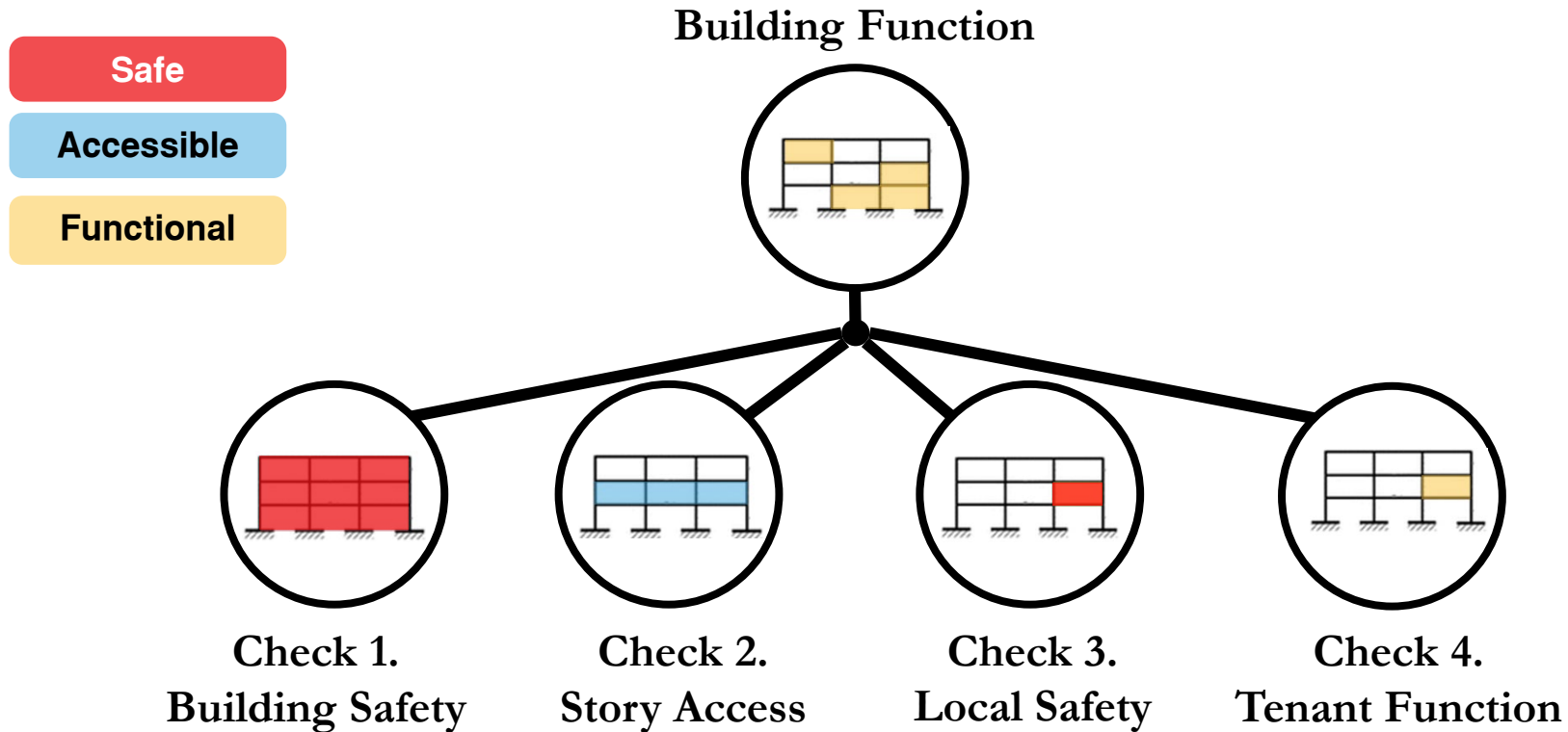
Level of Performance
X% of the building
floor area



Performance State
This tenant unit is/is-not
functional

(courtesy of A. Liel, D. Cook)

