Moving Resilience from Research to Practice

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Resilience

IN-CORE

"…the ability to prepare for and adapt to changing conditions and to withstand and recover rapidly from disruptions…"

-Presidential Policy Directive 21

"…the ability to prepare for and adapt to changing conditions and to withstand and recover rapidly from disruptions…"

-Presidential Policy Directive 21

Today's Presentation

- State of the research in community resilience modeling and measurement

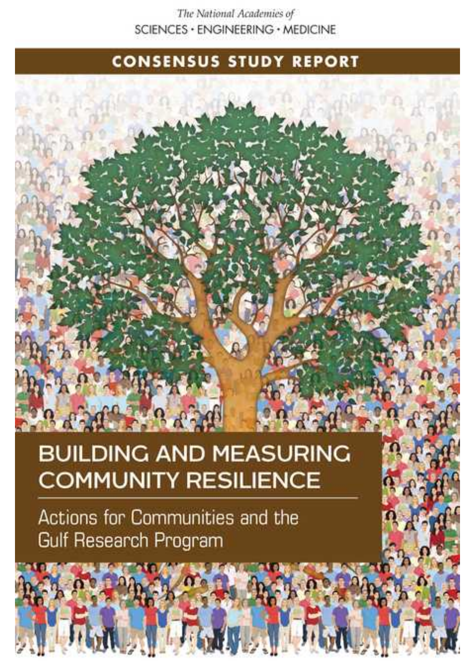
- Need for field studies to provide input for data-driven models – social science

- Web applications for partnerships to apply underlying research algorithms in a way that is useful and usable for communities

A new kind of research is needed …

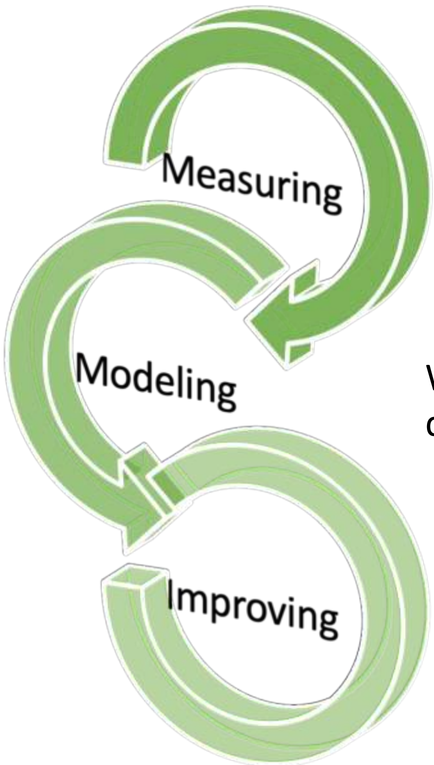
"A new kind of research is needed that:

- can address the dynamic state of communities and their changes in risk and resilience over time, and
- can link information or data from disparate programs with each other and to community resilience priorities, to ultimately
- link research, data, and information with decision making."



National Academies of Sciences, Engineering, and Medicine 2019. Building and Measuring Community Resilience: Actions for Communities and the Gulf Research Program. Washington, DC: The National Academies Press. https:doi.org/10.17226/25383.

How can we move from research to practice?



Our desire to improve community resilience requires measuring what we can and can't see, touch, or feel

We must integrate physics- and process-based models with empirical data-driven models thereby combining components from and across disciplines

We measure our models output and IF they represent something close to reality, alternative actions and ideas can be explored, and community resilience improved for future events

NIST-CoE Community Resilience Overview

- Improve the performance of built environment for natural hazards at the community scale
- Characterize interdependencies between social, economic, and physical systems
- Develop science-based tools that communities can use to assess/improve their resilience

First 5 years (2015-2020)

- ***Open-source inter-disciplinary computational environment (IN-CORE)*** to assess community resilience and support policies and decisions to advance community resilience goals.
- … architecture and management tools that support IN-CORE.
- ***Comprehensive set of testbeds and hindcasts*** to validate IN-CORE.

Knowledge Creation → Knowledge Implementation

Second 5 years (2020-2025)

- ***Measurement and decision science through IN-CORE***, including interdependencies, uncertainty, intermodal systems, and risk-informed decision support.
- … ***n and validation***, including integrated databases and longitudinal knowledge from field studies.
- ***Decision support and implementation*** of resilience science through ***technology transfer***.

