



# The Role of Disaster Metrology in Community Resilience

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NIST



# PEER: the early days

UC Berkeley UC San Diego UCLA UC Davis  
Stanford Caltech UC Irvine Washington USC

PSA/SLC

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Student Day  
Seismic Competition

PEER STUDENT  
RESEARCHERS

By University  
By Thrust Area

PROGRAMS FOR STUDENTS

PEER Education Page

OFFICERS/REPS

2005/2006 Officers

Welcome to the PEER Student Association (PSA) / PEER Student Leadership Council (SLC) Site!

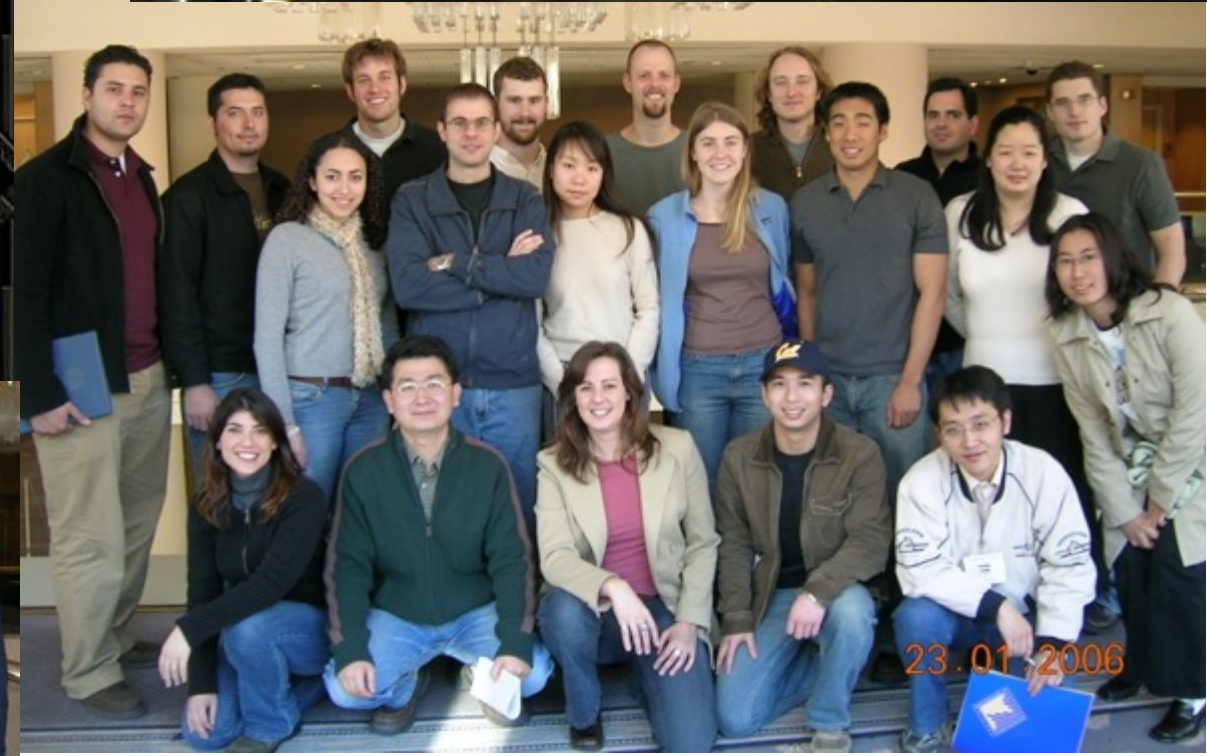


Seattle, Washington -- 2005 SLC Summer Retreat

Seismic Design Competition



21.01.2006



23.01.2006







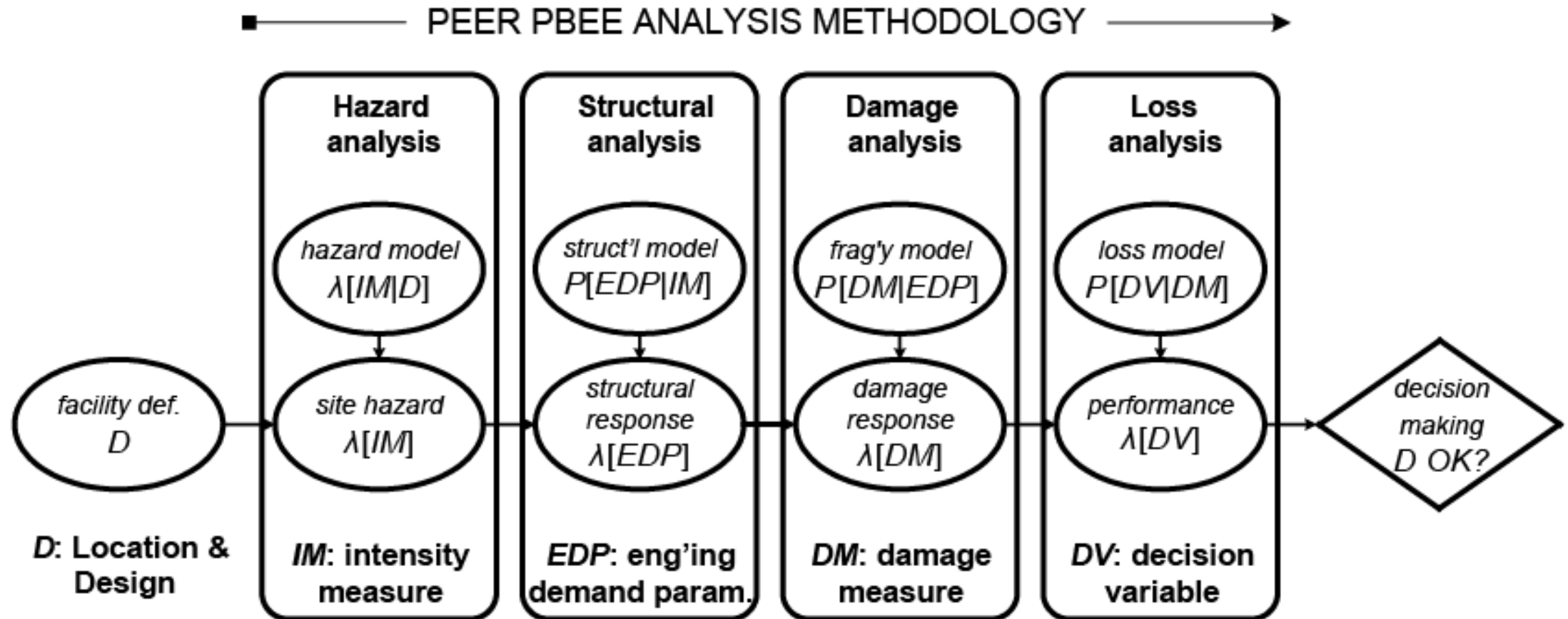
# Performance-Based Design: from the early days of PEER to ongoing research at NIST



## 2020 PEER Annual Meeting

The Future of Performance-Based Natural  
Hazards Engineering

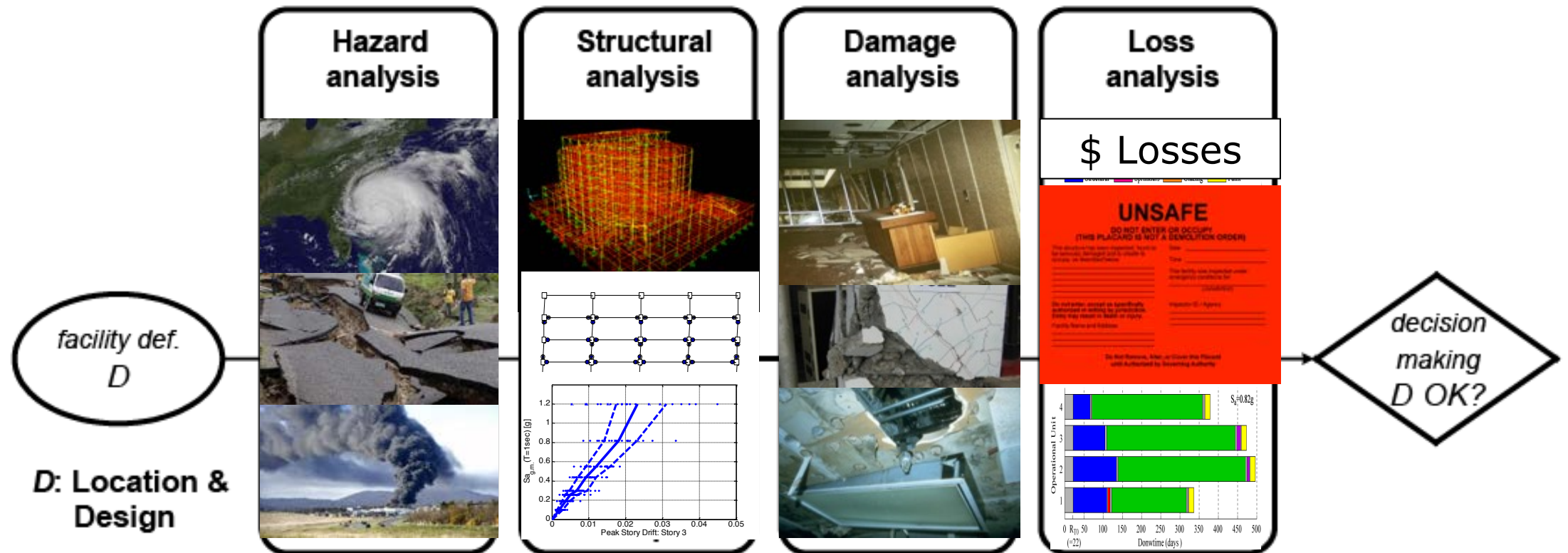
# Performance-Based Design: PEER methodology





# Performance-Based Design: PEER methodology

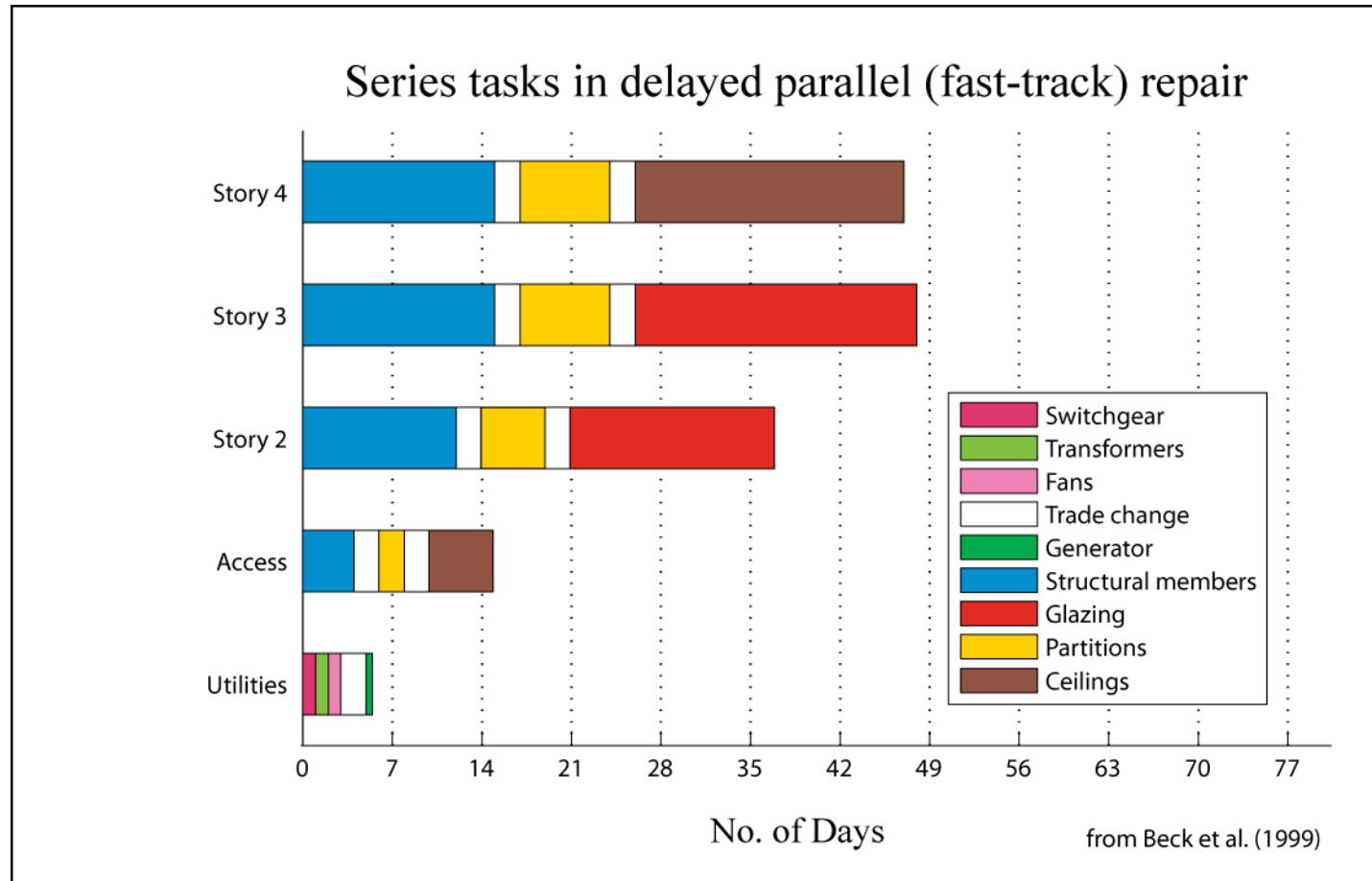
## PEER PBEE ANALYSIS METHODOLOGY





# Performance-Based Design: downtime in buildings

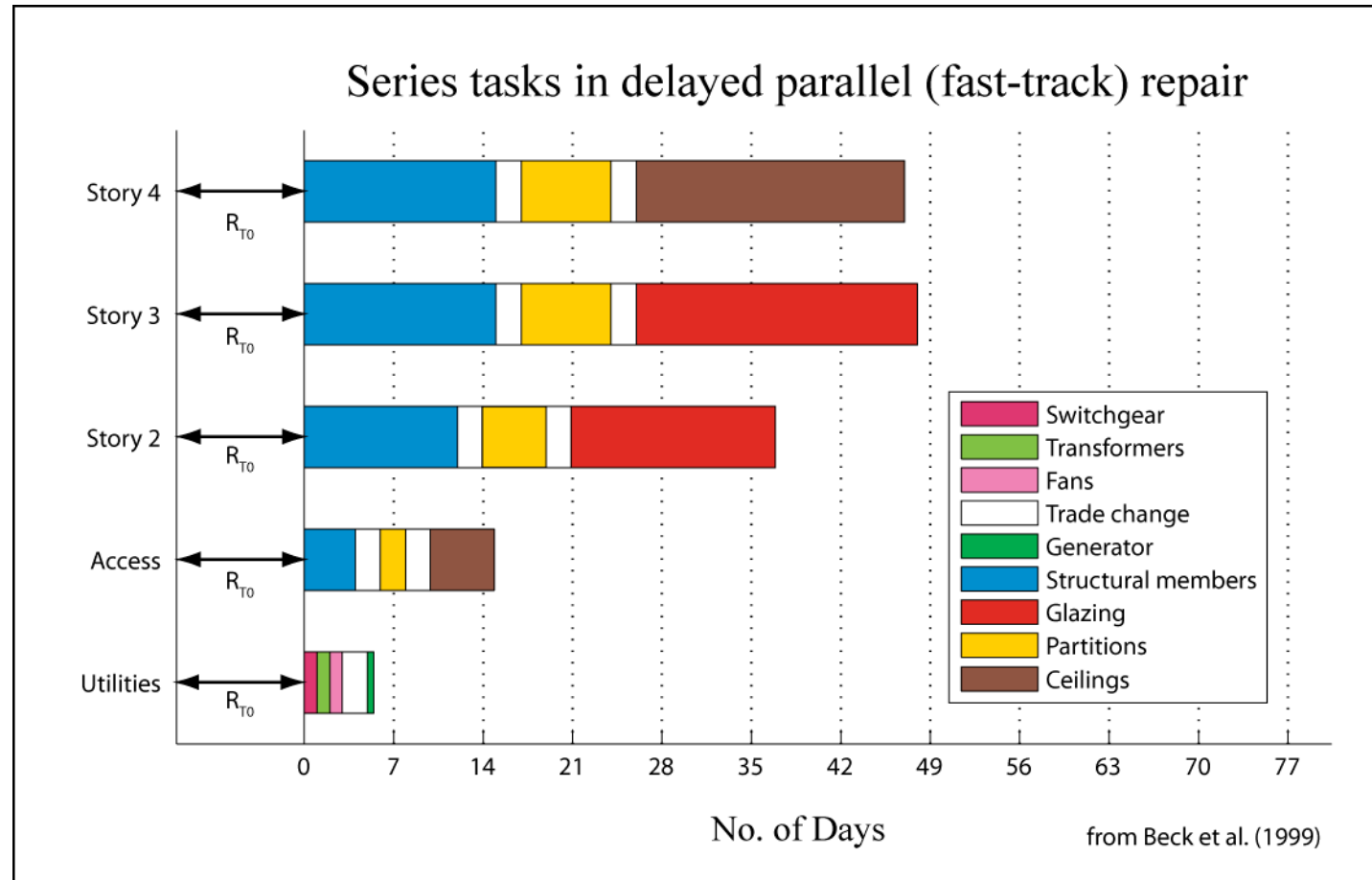
*Repair time* is the time needed to repair the earthquake damage and return the building to its pre-earthquake condition.