Assessment of Function



(courtesy of A. Liel, D. Cook)

Overall Building Safety Check



- ✓ Structural safety (red tags)
- ✓ Fire suppression
- ✓ Exterior falling hazards

(courtesy of A. Liel, D. Cook)

Story Access Check



✓ Stairs

✓ Door racking

(courtesy of A. Liel, D. Cook)

Local Safety Check



- ✓ Local vertical instabilities that do not cause red tags
- ✓ Interior falling hazards from structural and nonstructural components

(courtesy of A. Liel, D. Cook)

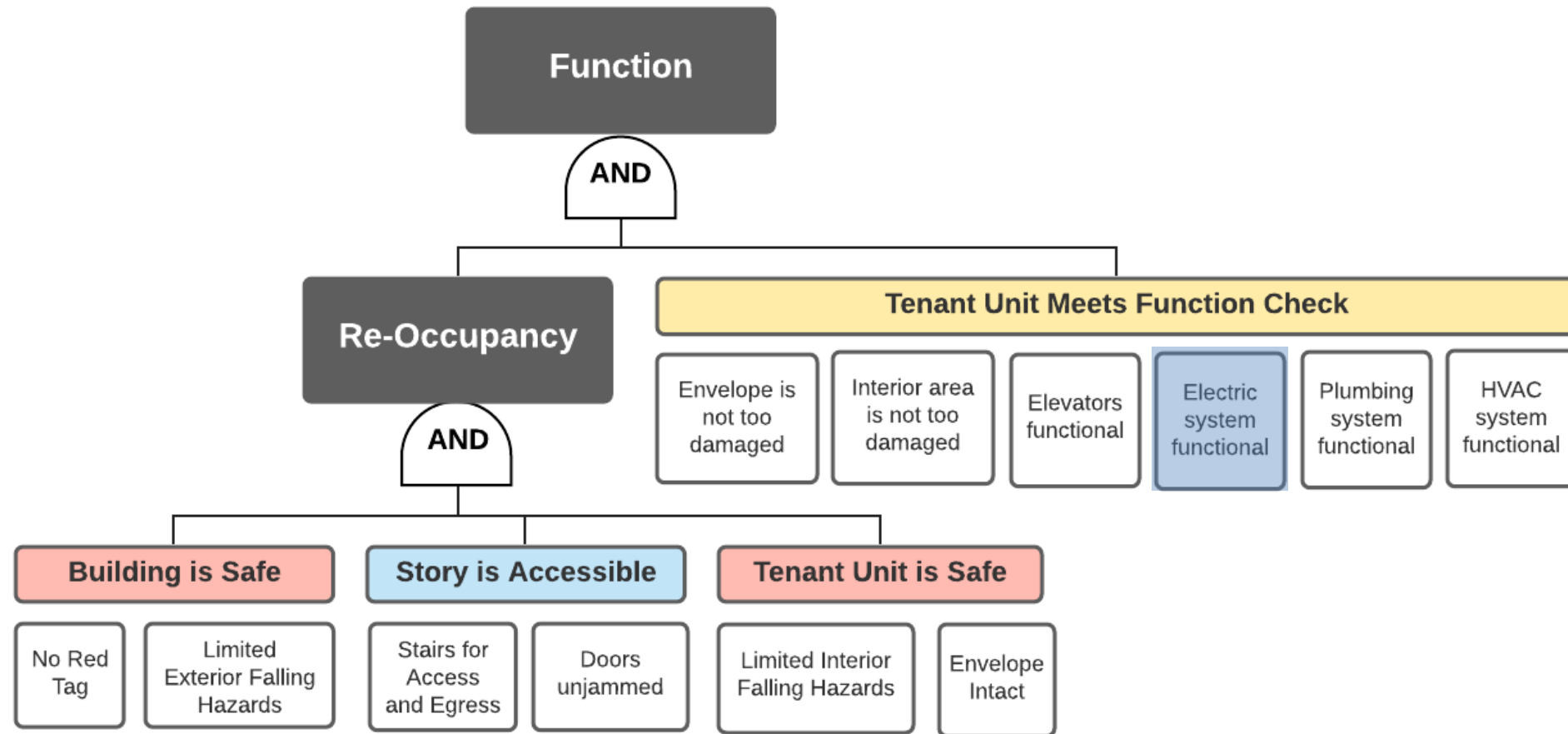
Tenant Function Check



- ✓ Extensive damage to structural components and architectural finishes
- ✓ Operation of building MEP systems
- ✓ Based on tenant-specific requirements