NIST CoE Executive Team

John van de Lindt
Co-Director

Jamie Kruse
Co-Director

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Task 1: Development of IN-CORE Platform
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Task 1: Development of IN-CORE Platform
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Shannon Van Zandt
Task 2: IN-CORE Outreach and Sustainability
Texas A & M University

Harvey Cutler
Task 3: Mitigation and Recovery
Colorado State University

Andre Barbosa
Task 4: Verification and Validation (V&V) of IN-CORE
Oregon State University

Jamie Padgett
Task 5: Modeling of Complex Systems
Rice University

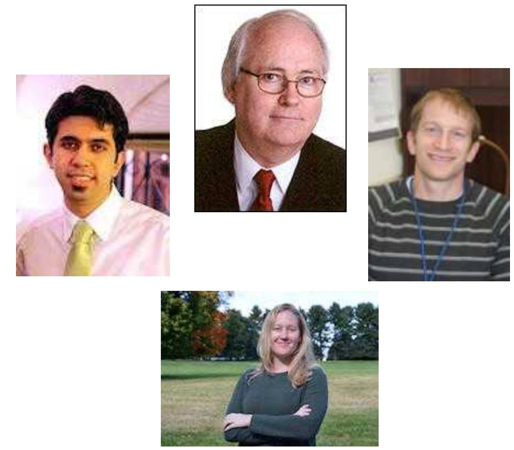
Paolo Gardoni
Task 6: Modeling of Interdependencies and Propagation of Uncertainty
University of Illinois at Urbana Champaign

NIST CoE Faculty, Developers, & Staff

NIST Collaboration Team

Applied Economics

Community Resilience



Earthquake

Disaster Failure Studies

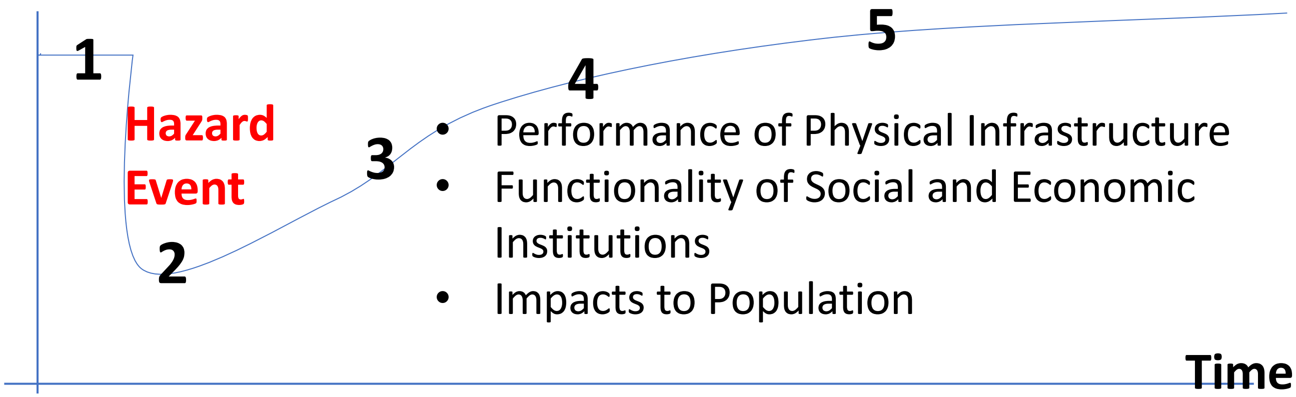
Materials and Structural Systems

Structures

No pictured:
Christopher Segura

Stages of Resilience

A process!



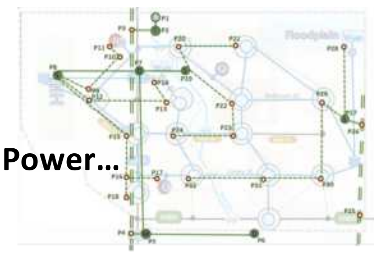
- Performance of Physical Infrastructure
- Functionality of Social and Economic Institutions
- Impacts to Population

1. Current state	**2. Immediate damage**	**3-5. Recovery Stages**
• Existing vs. Desired Performance • Dependencies	• Loss of Life/Injury • Physical Damage • Loss of Function • Decision Support	• Social and Economic • Repaired Damage • Recovered Functions • Decision Support

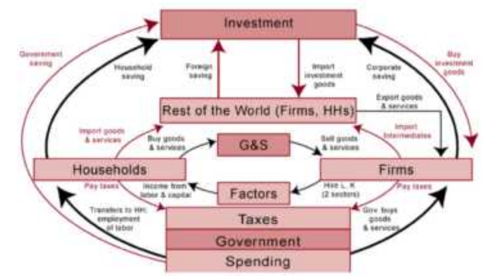
Begin by developing an integrated community model

Buildings…

Power…

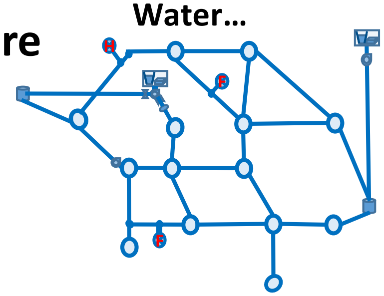


Economy



Physical infrastructure

Water…



Transportation…

Social (e.g . households, institutions)