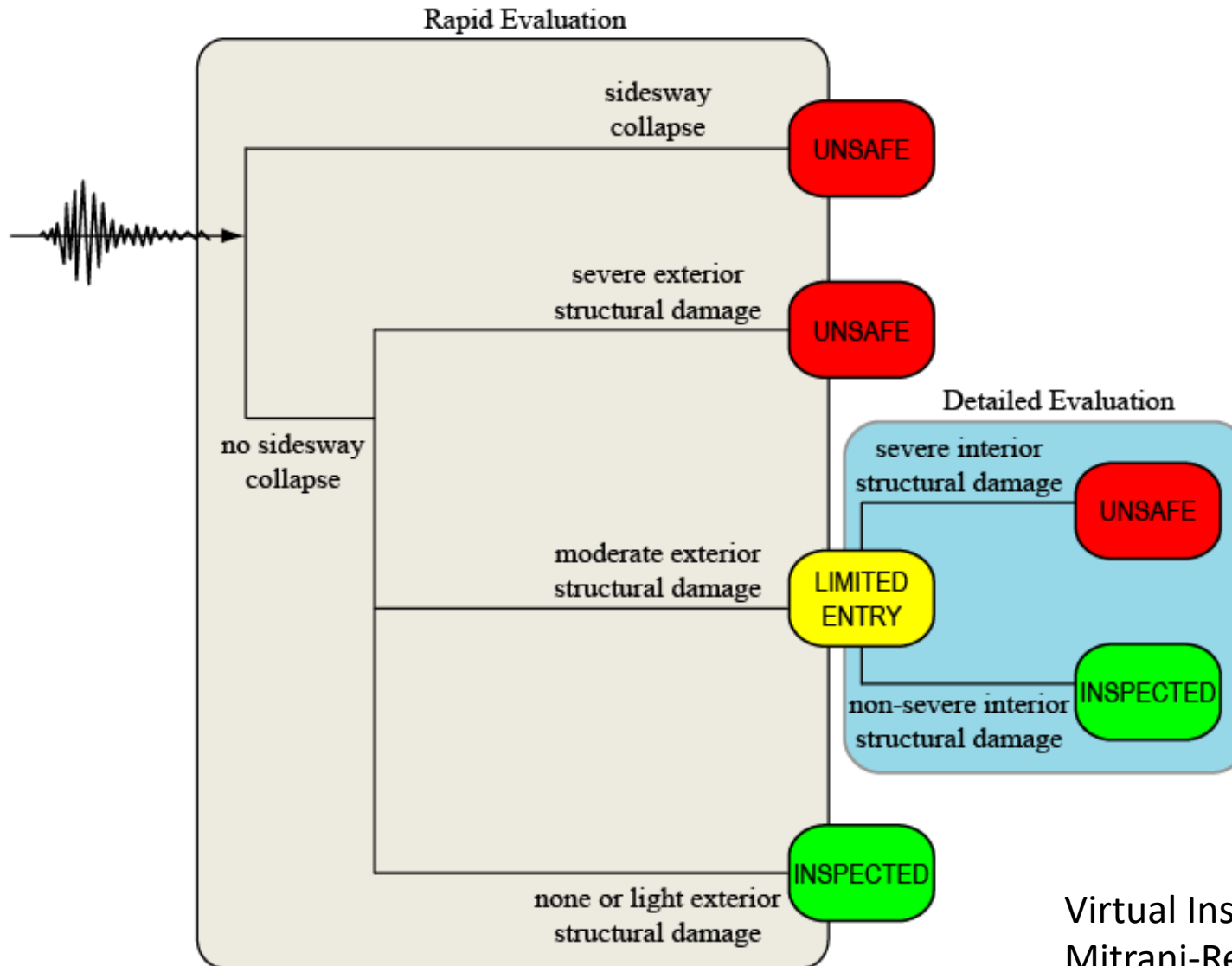
# Performance-Based Design: downtime in buildings

*Mobilization Time* is the delay before construction begins needed to assess damage and inspect building, time to consult with professional engineers, time for bidding process, time for clean-up, time to acquire items with long lead times.





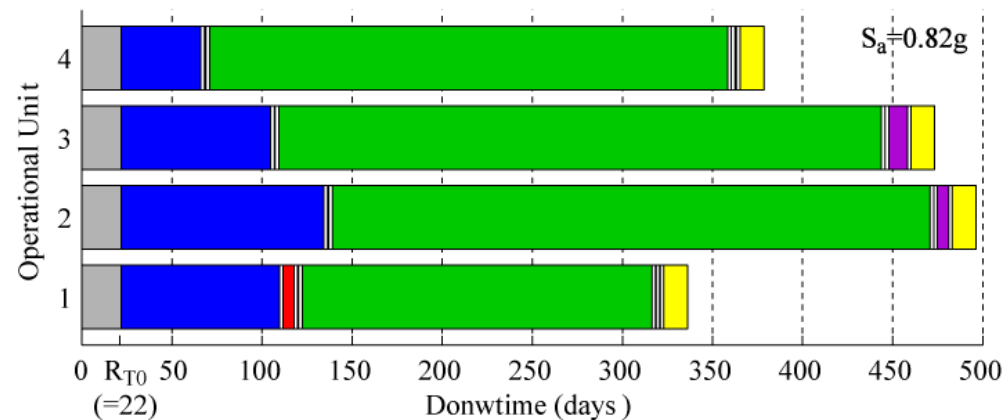
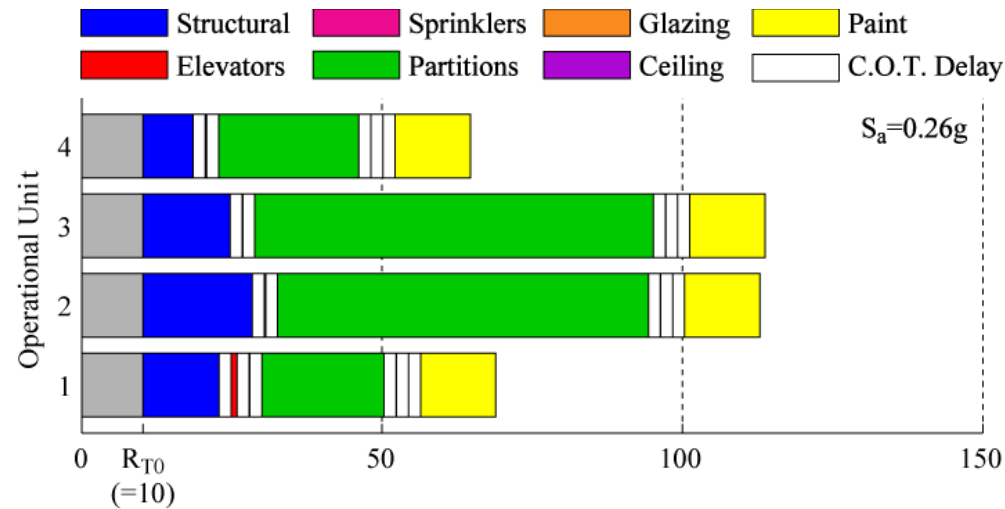
# Performance-Based Design: downtime in buildings



Virtual Inspector (Mitrani-Reiser 2007,  
Mitrani-Reiser et al. 2016)

# Performance-Based Design: downtime in buildings

## RC Perimeter-Frame Design of Office Building



Downtime (Mitrani-Reiser 2007)



# Performance-Based Design: downtime in buildings

FEMA P-58 procedures (Mitrani-Reiser, *Downtime Consultant*) provide the following measures of occupancy interruption:

- The length of time necessary to conduct repairs,
- The need to procure items with long lead-times,
- The probability that the building will be placarded as unsafe for occupancy.



## Seismic Performance Assessment of Buildings

Volume 1 – Methodology

FEMA P-58-1 / September 2012



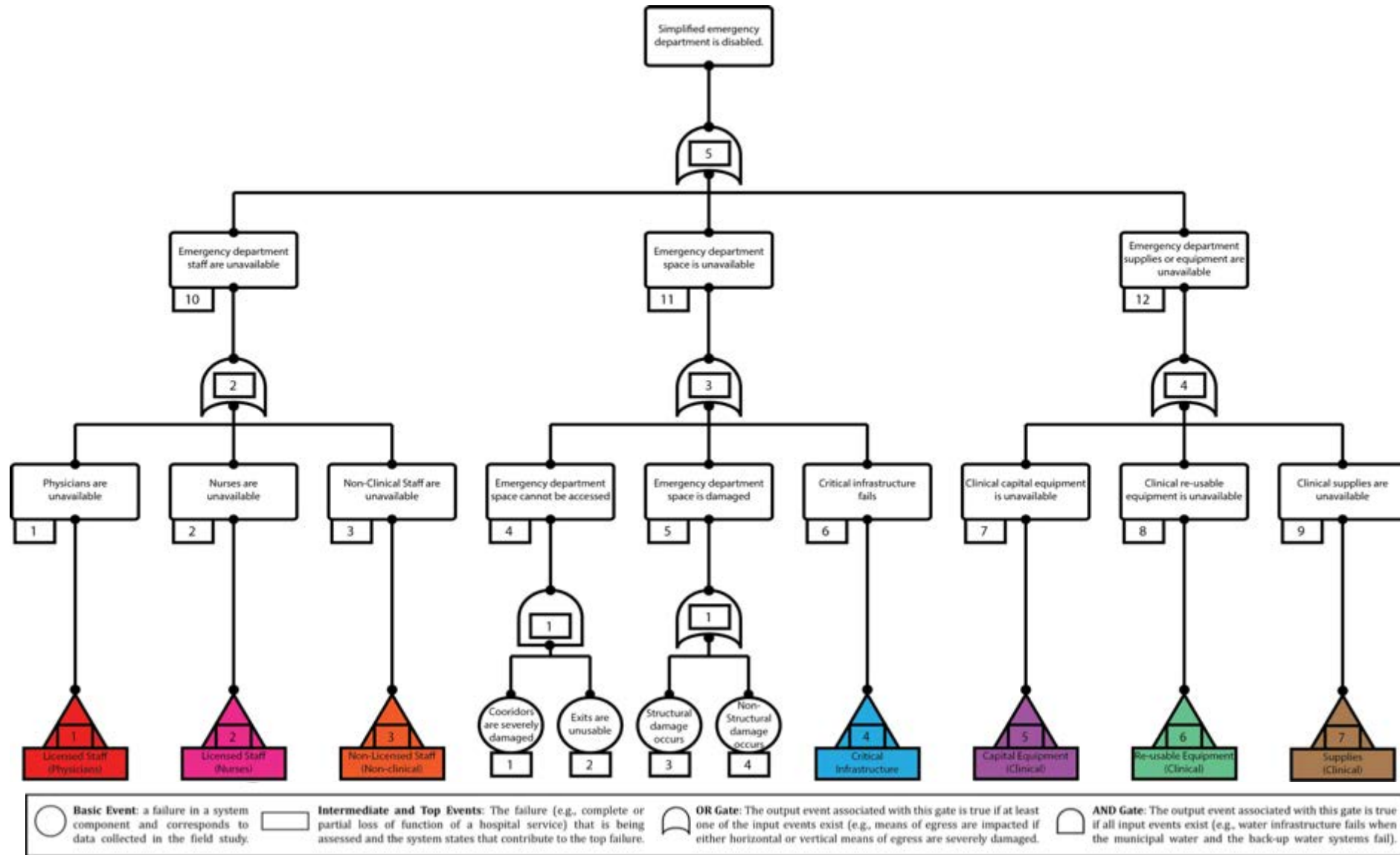
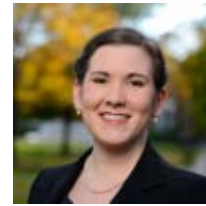
# Performance-Based Design: summary of (my) work in the early days of PEER

For some building occupancies (i.e., hospitals), the above procedures will not suffice in capturing the loss of important services:

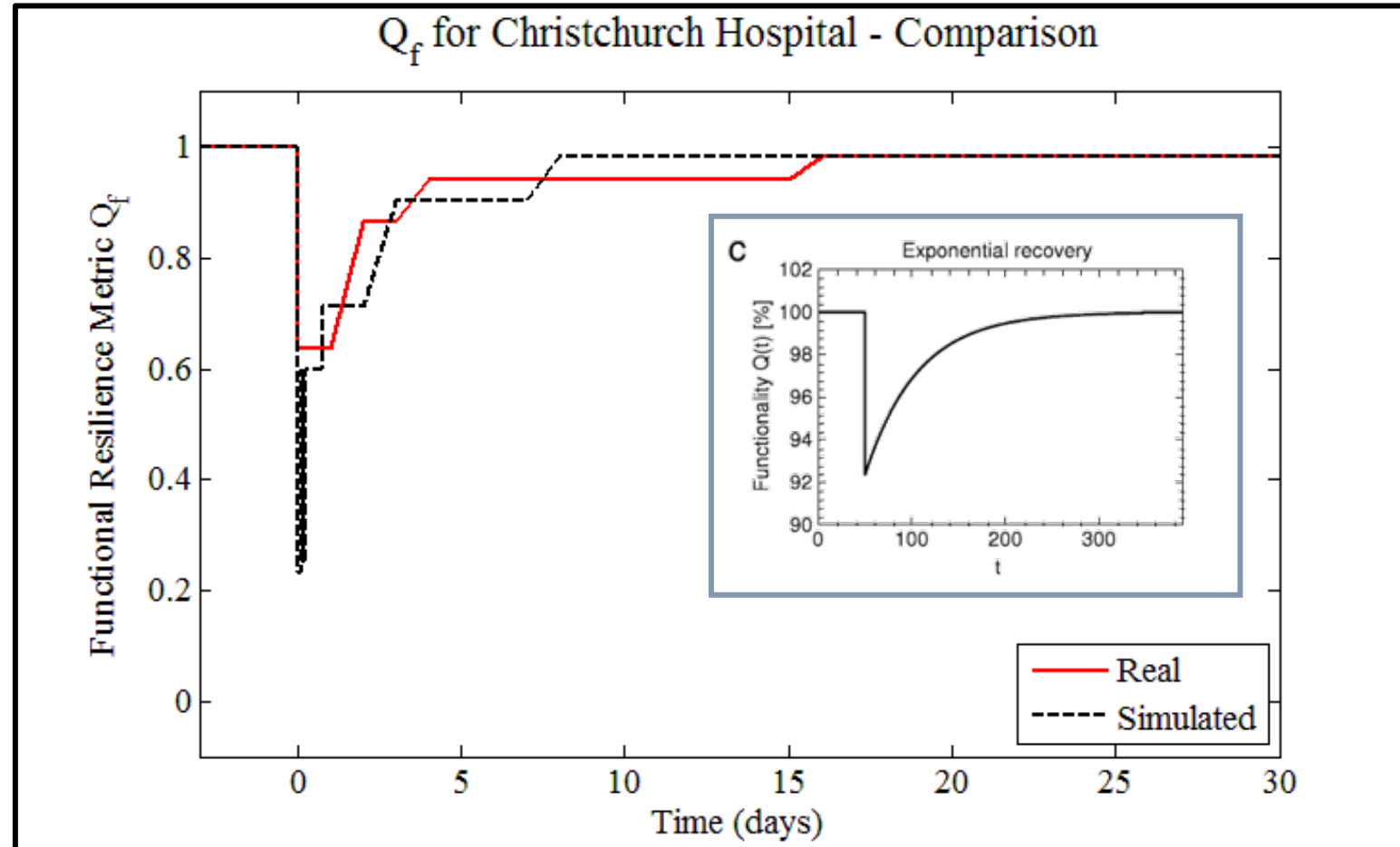
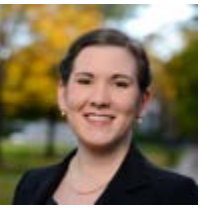
- **Need models that include infrastructure failures outside the building.**
- **Need occupancy-specific models that incorporate human infrastructure.**
- **Need systematic procedures for capturing building damage and loss of function over time in the field (earthquake reconnaissance).**