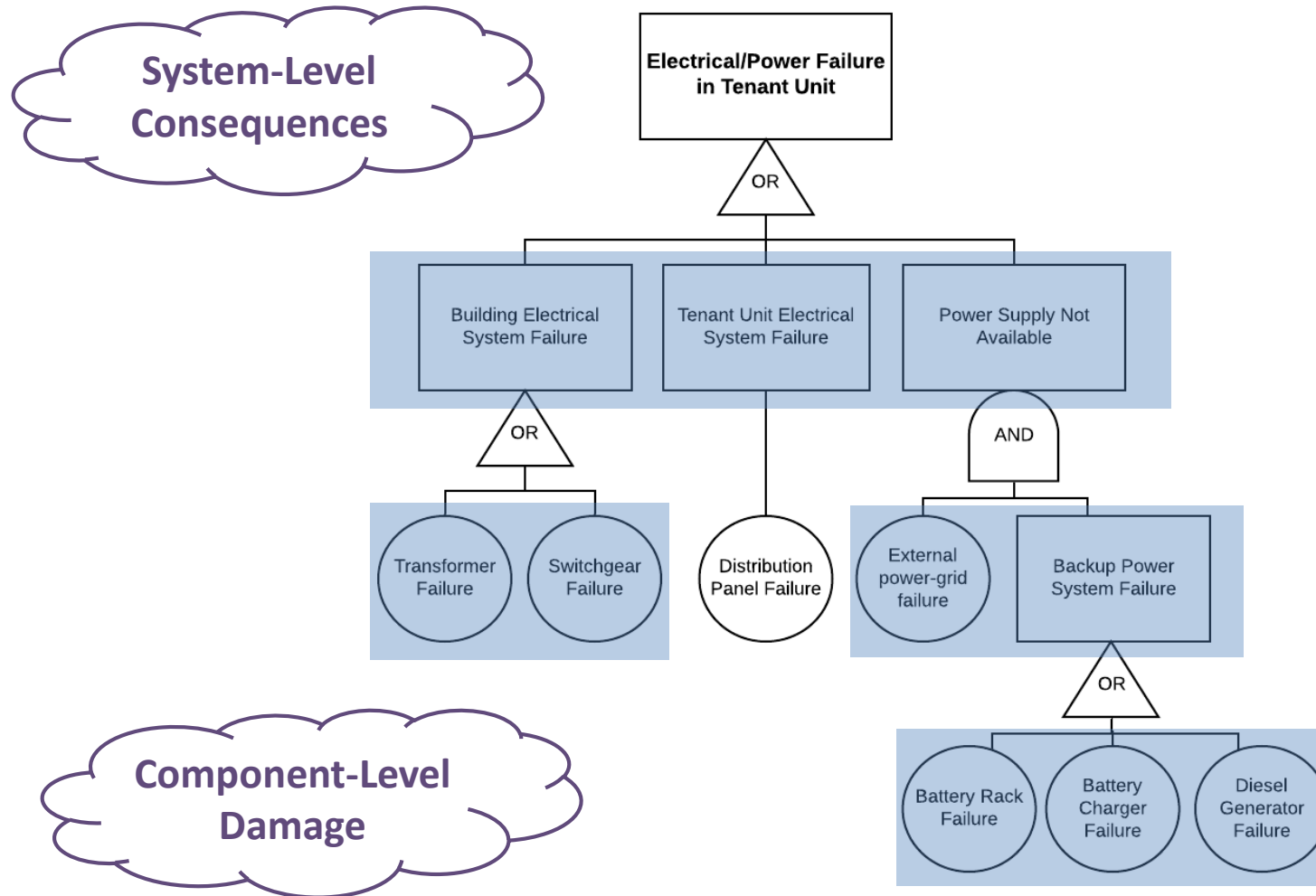
(courtesy of A. Liel, D. Cook)

Basic Fault Tree Logic



(courtesy of A. Liel, D. Cook)

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?