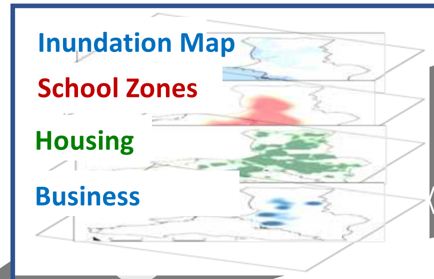
IN-CORE Interdependent Networked- Community Resilience Modeling Environment

- **Physical infrastructure**
- **Economic health**
- **Social services**
- **Information science**

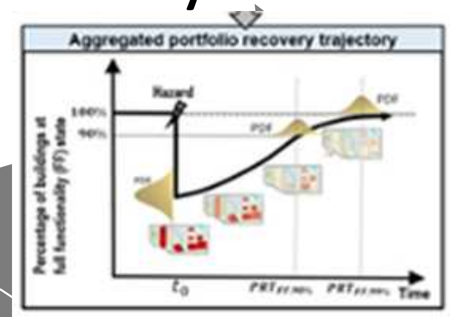
https://incore.ncsa.illinois.edu

https://github.com/IN-CORE/

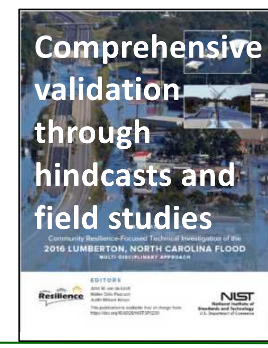
1 **Damage and loss; impacts of natural hazards on communities**



2 **Interdisciplinary recovery with fully integrated supporting databases**



3 **Alternative actions to enhance community resilience & inform planning**

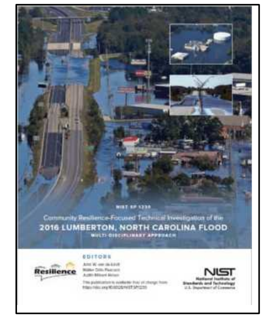


Measuring community resilience

Five areas of community stability

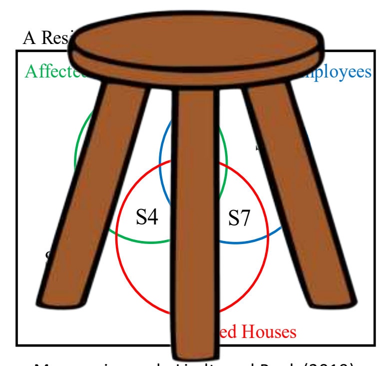
- Population
- Economics
- Social services
- Physical services
- Governance

Measuring community resilience



Five areas of community stability

- Population
  - Empirically derived models provide the basis for household dislocation
  - We can measure how many people remain
  - We know if they are still in their home
  - We don’t know where they go when they leave
  - Difficult to measure
    - Outmigration, Inmigration



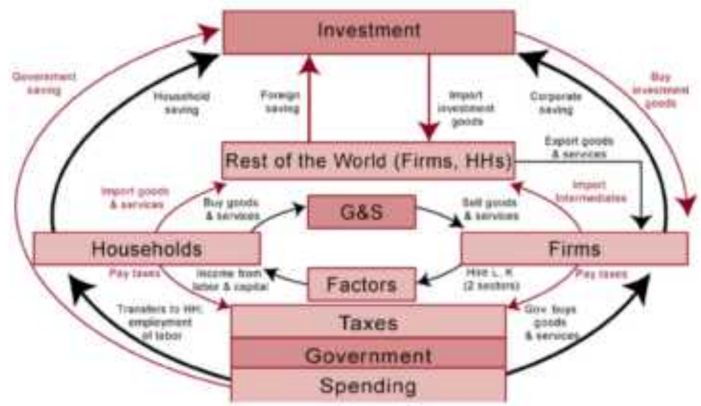
Masoomi, van de Lindt, and Peek (2019)

Sutley, E., Dillard, M., Hamideh, S., Peacock, W., Tobin, J., Peek, L., Seong, K., Barbosa, A., Tomiczek, T., van de Lindt, J., Gu, D. (2020) "Household Survey Instrument, January 19, 2018: Wave 2", in *A Longitudinal Community Resilience Focused Technical Investigation of the Lumberton, North Carolina Flood of 2016*. DesignSafe-CI. https://doi.org/10.17603/ds2-db3h-gy28

Measuring community resilience

Five areas of community stability

- Economics
    - Computable General Equilibrium (CGE) modeling
    - Widely accepted as SOTA/SOTS
    - Economic data is available at county levels
- What can we measure?
    - GDP at community level
    - Household Income (by subpop.)
    - Unemployment
    - Government tax revenues