# Building Functional Impacts: beyond physical damage

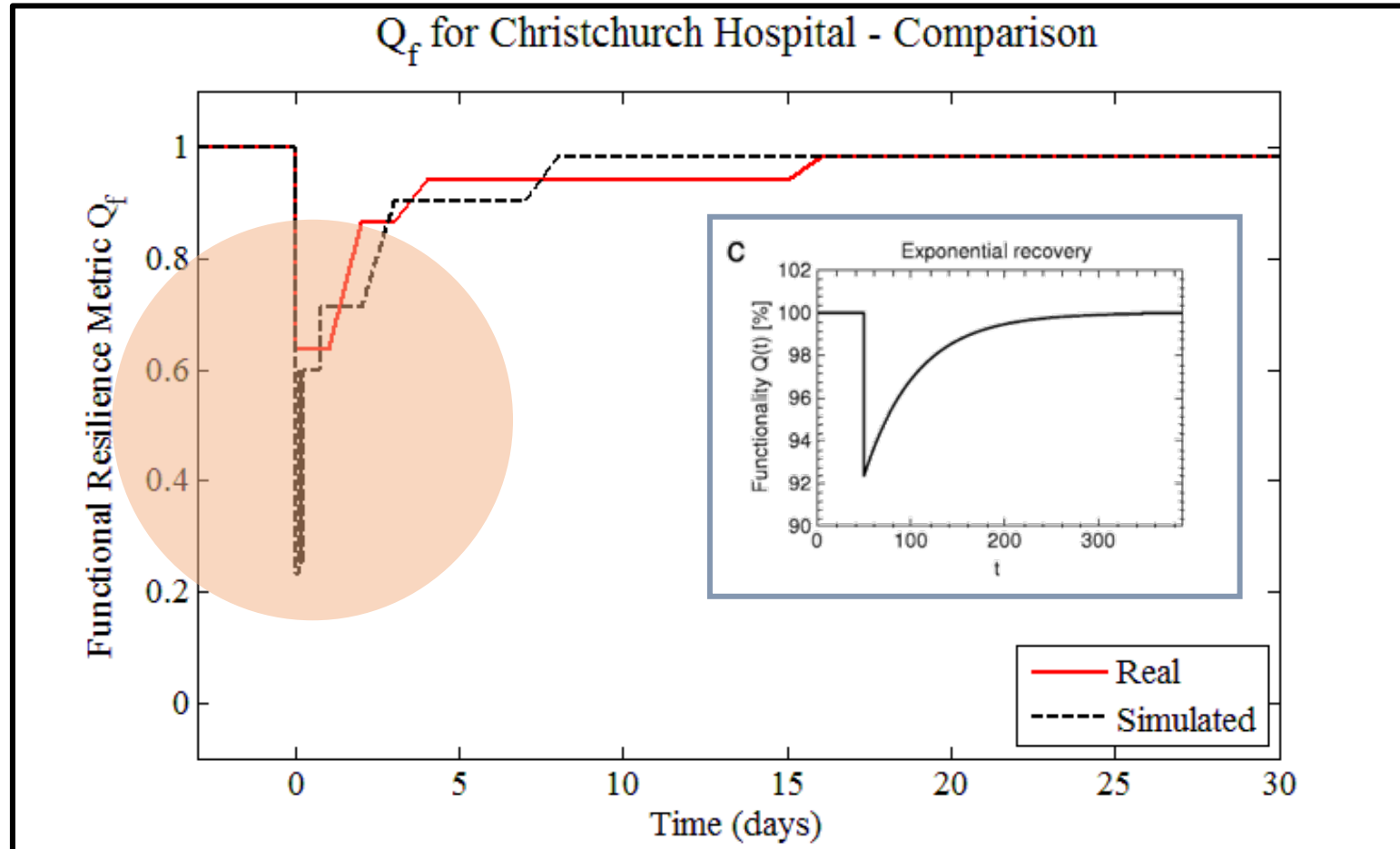
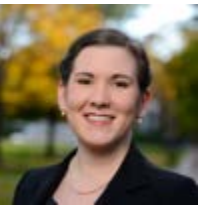


# Building Functional Impacts: beyond physical damage

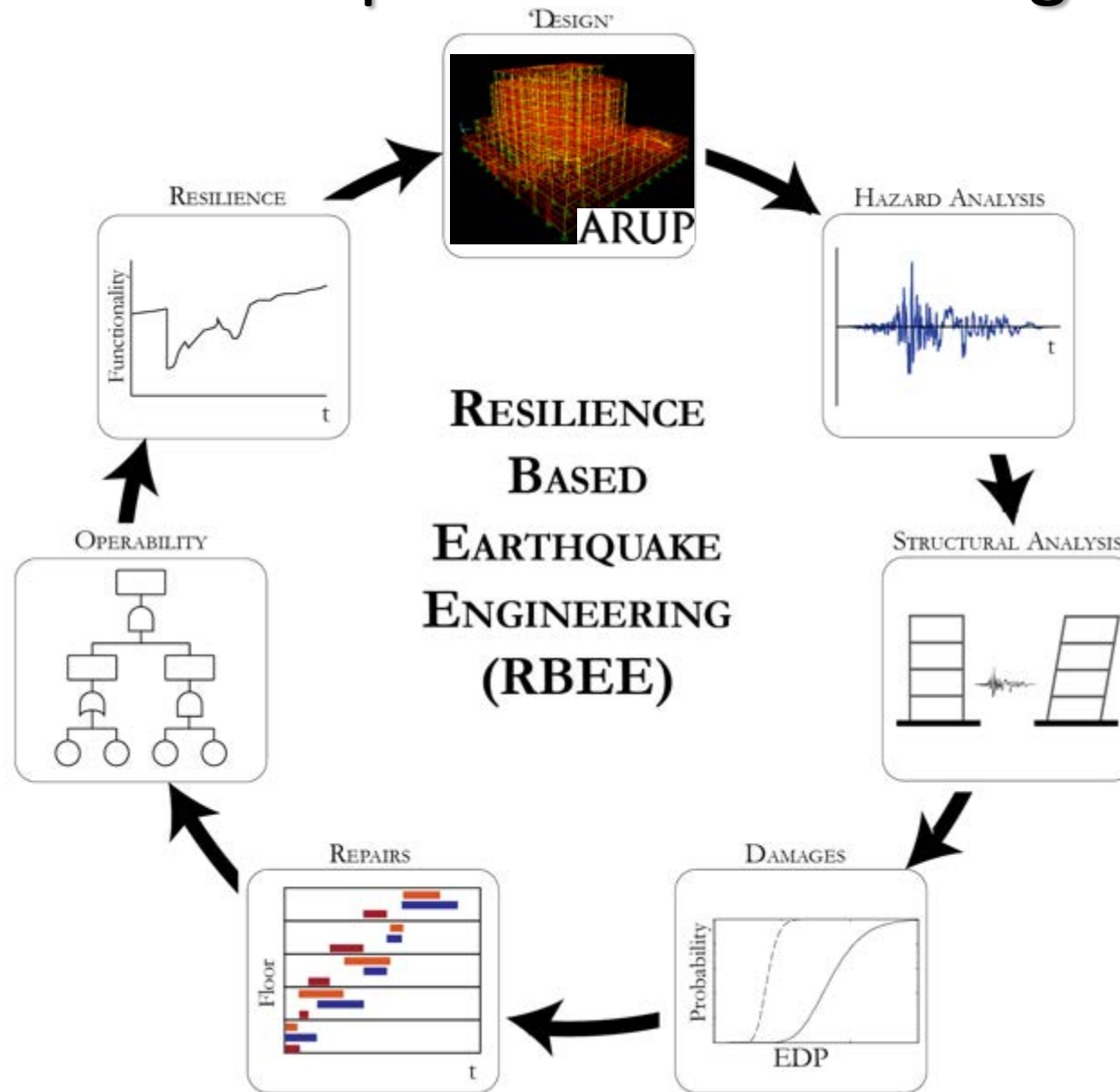




# Building Functional Impacts: beyond physical damage



# Resilience-Based Design: PBD with sharper focus on building functions

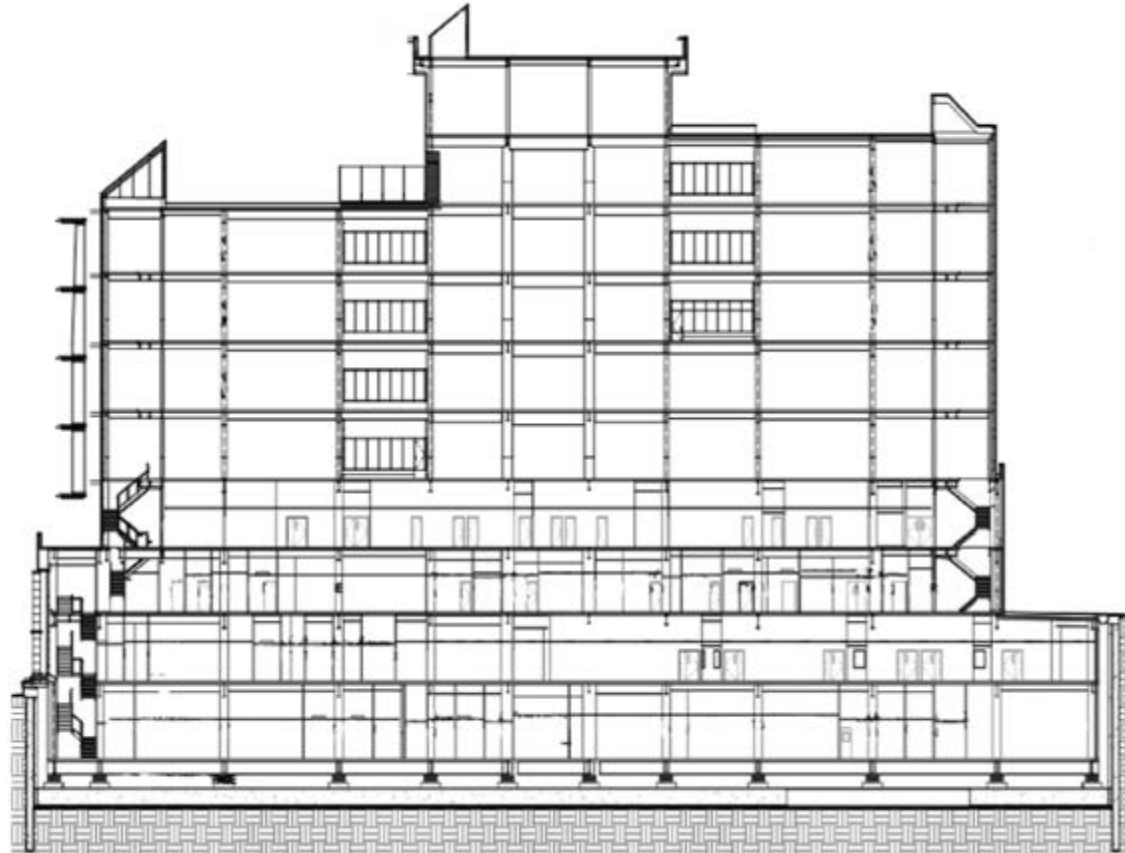




# Resilience-Based Design: PBD with sharper focus on building functions



## Services by Floor



### Mechanical Floor

**Level 7:** Medical/Surgical, Acute Care for Elderly  
Palliative Care, Roof Garden

**Level 6:** Medical/Surgical

**Level 5:** Medical/Surgical Unit, Forensic Unit

**Level 4:** Step Down Medical/Surgical,  
Step Down ICU, Dialysis

**Level 3:** Intensive Care Units (ICU)

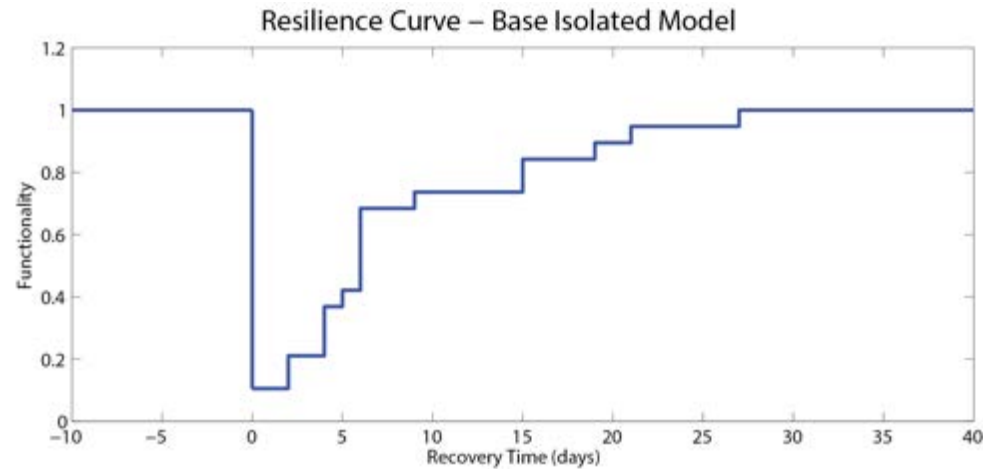
**Level 2:** Labor and Delivery, Postpartum, Pediatrics,  
Neonatal Intensive Care

**Level 1:** Emergency Department and Trauma Center

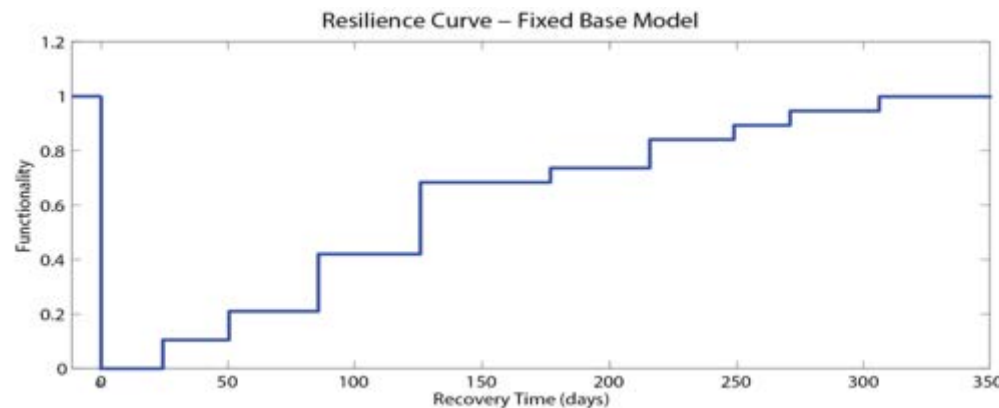
**Basement 1:** Operating Rooms, Pre-op, Post Op,  
Endoscopy, Blood Bank

**Basement 2:** Dietary, Pharmacy, Cardiology,  
Pulmonary, Diagnostic Imaging (Xray),  
Sterile Processing

# Resilience-Based Design: PBD with sharper focus on building functions



26 days until all  
hospital services  
are functional



~300 days until all  
hospital services are  
100% functional

# Building Functional Impacts: summary of (my research group's) work related to PBD

The above procedures, while useful for stakeholders of individual buildings (nodes), these do not suffice in capturing disaster impacts on important community institutions:

- **Need models that include interdependent critical lifelines and supply chains.**
- **Need to capture the 'networked' system of buildings that provides specific community services.**
- **Need performance metrics that are relevant to the entire system and to the stakeholders managing these institutions.**



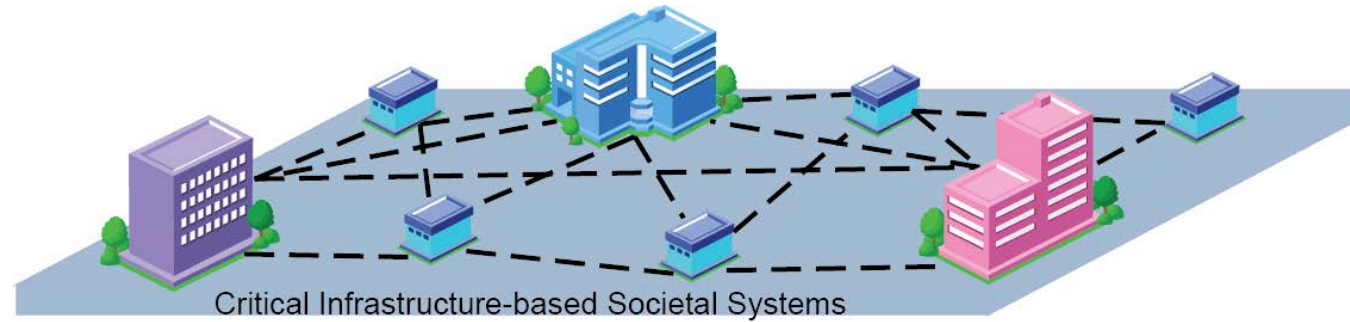
# NSF RIPS: Resilience of Critical Infrastructure-based Societal Systems (CIBSS)