(courtesy of A. Liel, D. Cook)

Repairs and Repair Scheduling

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

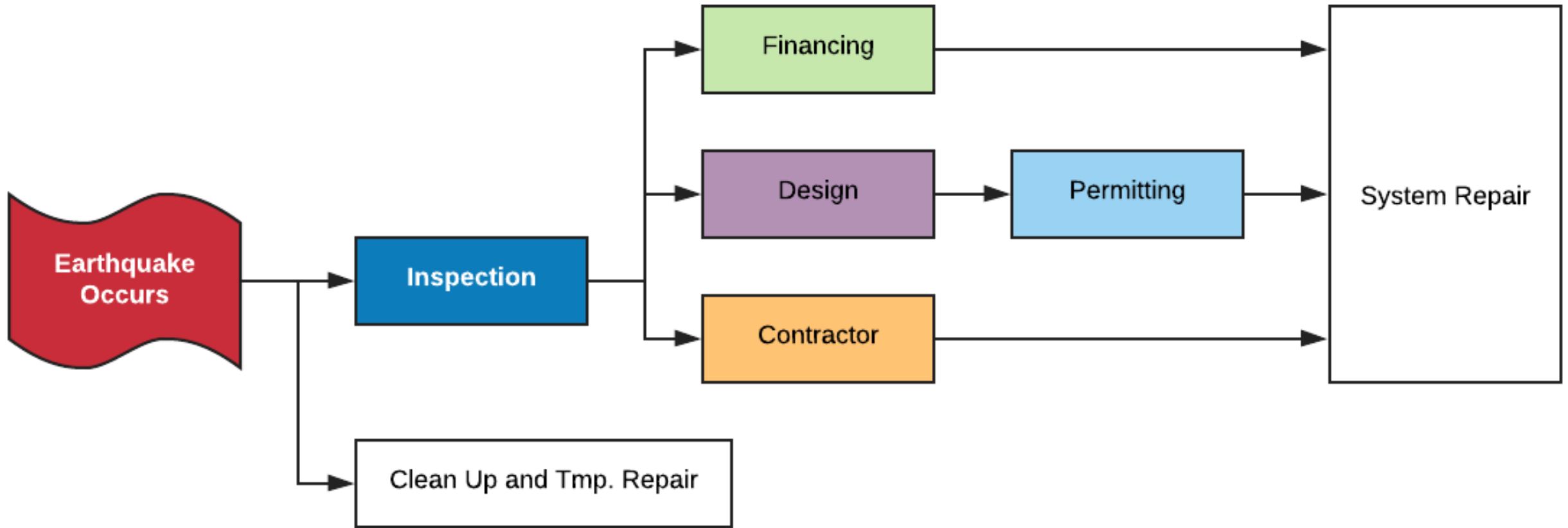
Series

Story	Repair Month				
	1	2	3	4	5
5					
4					
3					
2					
1					

Parallel

Story	Repair Month				
	1	2	3	4	5
5					
4					
3					
2					
1					

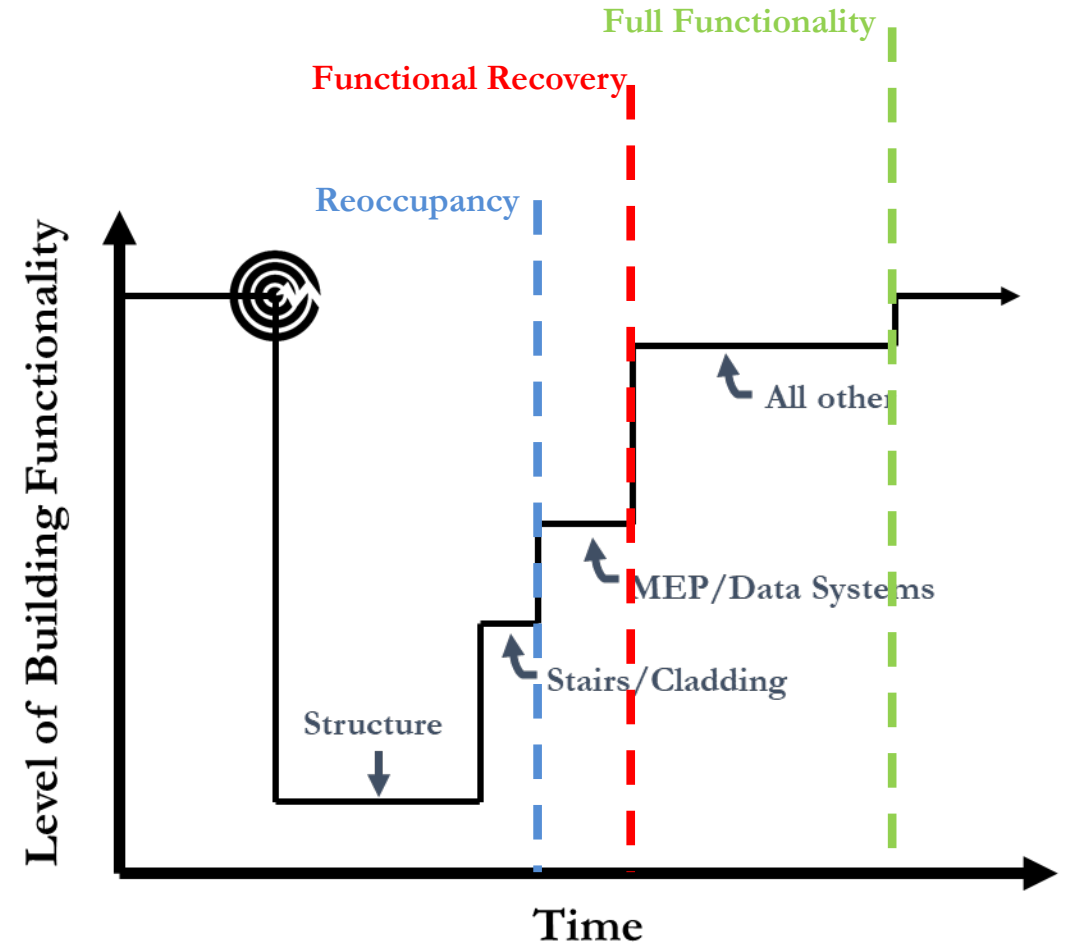
Impeding Factors and Repair Scheduling



(courtesy of A. Liel, D. Cook)

Repair Sequencing

1. Temporary and/or structural repairs necessary for safety
2. Access repairs (stairs, doors, elevators) necessary for occupancy
3. Other repairs necessary for occupancy (HVAC, lighting, exterior envelope containment)
4. Other repairs necessary for function (data, special equipment)
5. Nice to have repairs (patch and paint)



Conclusions

- The ATC-138 Project has developed a working (beta) version of the methodology that:
 - Quantifies time to recovery of function
 - Maps component damage to building function through a series of fault trees
 - Identifies reoccupancy, functional recovery, and full functionality as separate repair states
 - Shows the restoration of building function over time
 - Summarizes specific component damage states affecting building function (to aid resilient design)

Conclusions

- It is envisioned that this methodology can eventually be used to:
 - Design buildings to meet functional performance objectives
 - Provide cost-benefit data for decision makers to inform development of functional recovery policy
 - Quantify risk-based prescriptive requirements for functional recovery design in future editions of the building code

Thank you!