Measuring community resilience

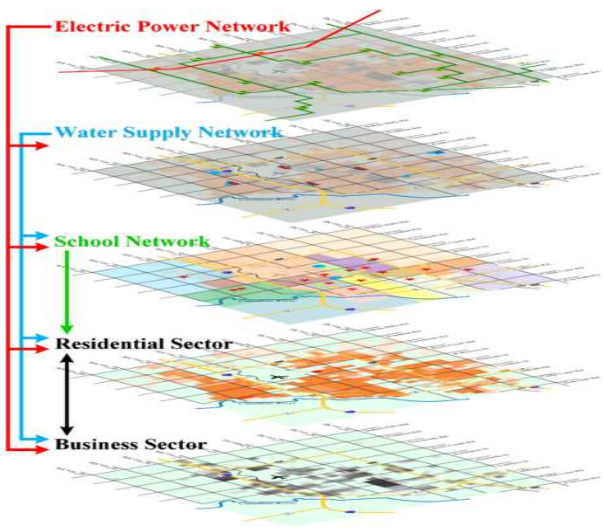
Five areas of community stability

- Social services
  - Healthcare systems including hospitals, clinics, long-term care facilities, dialysis centers
  - School systems
  - We have the ability to measure quantity but not quality – after the fact
  - We don't know what we don't know (Christchurch, NZ)
- Models are under development and need data

Measuring community resilience

Five areas of community stability

- Physical services
  - Measurement is used in design of engineered systems
  - True inter- and cross- dependencies is progressing but standardization gaps; dependencies possible
- Measuring
  - Buildings functional with dependency
  - Percent buildings receiving water, electrical power