# Critical infrastructure-Based Societal Systems (CIBSS)

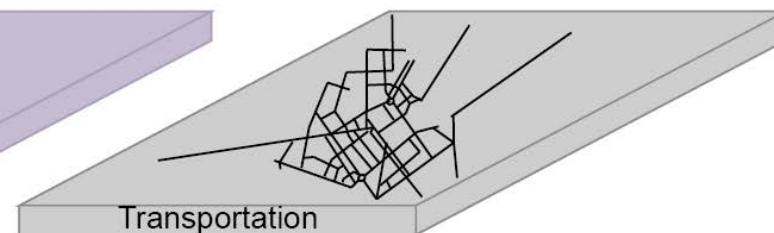
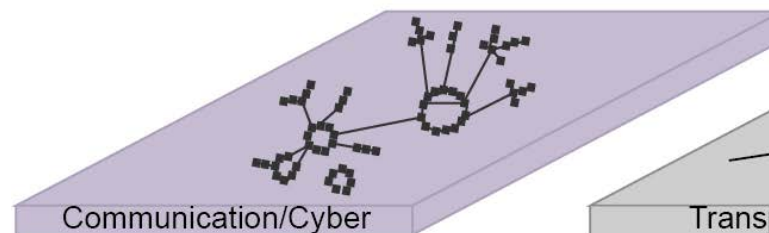
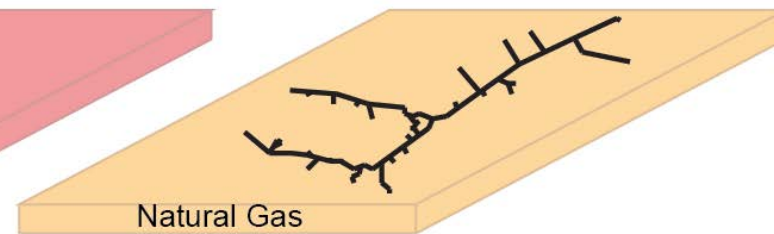
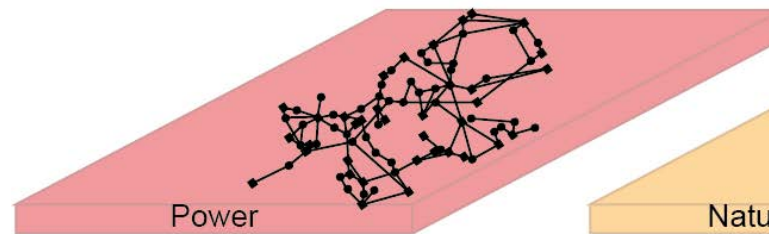
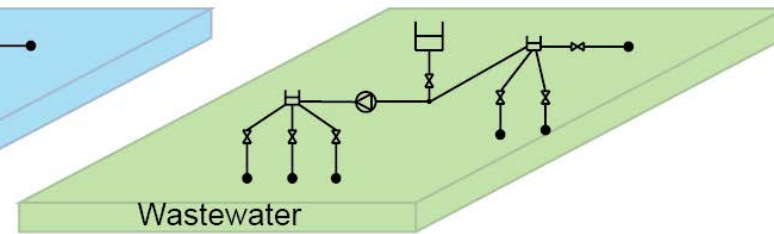
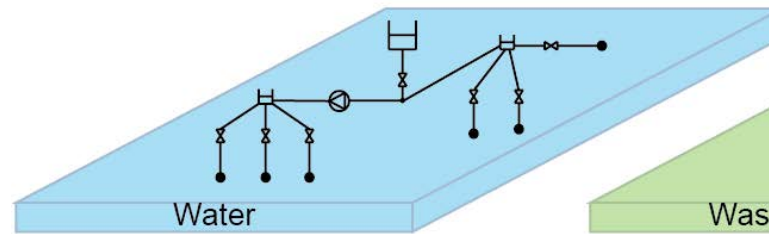
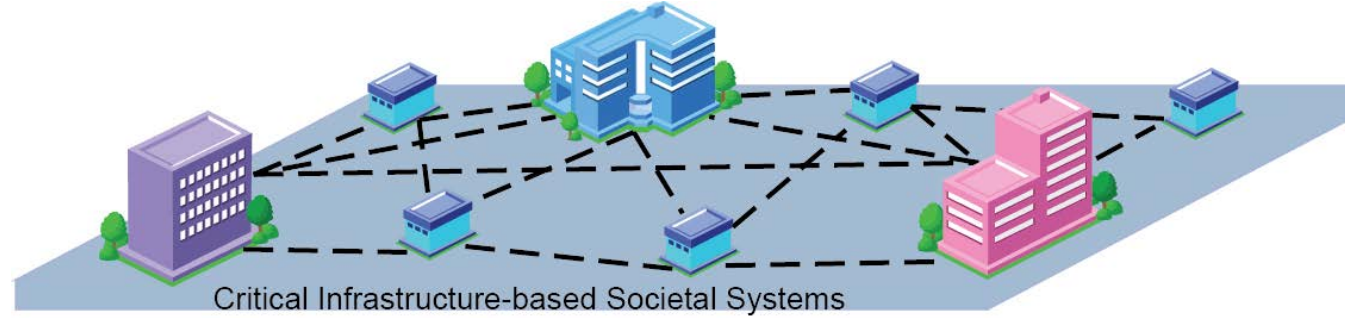


# Critical infrastructure-Based Societal Systems (CIBSS)



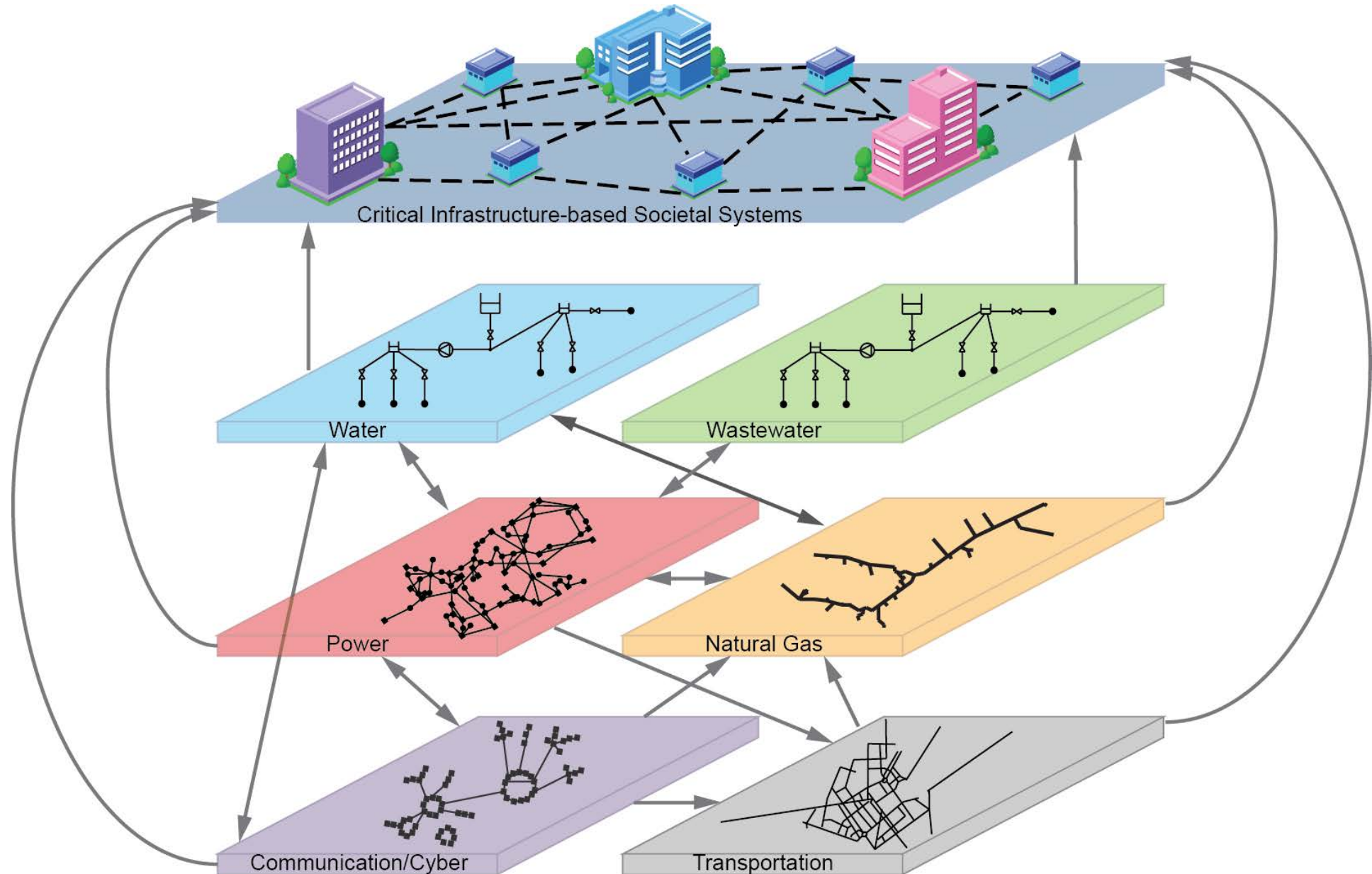


# Critical infrastructure-Based Societal Systems (CIBSS)



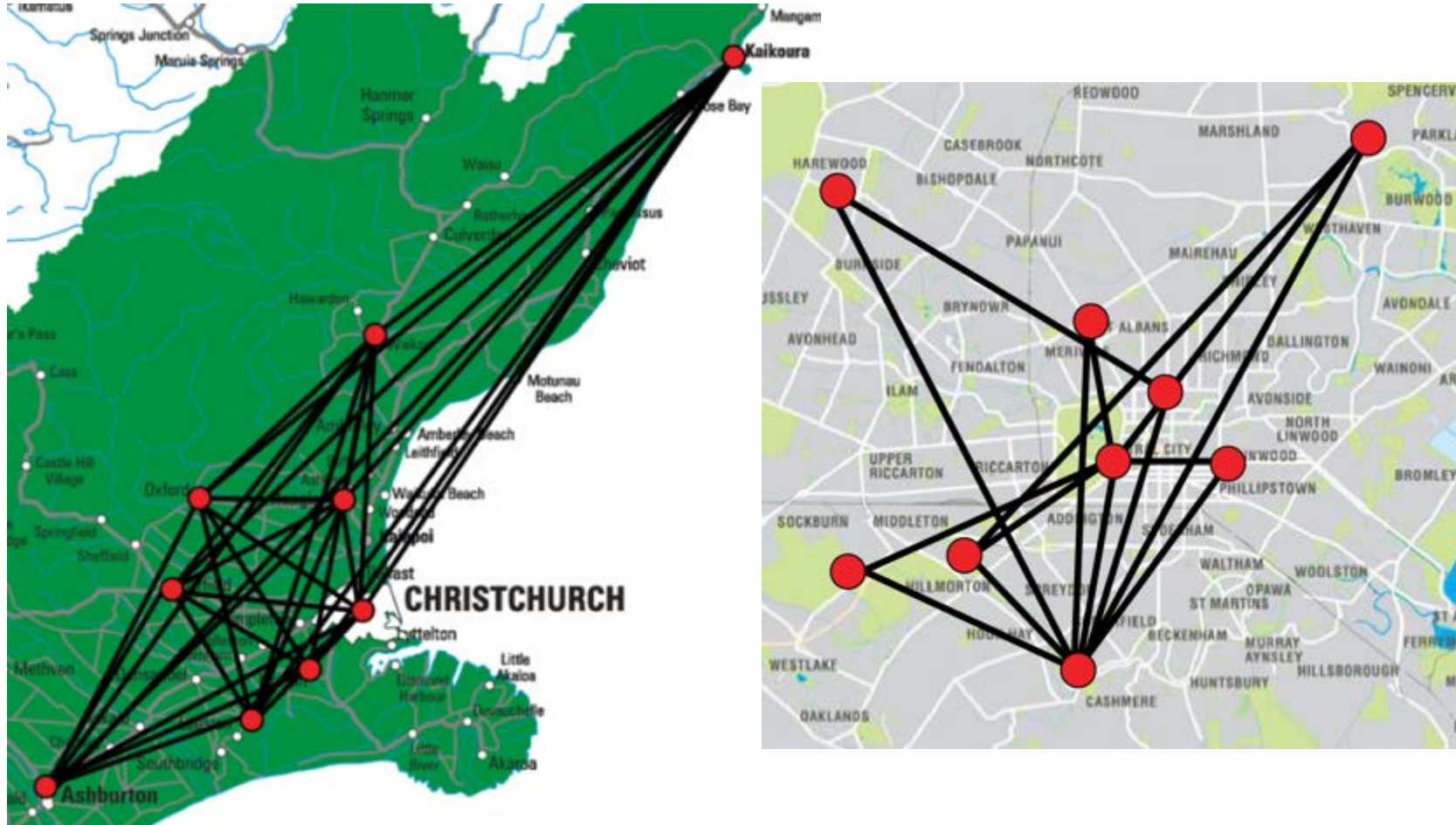


# Critical infrastructure-Based Societal Systems (CIBSS)



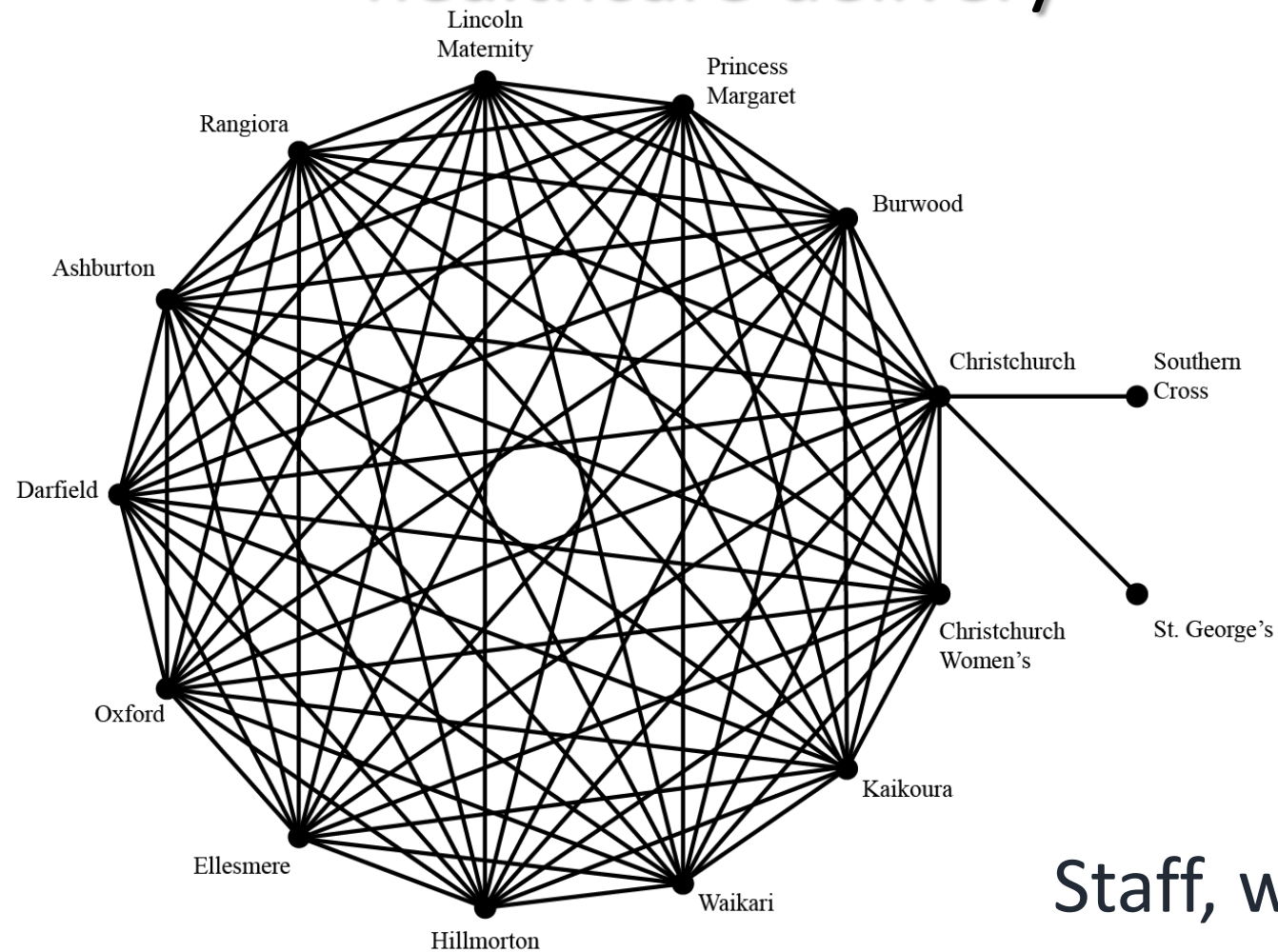


# Critical infrastructure-Based Societal Systems (CibSS): healthcare delivery





# Critical infrastructure-Based Societal Systems (CIbSS): healthcare delivery

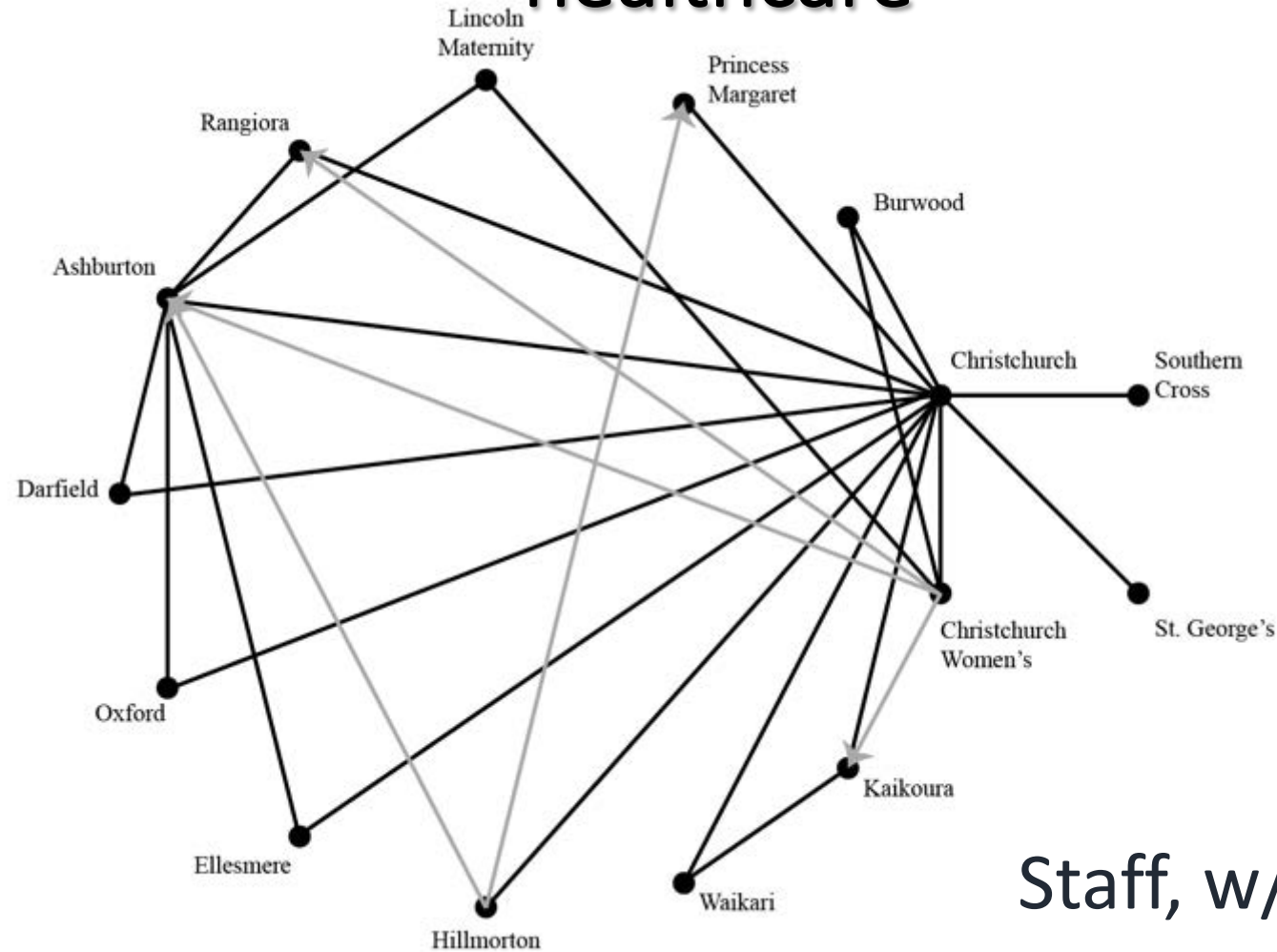
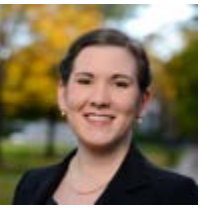


Nodes:	15
Edges:	160
Diameter:	2

Staff, w/ CDHB

Network structure for the healthcare system in the Canterbury region based on staff sharing agreements, including the facilitation provided by the CDHB.