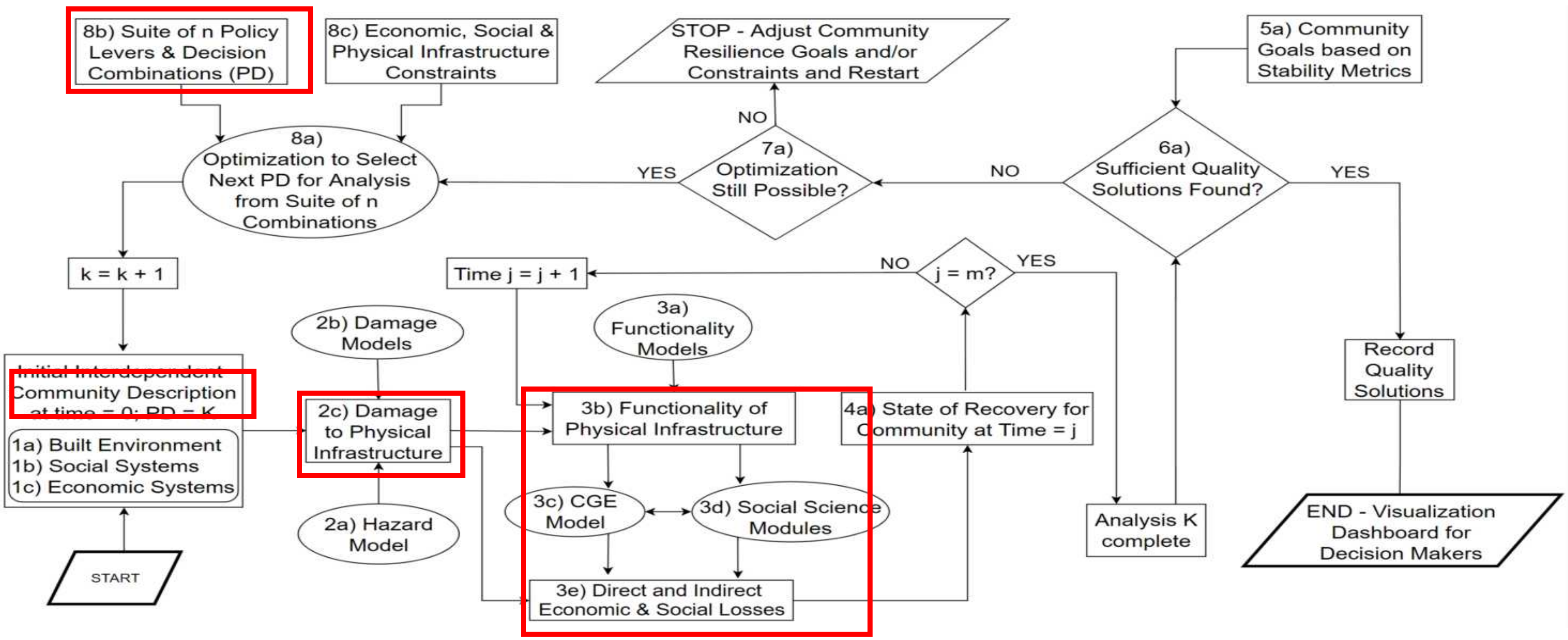


Measuring community resilience

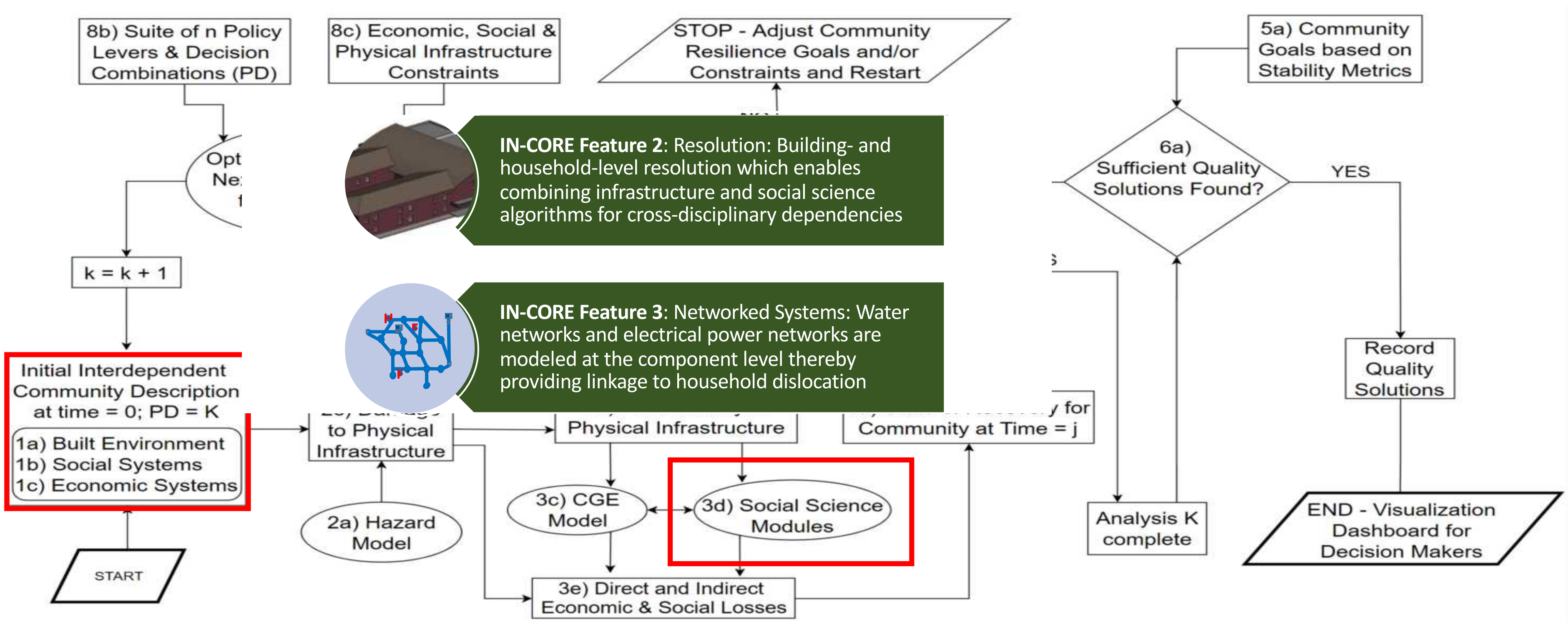
Five areas of community stability

- Governance
- We know things like below matter
  - Tenure of Leadership (mayor or city manager years served, community council rate of turnover)
  - Local government budget
  - Budget to debt ratio
  - BCEGS rating
  - Bond rating
- But how can they be modeled ?

Modeling community resilience



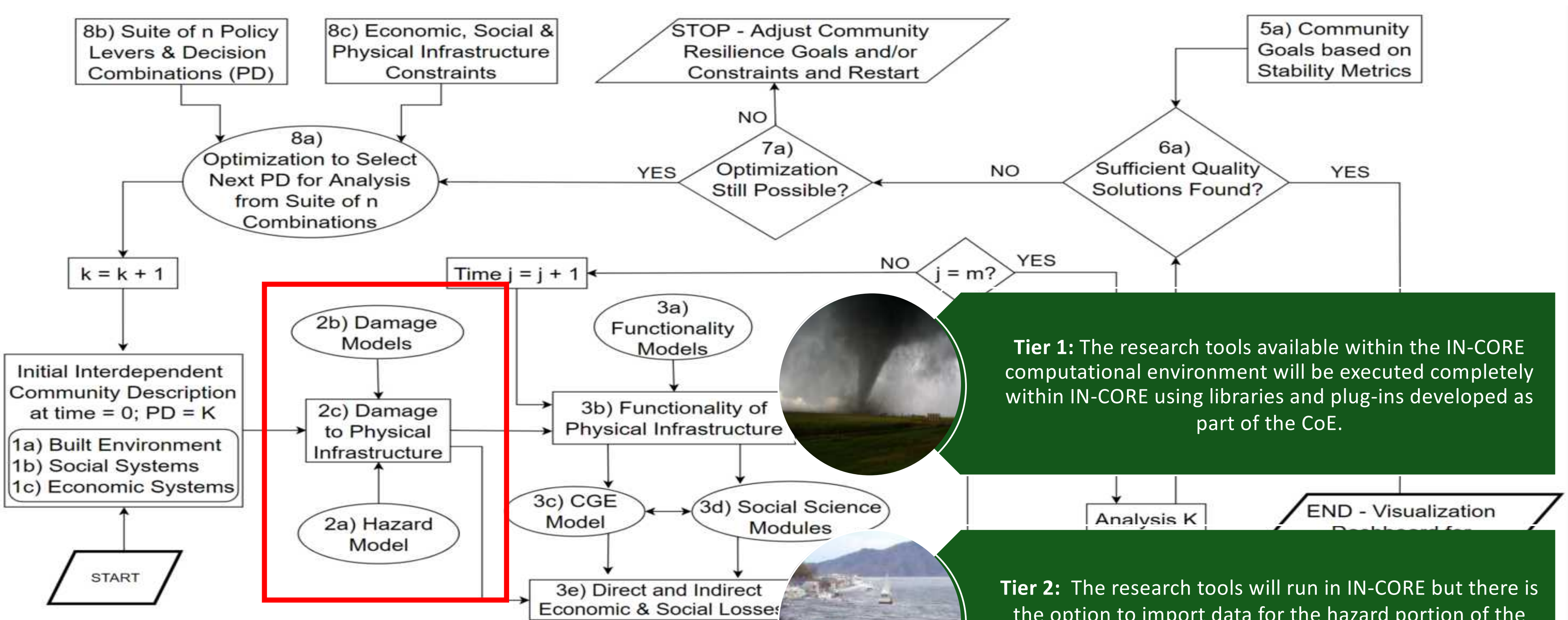
Modeling community resilience



IN-CORE Feature 2: Resolution: Building- and household-level resolution which enables combining infrastructure and social science algorithms for cross-disciplinary dependencies

IN-CORE Feature 3: Networked Systems: Water networks and electrical power networks are modeled at the component level thereby providing linkage to household dislocation