# Critical infrastructure-Based Societal Systems (CibSS): healthcare

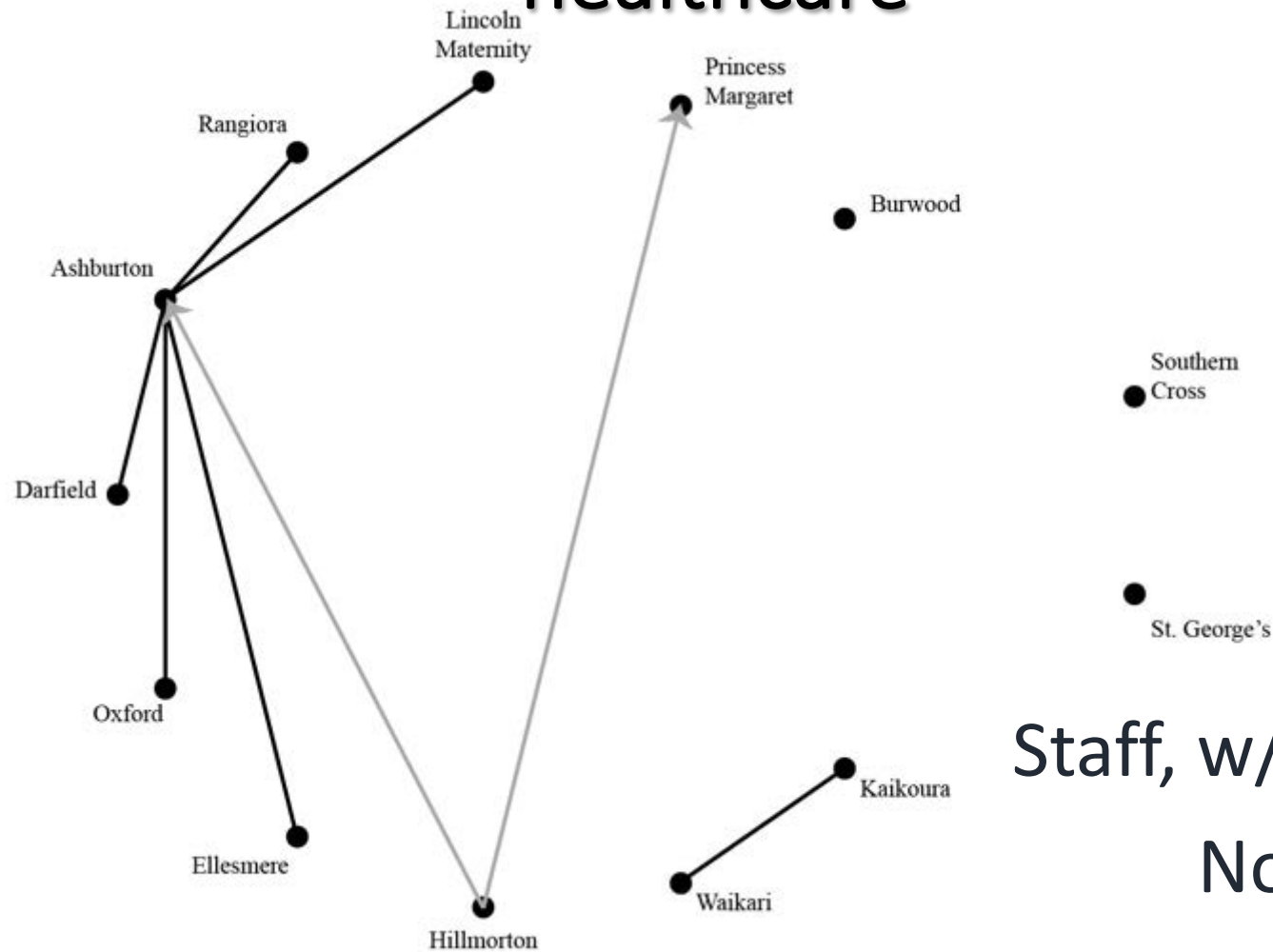


Nodes:	15
Edges:	47
Diameter:	3

Staff, w/o CDHB

Network structure excluding the facilitation provided by the CDHB. Black lines indicate that directed edges exist in both directions. Gray arrows indicate directed edges exist only in that direction.

# Critical infrastructure-Based Societal Systems (CibSS): healthcare



Nodes:	13
Edges:	14
Diameter:	N/A
Subgraphs:	6

Staff, w/o CDHB  
Node Loss

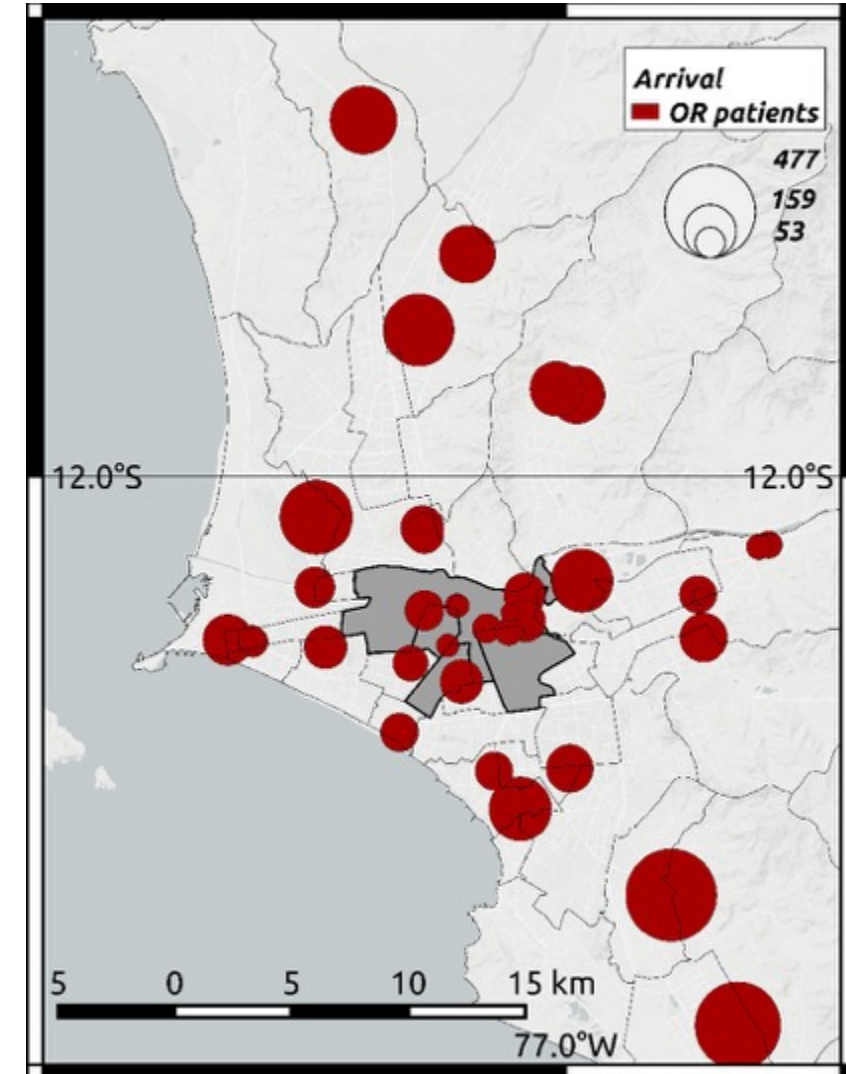
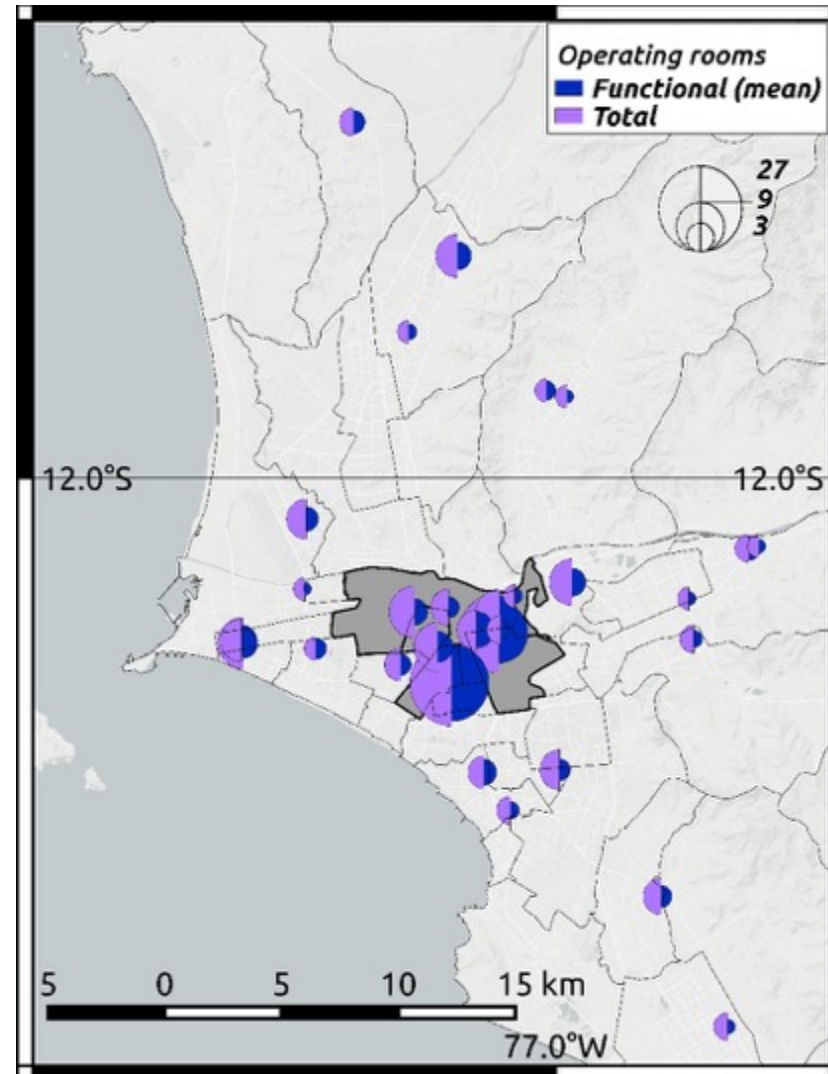
Network structure based on staff sharing agreements, excluding the facilitation provided by the CDHB, with Christchurch Hospital and Christchurch Women's Hospital removed.



# Critical infrastructure-Based Societal Systems (CibSS): healthcare



- Hospital centralization
  - Functional operating rooms: **59% located at the center**
- Injuries in the periphery
  - Injuries needing surgical procedures: **only 13% located at the center**





# Critical infrastructure-Based Societal Systems (CibSS): services across a community



## Population Displacement



## Economic Security



## Food Security



## Healthcare Delivery



# Critical infrastructure-Based Societal Systems (CIBSS): services across a community

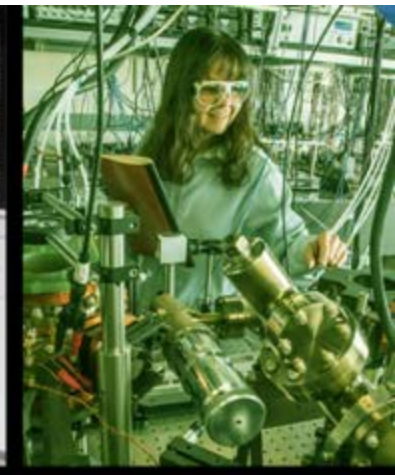
We're making progress, but we still need:

- **Holistic approach to capture community functioning over time.**
- **Models that interface multiple scales (building – institution – community).**
- **To effectively use data that is collected over a wide range of time scales (e.g., census, tax assessors, reconnaissance, etc.).**
- **Models that capture the complex interactions of many community institutions.**



# The National Institute of Standards and Technology (NIST)

- Founded in 1901 and is now part of the U.S. Department of Commerce
- One of the U.S.'s oldest physical science laboratories
- Innumerable products and services rely in some way on technology, measurement, and standards provided by NIST, including the smart electric power grid, electronic health records, atomic clocks, and advanced nanomaterials
- NIST measurements support the smallest of technologies to the largest and most complex of human-made creations—from nanoscale devices up to earthquake-resistant skyscrapers and global communication networks





# Disaster Resilience Work across NIST (and scales)



Structural  
& EQ  
Engineering

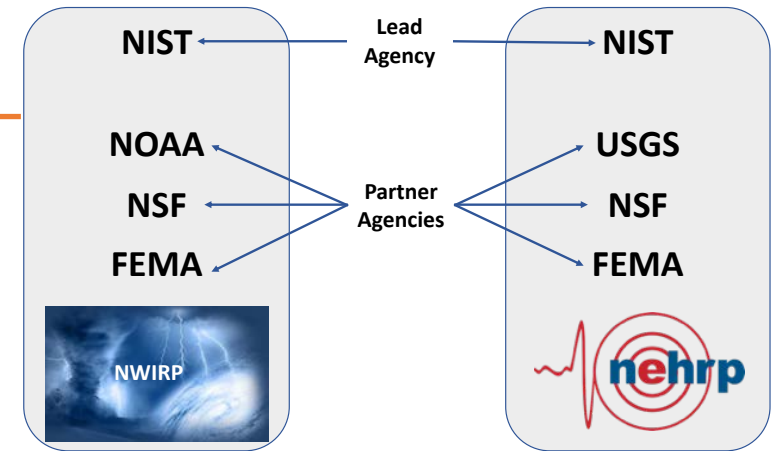
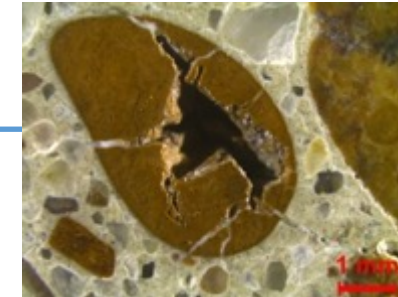
Materials  
Science