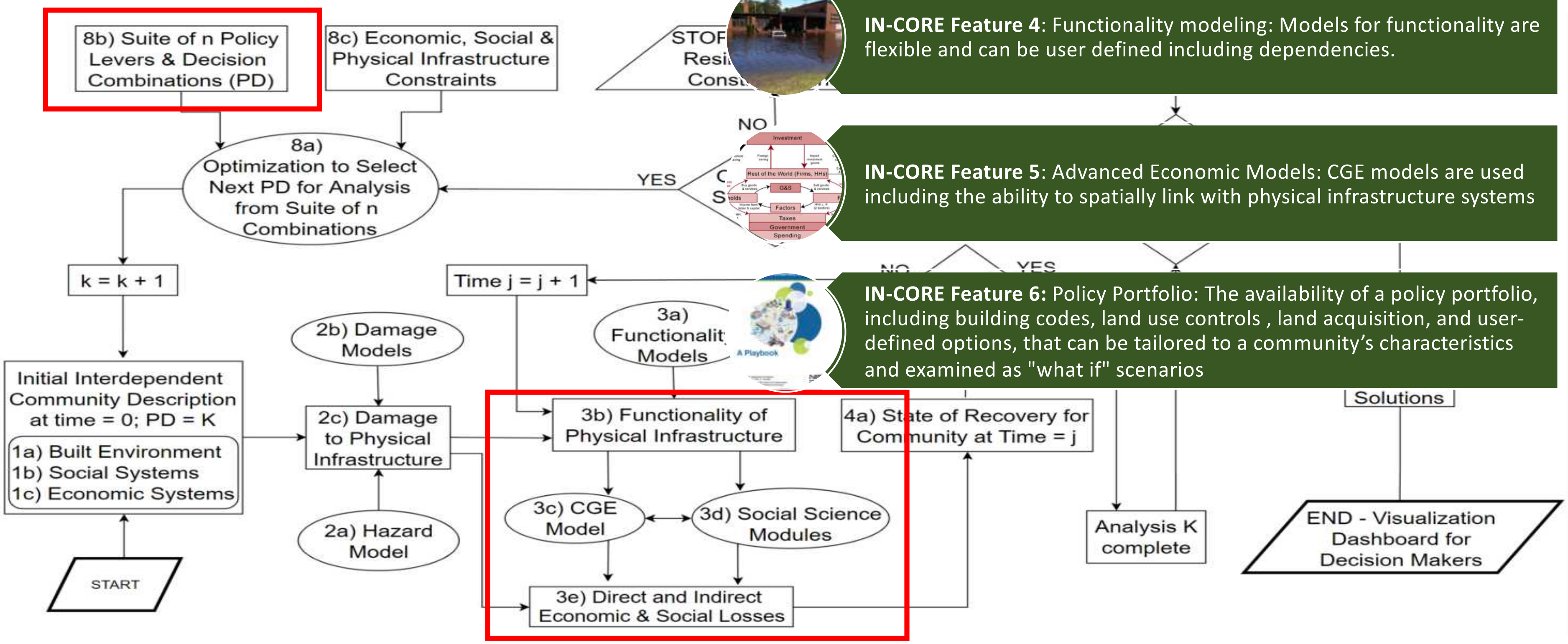
Modeling community resilience



Tier 1: The research tools available within the IN-CORE computational environment will be executed completely within IN-CORE using libraries and plug-ins developed as part of the CoE.

Tier 2: The research tools will run in IN-CORE but there is the option to import data for the hazard portion of the analysis, e.g. a wind field shape file from an outside software (or other) source, overland surge flow from ADCIRC, etc.

Modeling community resilience

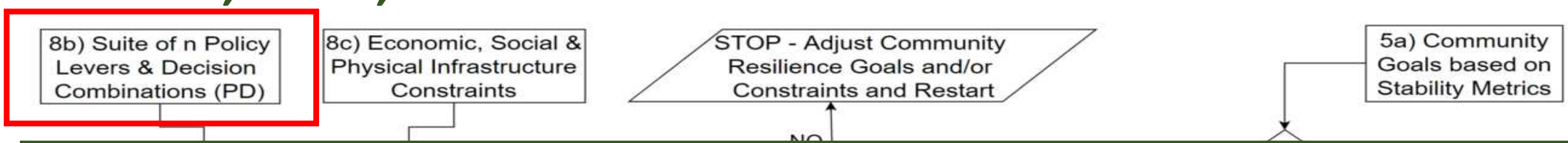


IN-CORE Feature 4: Functionality modeling: Models for functionality are flexible and can be user defined including dependencies.

IN-CORE Feature 5: Advanced Economic Models: CGE models are used including the ability to spatially link with physical infrastructure systems

IN-CORE Feature 6: Policy Portfolio: The availability of a policy portfolio, including building codes, land use controls , land acquisition, and user-defined options, that can be tailored to a community's characteristics and examined as "what if" scenarios

Explore Different Scenarios: Cost-Benefit but in terms of societal benefits, costs, and resilience



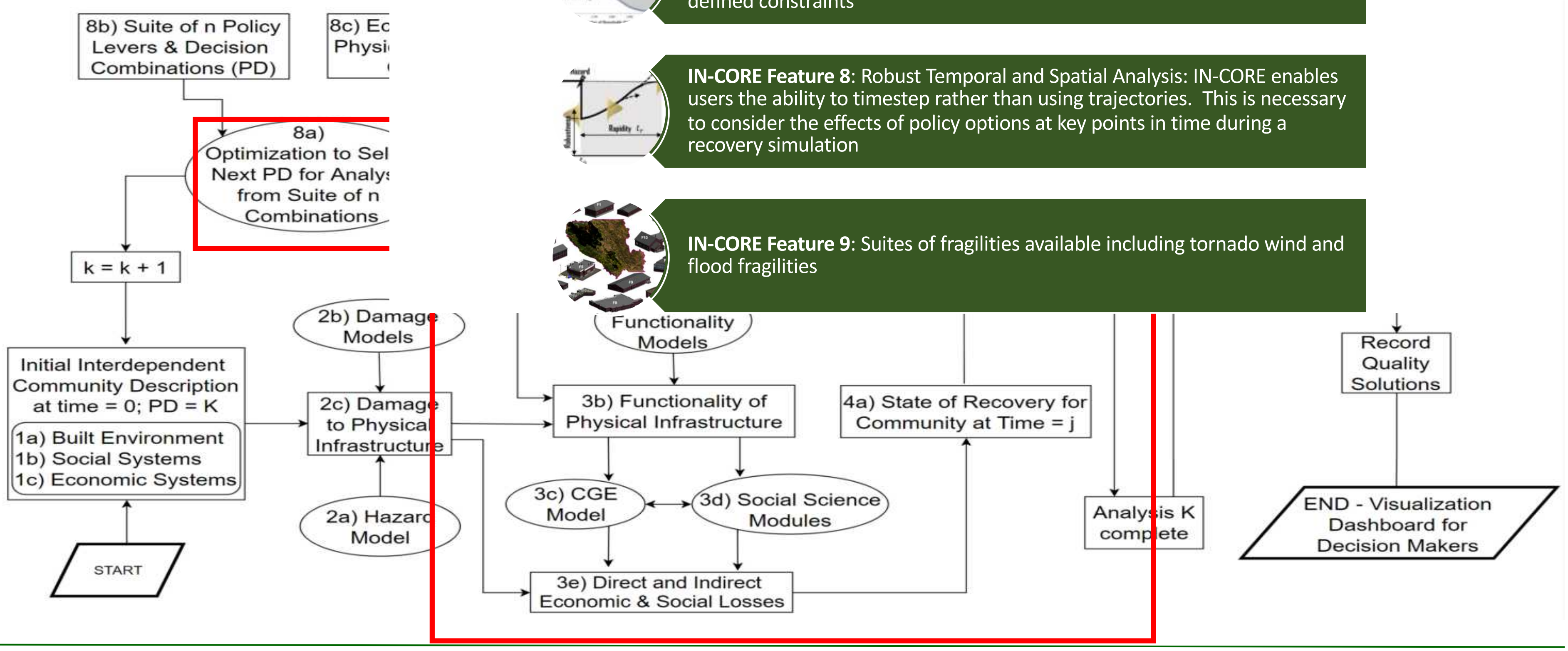
IN-CORE Feature 6: Policy Portfolio: The availability of a policy portfolio, including building codes, land use controls , land acquisition, and user-defined options, that can be tailored to a community’s characteristics and examined as "what if" scenarios