Community  
Resilience

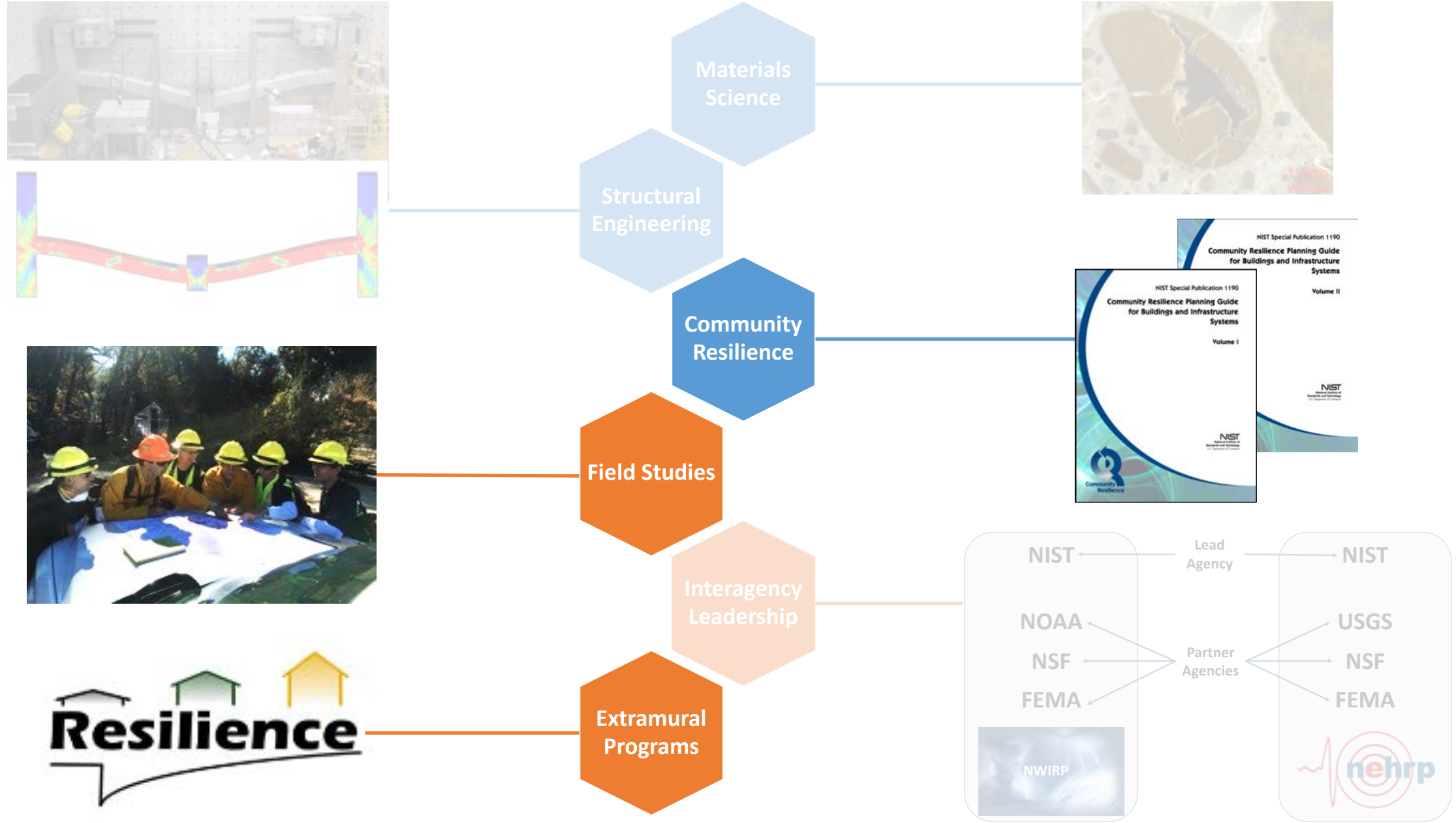
Field Studies

Interagency  
Leadership

Extramural  
Programs

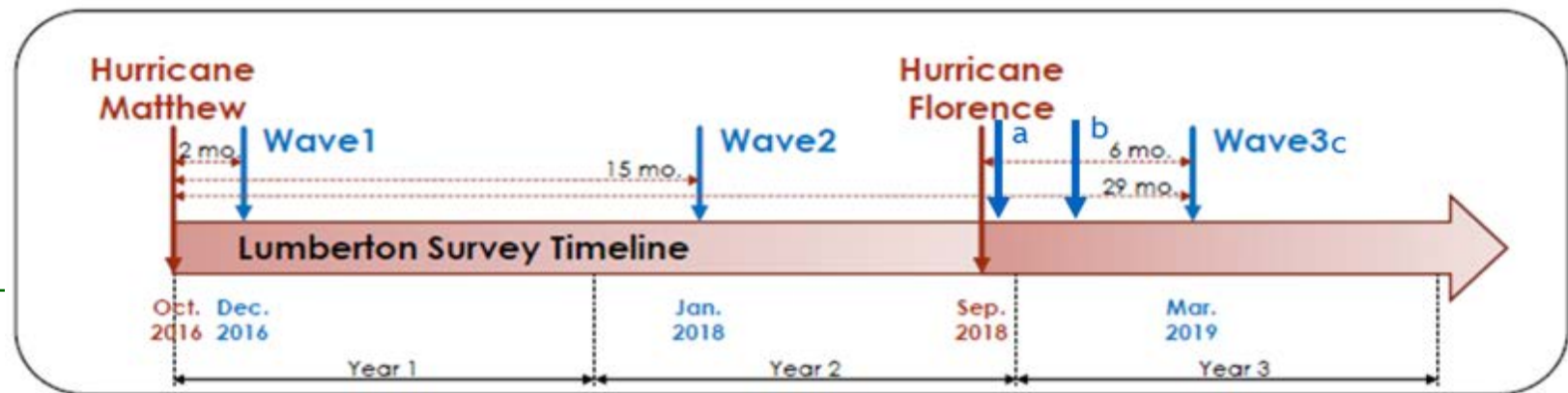
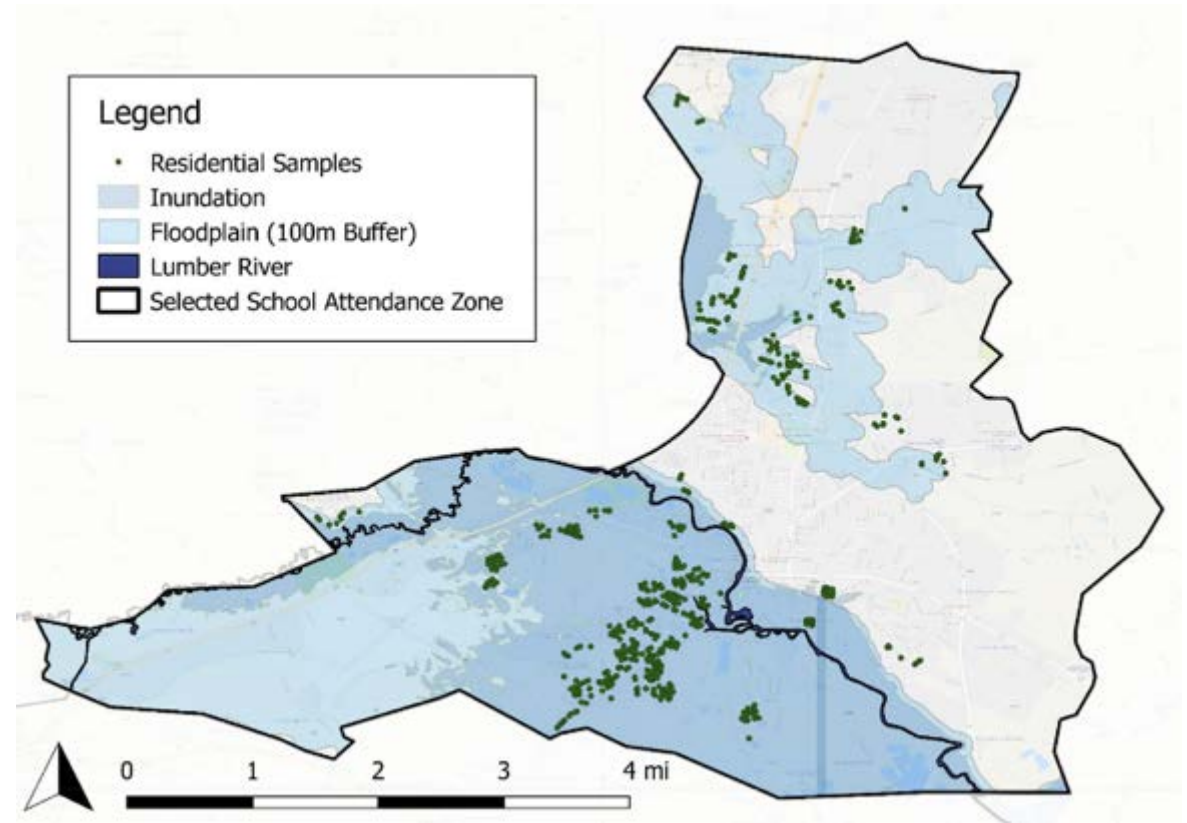


# Disaster Resilience Work across NIST (and scales)





# Longitudinal Study of Lumberton, North Carolina

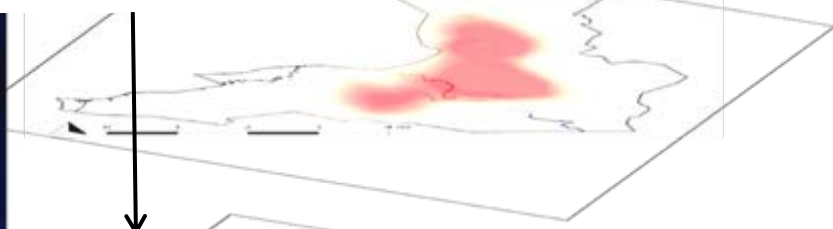


# How does disaster recovery differ across a community?

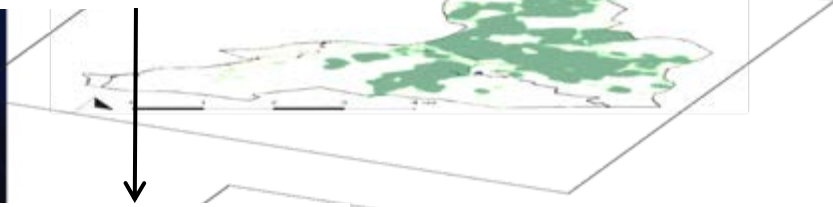
Inundation Map



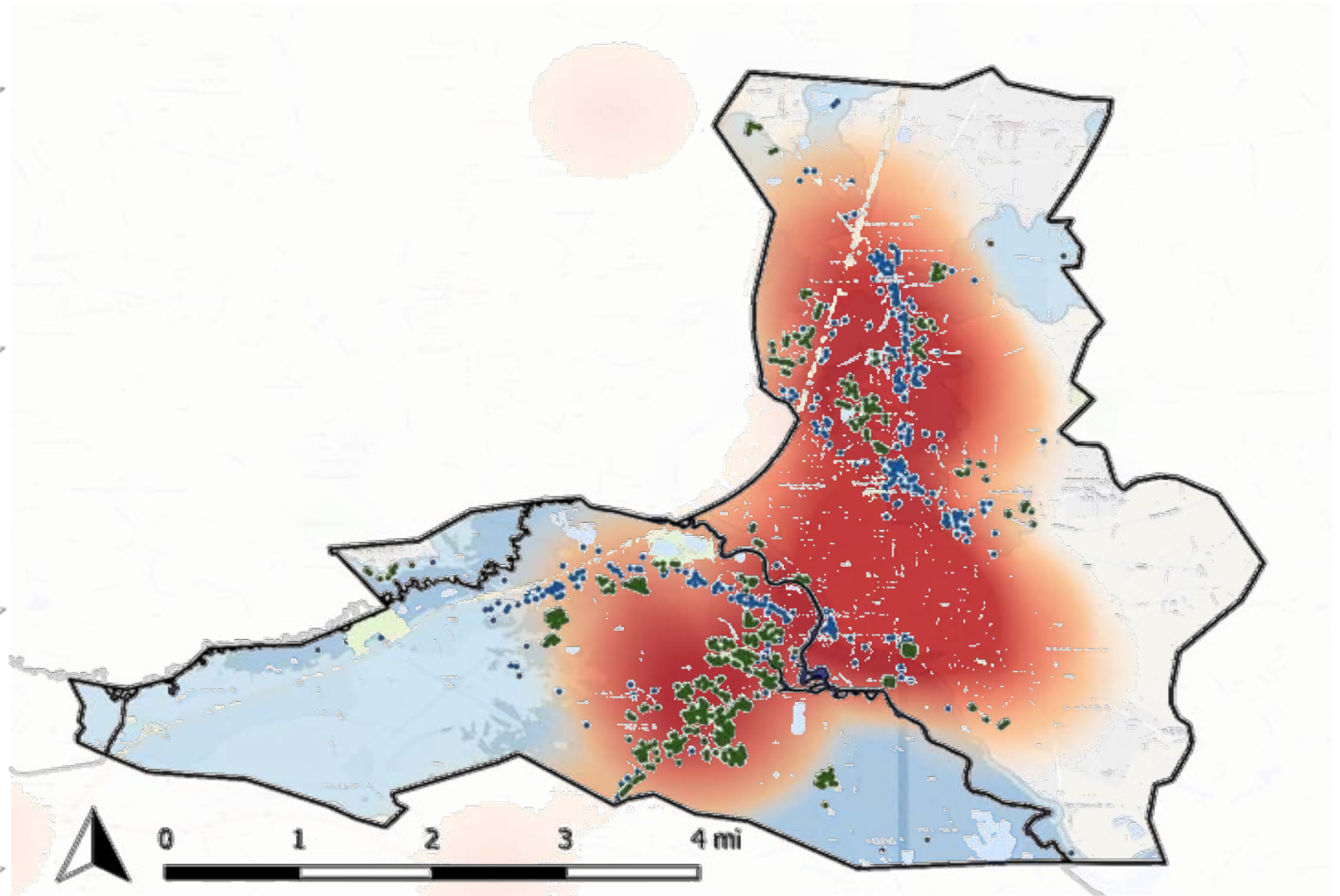
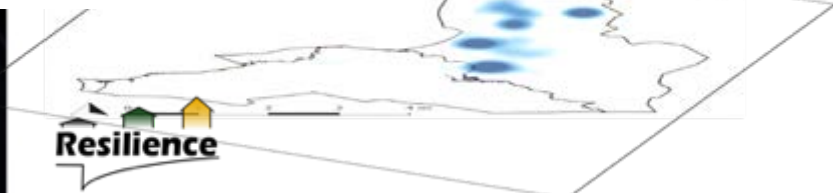
School Zones



Housing Samples

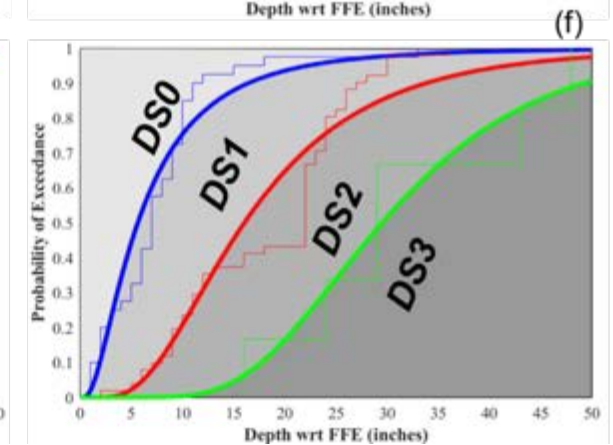
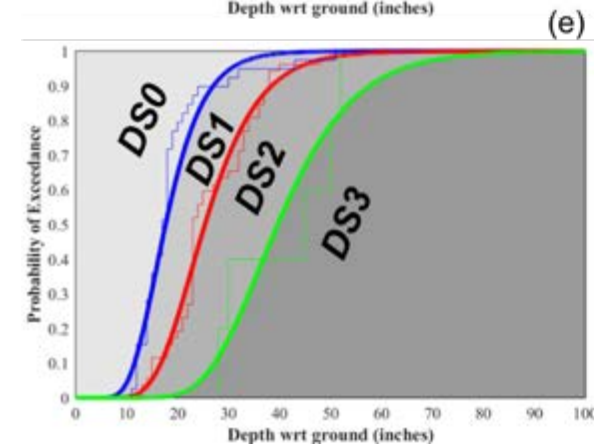
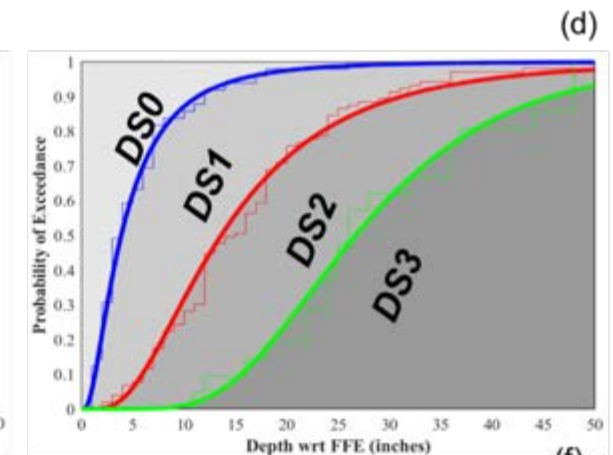
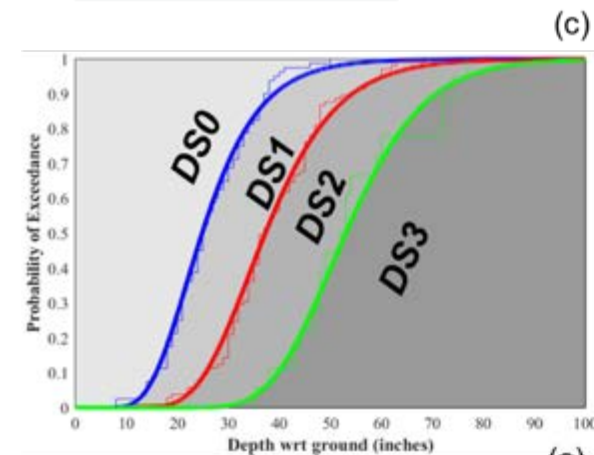
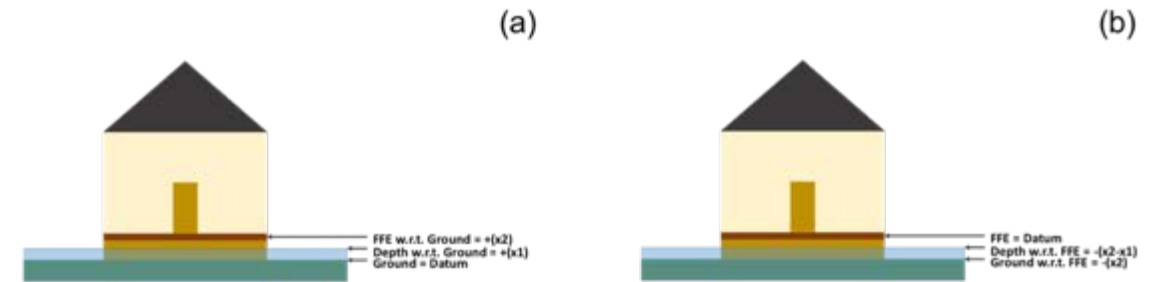


Business Samples





# Standardizing (Built Infrastructure) Field Measurements





# Standardizing (Social Infrastructure) Field Measurements

## North Carolina Flood Field Study: Household Survey

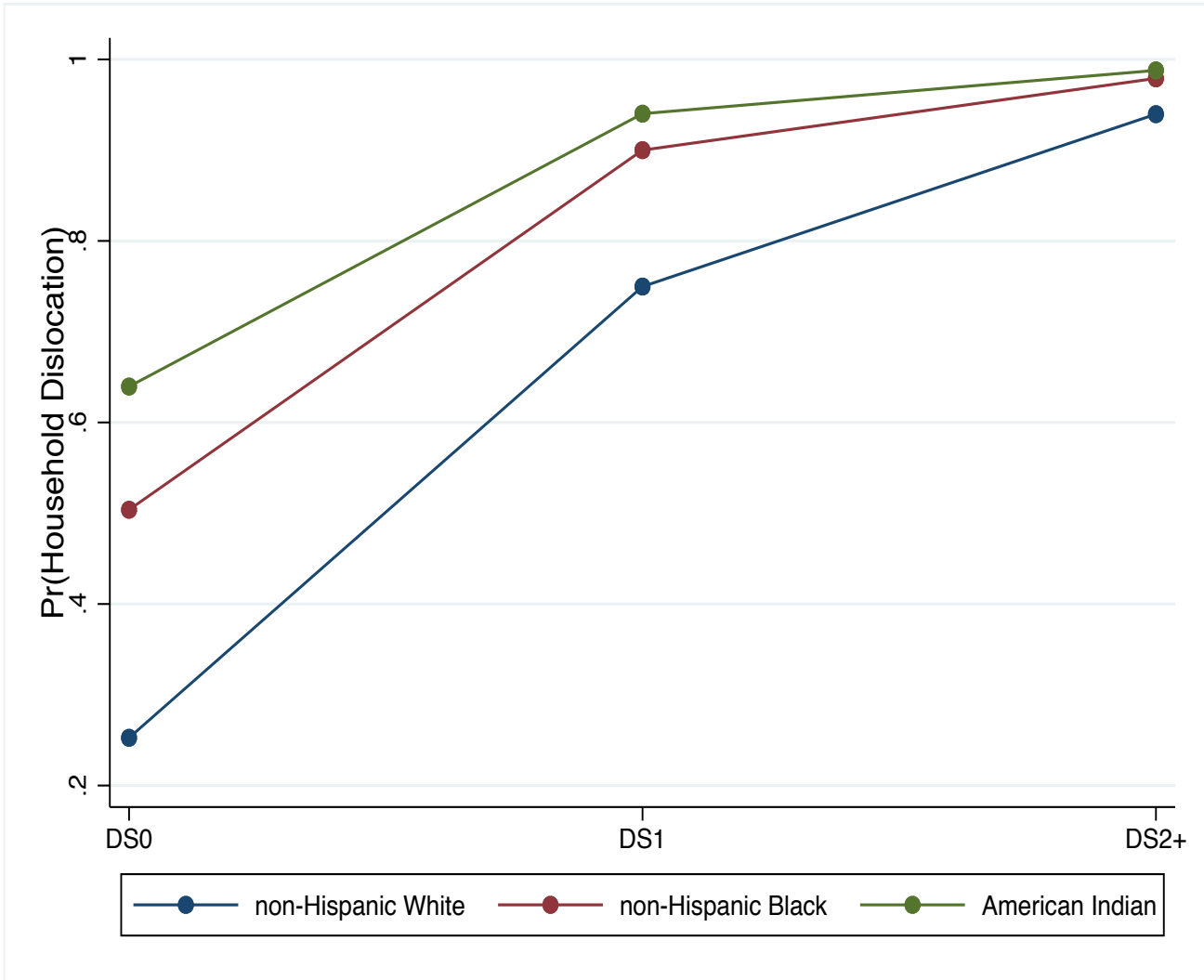
Note these initial questions are answered with respect to the sampled Housing Unit (HU) and the structure in which it is located.

Housing Unit/Sample Unit Description:		Address: _____	
Verified by Respondent? YES NO			
Interview Attempt 1: Date/Time:	Interview Attempt 2: Date/Time:	Interview Attempt 3: Date/Time:	
Building Type:	1. Single Family	2. Multi-Family # of HUs _____	3. Manufactured/ Mobile home
Housing Unit (HU) appears occupied Habited or not habited?	YES: household present	YES, evidence of current habitation	Yes, occupied confirmed by neighbor
		NO: not occupied, appears abandoned	NO, damage and not habitable
		Yes, occupied, confirmed by management	DK: Indeterminate/ uncertain
		NO: not occupied, under repair/reconstruction.	
Interview Attempt Result code:	Result of Interview attempt 1: _____	Result of Interview attempt 2: _____	Result of Interview attempt 3: _____
	Appointment or follow up: day and time Day/time: _____		
	Result/ completion codes: 1. Completed interview 2. Incomplete/partial - 3. Not available or inconvenient (try to avoid and set , appointment set	4. Soft refusal - closing team assignment. 5. Hard Refusal - contact captain, perhaps replacement 6. No Answer or response, but evidence or confirmed occupied.	7. Ineligible, [needs follow interview attempt] 8. Ineligible (with information about previous residents) 9. Ineligible total - new construction - post HM 10. Ineligible property - structure not a residence 11. Bad address - could not locate HU. 12. Not occupied residence, abandoned property, home destroyed. 13. No access. Gated community or safety fence preventing entry to damage residence(s). NOTE IF structure destroyed or abandoned, code as 12.

Assessment of occupancy and information about HU and household gained from neighbors, apartment managers, etc.

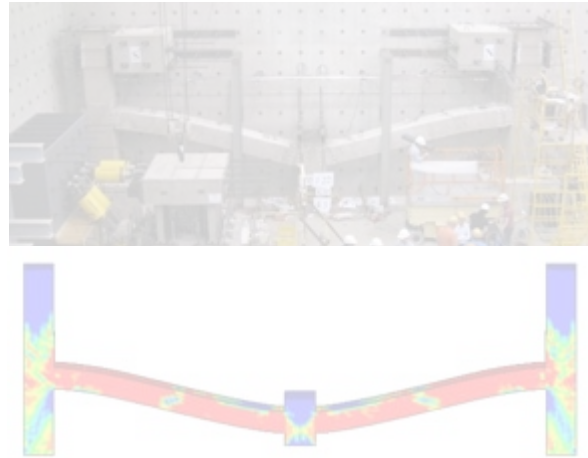
Does the Housing Unit appear to be currently occupied?	YES NO DK	IF YES: nature / source of the evidence: _____ Other: _____	If Neighbor, manager, or other person can provide information	Was the HU occupied at time of HM?: YES NO	IF YES: # of persons _____	
Evidence that Housing unit was occupied at the time of HM?	Yes NO DK	IF YES: nature of the evidence: _____ Other: _____		Is same household there now? YES NO DK	IF YES: # of persons _____	IF No: Will former HH return? YES NO DK
		1. Signs of current/previous occupancy 2. Neighbor 3) Management 4) other - specify in space		IF NO: New residents in HU? YES NO DK	IF YES: # of persons _____	

Space for Additional Comments/Observations:





# Disaster Resilience Work across NIST (and scales)



Materials Science

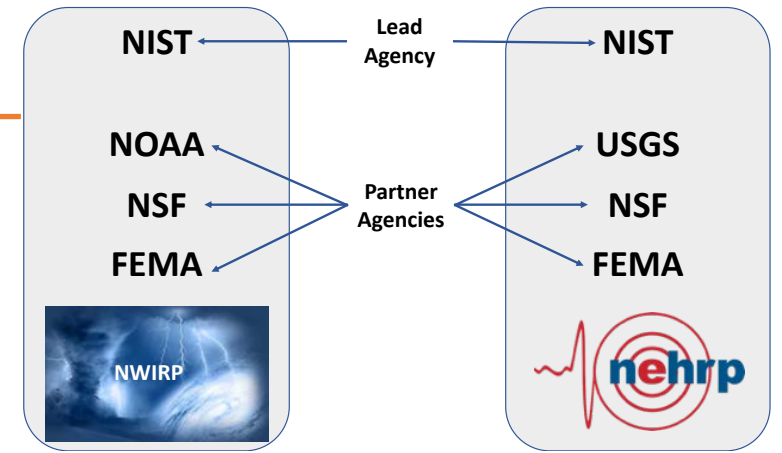
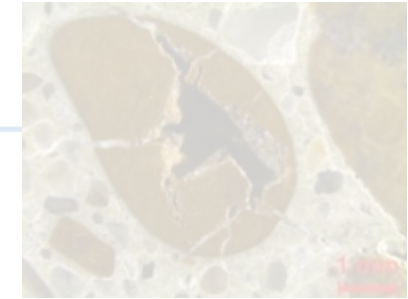
Structural Engineering

Community Resilience

Field Studies

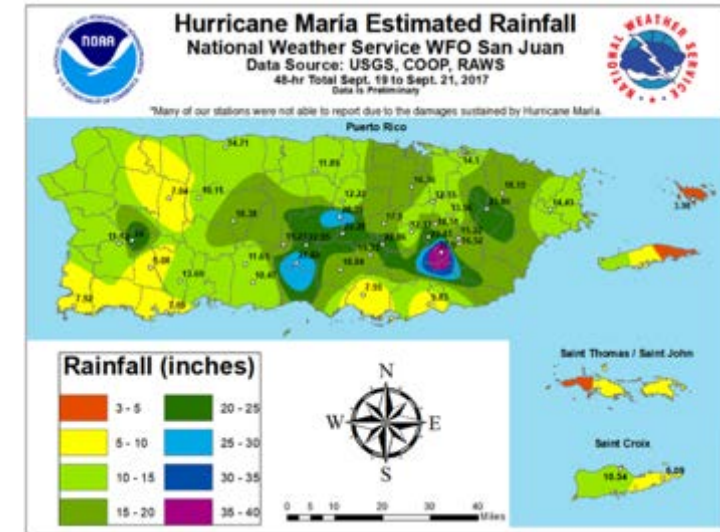
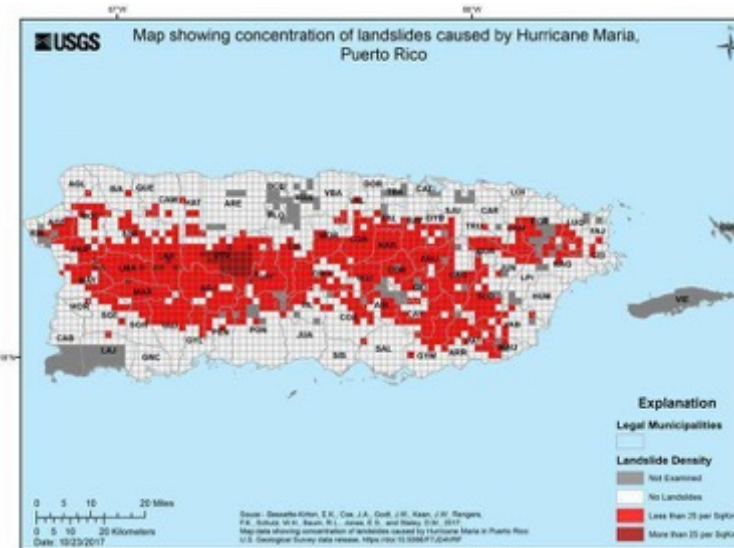
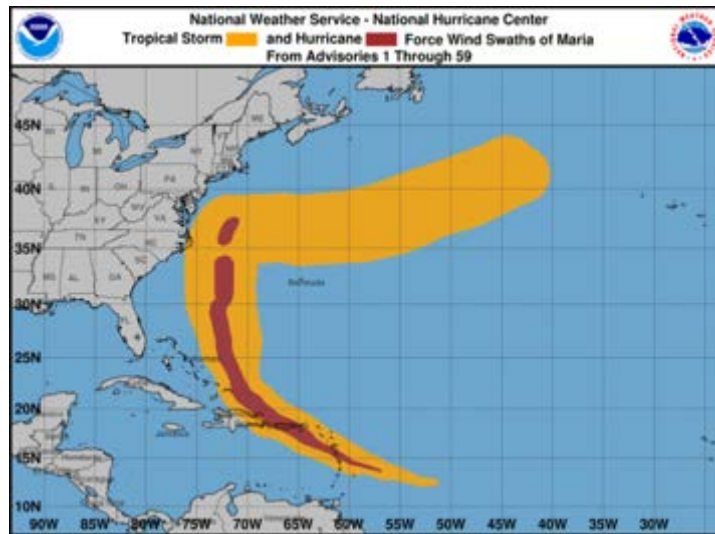
Interagency Leadership

Extramural Programs





# Hurricane Maria Program at NIST



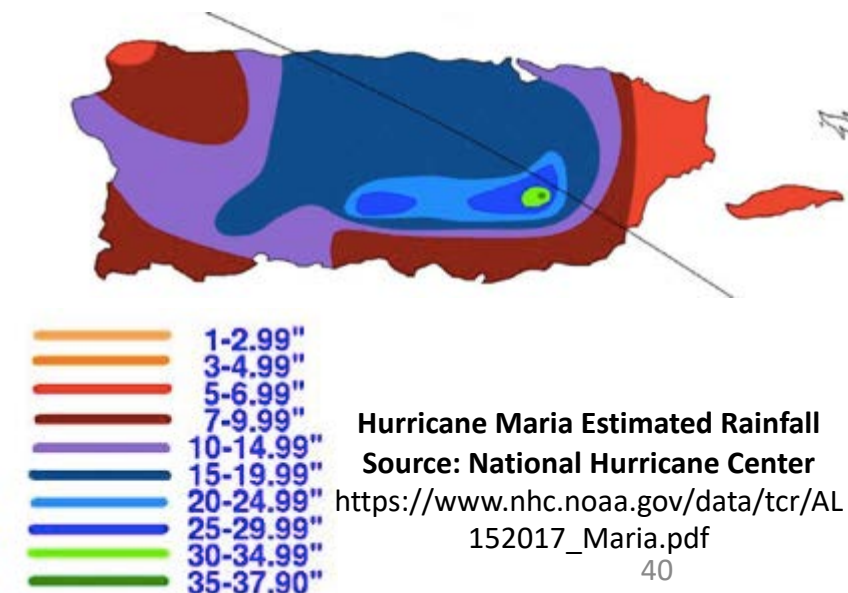
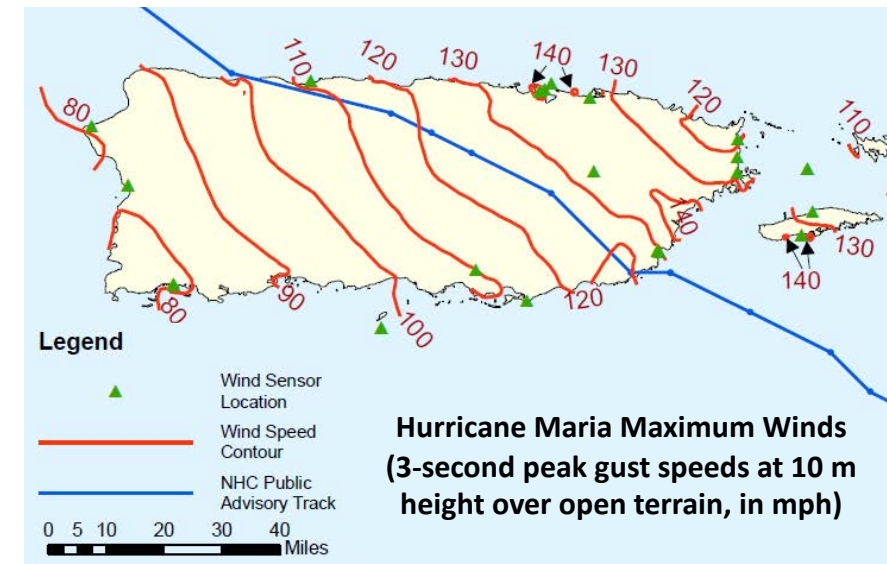
- NIST is studying Hurricane Maria's effects on Puerto Rico's buildings and emergency communications systems and recovery from the hurricane.
- Program is authorized by two federal statutes *NCST* and *NWIRP*.
- Goal: **recommend improved codes, standards, and practices to help communities in Puerto Rico and across the U.S. to be more resilient.**

# Project 1: Characterization of Hazards

**Investigative Goal:** Characterize the wind environment and technical conditions associated with deaths and injuries.

**Background:** Hurricane Maria subjected Puerto Rico to multiple hazards: peak gusts exceeded 140 mph, peak coastal inundation exceeded 6 ft, rainfall totaling up to 40 inches causing inland flooding. The storm damaged instrumentation, resulting in challenges to the metrology of the hazards related to the windstorm.

**Investigative Objective:** Characterize the wind environment associated with Hurricane Maria's impact on Puerto Rico, using measurements and modeling of the time-dependent hurricane wind-field in conjunction with wind tunnel studies of topographic effects, and to document other hazards associated with the hurricane, including storm surge, rainfall, flooding, and landslides.



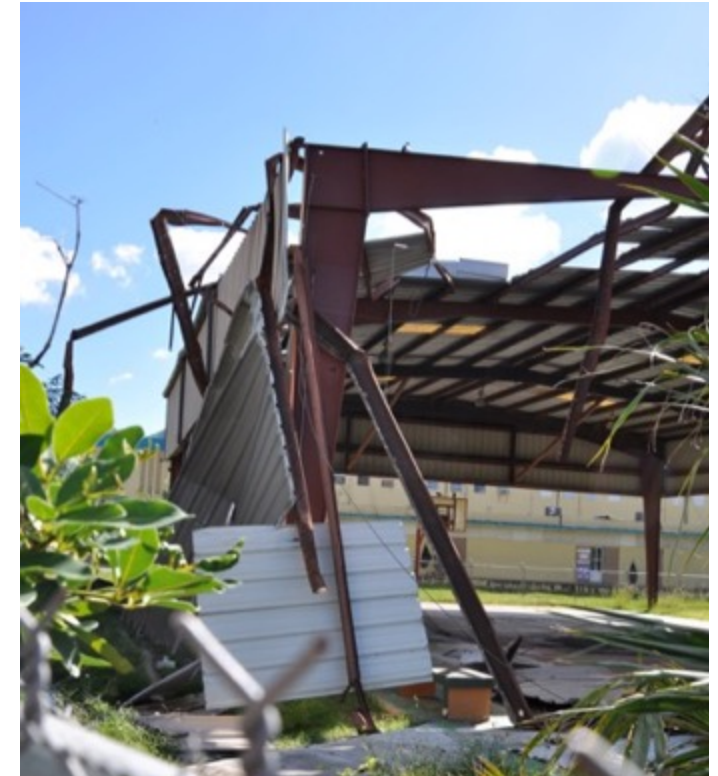


# Project 2: Performance of Critical Buildings

**Investigative Goal:** Characterize the performance of representative critical buildings, and designated safe areas in those buildings, including their dependence on lifelines.

**Background:** Preliminary observations of engineered structures showed: limited ***structural*** damage to reinforced concrete and concrete-block buildings with concrete roofs; some failures of non-concrete roofs (wood or steel frame) on reinforced concrete and concrete-block buildings; and wind-induced damage to and failure of metal building systems, potentially due to corrosion.

**Investigative Objective:** Characterize the performance of critical buildings in Hurricane Maria by (1) documenting failures of structural systems, building envelopes, and rooftop equipment, along with the resulting damage caused by wind-driven rain for a representative sample of hospitals and schools, (2) identifying dependencies in loss of function on lifelines, (3) characterizing wind loads on building envelopes and rooftop equipment through wind tunnel testing for a subset of these hospitals and schools to correlate with observed damage, and (4) evaluating the adequacy of existing selection criteria and design requirements for storm shelters.





# Project 3: Public Response and Emergency Comm's

**Investigative Goal:** Characterize the performance of emergency communications systems and the public's response to such communications.

**Background:** Preliminary observations highlighted severe evacuation and emergency response challenges: the threat of a Category 5 hurricane hitting an island that had just been affected by Hurricane Irma two weeks prior; an island's heterogenous terrain that posed different risks (flooding, heavy winds, storm surge, landslides), requiring different protective actions; societal preference for sheltering in place; lack of communication between emergency and building officials, and with the public for extended periods of time; and many people/families requiring rescues, e.g., from flooding in multiple towns on the island.

**Investigative Objective:** Investigate the role of emergency communications in public response for those under imminent threat from Hurricane Maria. This project will also investigate the use of communications in disaster response (during and immediately after the hurricane event).



# Project 4: Characterization of Morbidity and Mortality

**Investigative Goal:** Characterize the wind environment and technical conditions associated with deaths and injuries.

**Background:** The official death toll by the Puerto Rico's Dept. of Public Safety was initially **64\***, but on June 13, 2018 the Government of Puerto Rico revealed that there were **1,427\*\*** more deaths in the four months after the hurricanes than normal (based on the previous four years), and updated the official count to **2,975\*\*\*** based on George Washington University's study. It has been challenging to develop guidance/policy to prevent disaster attributed mortality due to the ***lack of standards, consistent data collection and reporting.***

**Investigative Objective:** Complete a quantitative morbidity and mortality assessment of Puerto Rico, to better understand how damaged buildings and supporting infrastructure played a role in the injuries and deaths associated with Hurricane Maria. The study results will provide guidance to improve codes, standards and inform future approaches to accurately attribute and predict life loss due to building failure(s).





# Project 5: Recovery of Business and Supply Chains

**Study Goal:** Characterize the impacts to and recovery of small and medium-sized manufacturers (SMMs), as well as businesses in retail and service industries.

**Background:** Manufacturing and retail business services are an important part of understanding the impacts of Hurricane Maria, as well as the long term recovery of Puerto Rico and its supply chains.

**Manufacturing** activity in the Commonwealth accounts for about **45% of Puerto Rico's Gross Domestic Product (GDP) and over 20% of its employment** (PR BLS 2017). According to FEMA (2015), 40% of small businesses never reopen after a disaster and another 25%, that do reopen, fail within a year. Evidence suggests that businesses located in communities that are facing economic downturn ahead of a natural disaster event typically fare less well in recovery (e.g., Corey and Deitch 2013).

**Study Objective:** Characterize the recovery of small- and medium-sized businesses, including manufacturing, retail, and service sectors in Puerto Rico to provide greater understanding of business continuity resilience planning and supply chain continuity and how these may differ between industries/affected regions.





# Project 6: Recovery of Social Functions

**Study Goal:** Characterize the impacts to and recovery of education and healthcare services.

**Background:** NIST investigation will include a project focused on the recovery of education and healthcare services associated with critical buildings (schools and hospitals) in Puerto Rico. Both education and healthcare services are an important part of understanding the impacts of Hurricane Maria, as well as the long term recovery of Puerto Rico. The Department of Education in Puerto Rico is expected to close over 283 schools, and will receive nearly \$600 million in emergency federal assistance for school recovery and rebuilding.

**Study Objective:** Examine the recovery trajectories of sampled schools and hospitals in Puerto Rico to identify the underlying characteristics and conditions associated with recovery of critical social functions from Hurricane Maria.

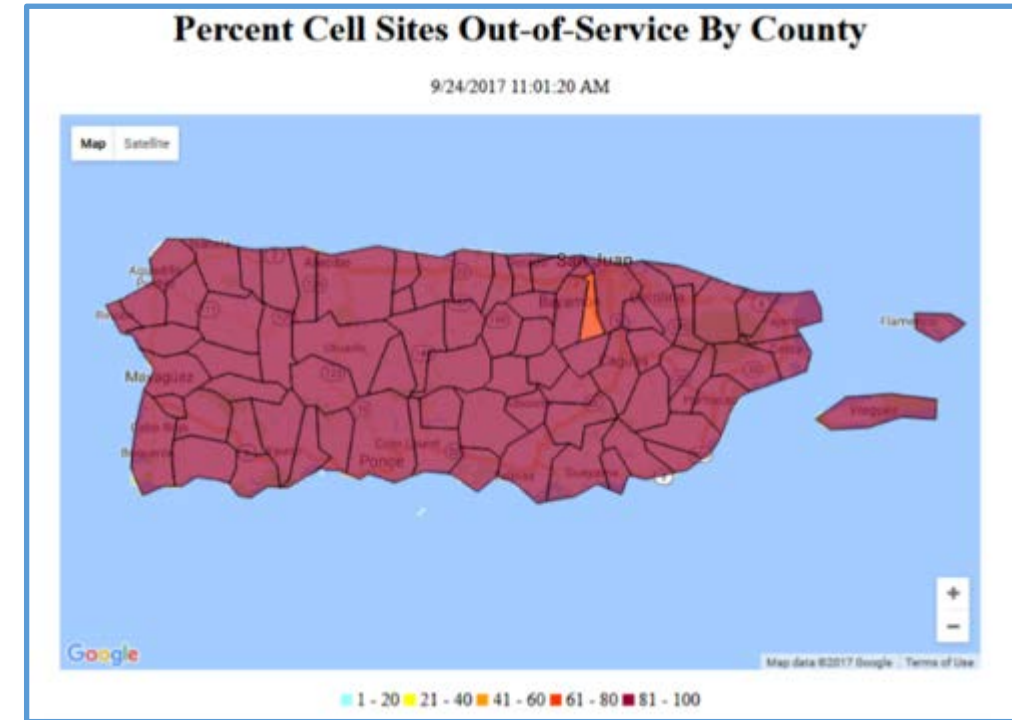


# Project 7: Recovery of Infrastructure Systems

**Study Goal:** Characterize the impacts to and recovery of infrastructure systems in Puerto Rico, with a focus on infrastructure that supports the functioning of critical buildings (i.e., hospitals and schools) and emergency communications.

**Background:** Puerto Rico's experience with Hurricane Maria presents an opportunity to better understand the infrastructure support of critical buildings. This support may be direct, e.g., delivering power to a hospital, or indirect, e.g., delivering power for telecommunications equipment that provides for hospital communications. Cascading impacts and the recovery of power, water, and transportation infrastructure are the focus. Also, wireless communications equipment failure is the focus.

**Objective:** Investigate dependencies of building function on distributed infrastructure, including cascading loss of function and sequencing of recovery activities, and also to investigate causes of the loss of functionality and extended-duration outage of the wireless communication system in Puerto Rico following Hurricane Maria.



# NIST Disaster Metrology and Community Resilience Research

- Lumberton Longitudinal Project
- Hurricane Maria Program (many projects)
- Systems-based CR Modeling Project (ARC @ NIST, IN-CORE @ CoE)
- Community Resilience Metrics Project
- Immediate Occupancy Project
- Functional Recovery Project
- Reliability of Fiber Reinforced Composite Systems Project
- Implementation of Community Resilience Planning Guide
- Economic Decision Guide for Buildings and Infrastructure Systems (EDG) and associated software (EDGe\$)
- Tornado Hazard Maps
- Pre-standard for Performance-Based Design for Wind






# Disaster Resilience Symposium at NIST

## SYMPOSIUM

 August 7 - 8, 2019

 NIST, 100 Bureau Drive,  
Gaithersburg, MD  
(Green Auditorium)

**Registration ended on July 31, 2019.**

All attendees must be pre-registered to gain entry to the NIST campus. Photo identification must be presented at the main gate to be admitted to the conference. International attendees are required to present a passport. Attendees must wear their conference badge at all times while on the campus. There is no on-site registration for meetings held at NIST.

## Disaster Resilience 2018 Notice Of Funding Opportunity (NOFO)

2018 Disaster Resilience  
Symposium +

2019 Disaster Resilience  
Symposium -

**Presentation Gallery**

Related Links

Resources +

## Presentation Gallery

### 2019 Disaster Resilience Symposium August 7-8, 2019 NIST, Gaithersburg, MD



Building a Resilient Society in  
Response to Wildfires: 2019 Disaster  
Resilience Symposium



WUI Research @ NIST: 2019 Disaster  
Resilience Symposium



Earthquake Research @ NIST: 2019  
Disaster Resilience Symposium



Liquefaction-Targeted Ground  
Motion Parameters: 2019 Disaster  
Resilience Symposium



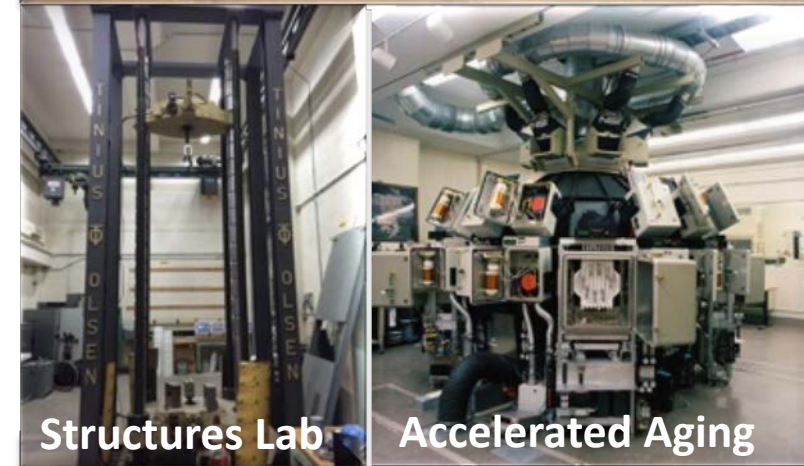
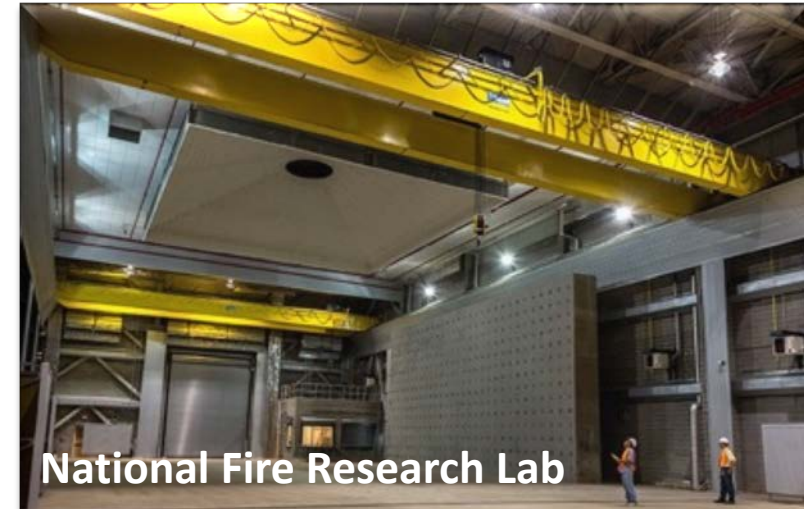
Decision-Oriented Column  
Simulation Capabilities for  
Enhancing Disaster Resilience of  
Reinforced Concrete Buildings: 2019  
Disaster Resilience Symposium  
(Group Presentation)



Resilience of Steel Moment Frame  
Systems with Deep Slender Column  
Sections: 2019 Disaster Resilience  
Symposium

# Ongoing Opportunities at NIST

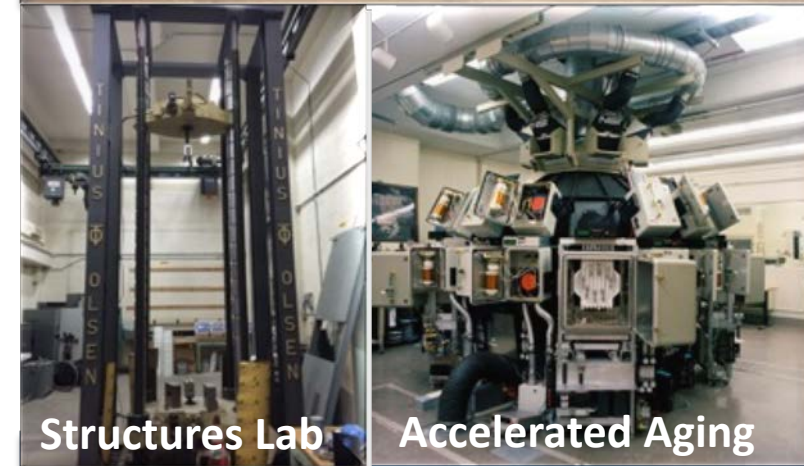
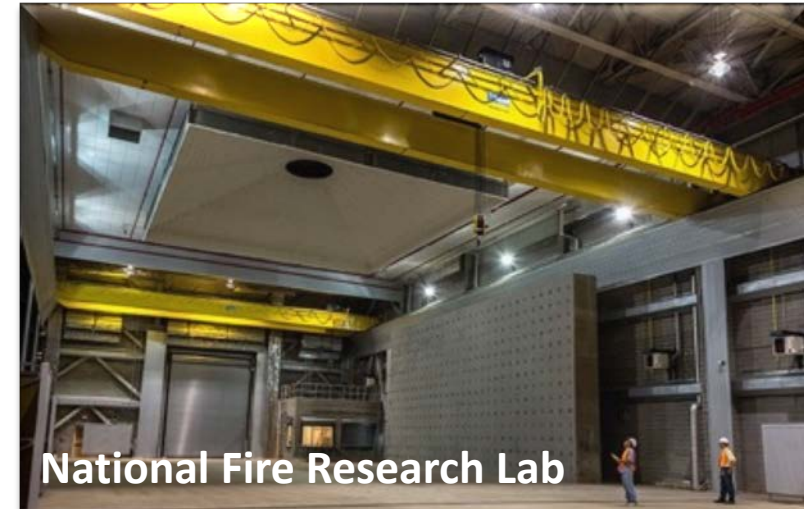
- Summer Undergraduate Research Fellowship (SURF): <https://www.nist.gov/surf>
- \*NIST Pathways Program for currently enrolled students (high school through post-grad): <https://www.nist.gov/ohrm/student-and-other-opportunities>
- \*NIST NRC Postdoc Fellowship: <https://www.nist.gov/iaao/nist-nrc-postdoctoral-research-associateships-program>
- PREP, Guest Researchers, and Sabbaticals
- \*Term Appointments and many others!
- \* *US citizens only*





# Opportunities at NIST

- Systems Modeling Researcher
- Social Science Researcher
- Earthquake Engineering Research Leadership
- Disaster and Failure Studies Leadership





# Thank you

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*Materials & Structural Systems Division*

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