Modeling co

IN-CORE Feature 7: Optimization and Decision Support: Decision support on allocation of limited resources (budget, labor, etc.) towards mitigation and recovery efforts to meet one or more objectives subject to community-defined constraints

IN-CORE Feature 8: Robust Temporal and Spatial Analysis: IN-CORE enables users the ability to timestep rather than using trajectories. This is necessary to consider the effects of policy options at key points in time during a recovery simulation

IN-CORE Feature 9: Suites of fragilities available including tornado wind and flood fragilities



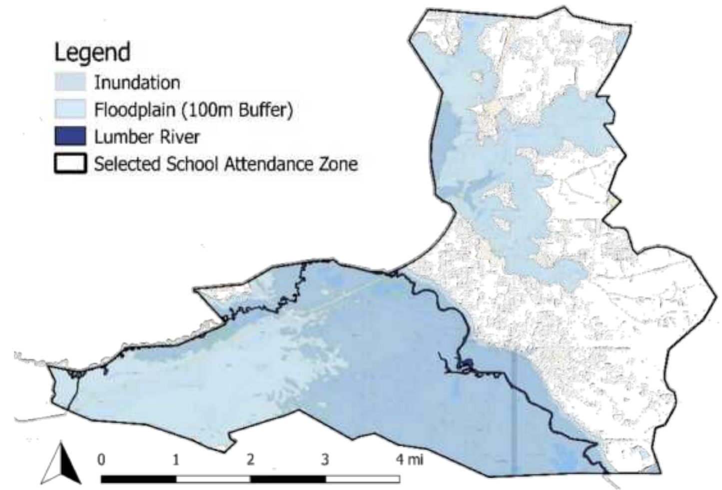
Modeling community resilience: components

- Measurement science is implemented on a platform called Interdependent Networked Community Resilience Modeling Environment (IN-CORE)

- It incorporates a risk-informed approach to decision-making that enables quantitative comparisons of alternative resilience strategies.

- On the platform, users can run scientific analyses that model the impact of natural hazards and study their impact on communities to improve resilience.

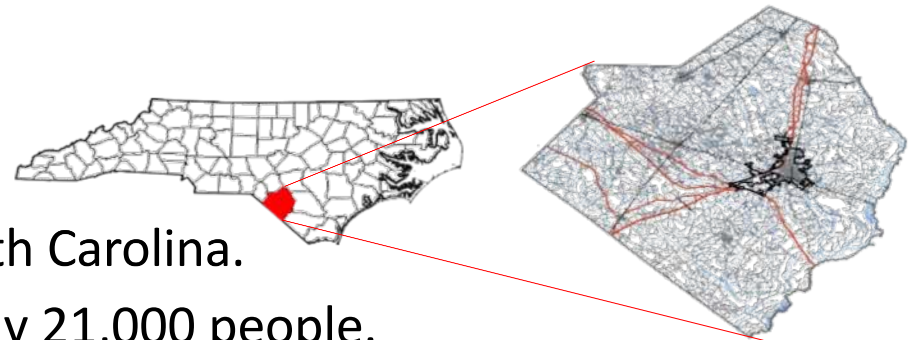
Lumberton, North Carolina



Purpose: Focus on flood scenarios; damage, disruption and recovery data collection for housing, businesses, and schools; community-level interdependencies.

- Validate data collection and sampling processes, data structure
- Inform data-driven recovery models and policy levers
- Validate integrated engineering-social science models
- Establish feedback loop with FEMA and the City

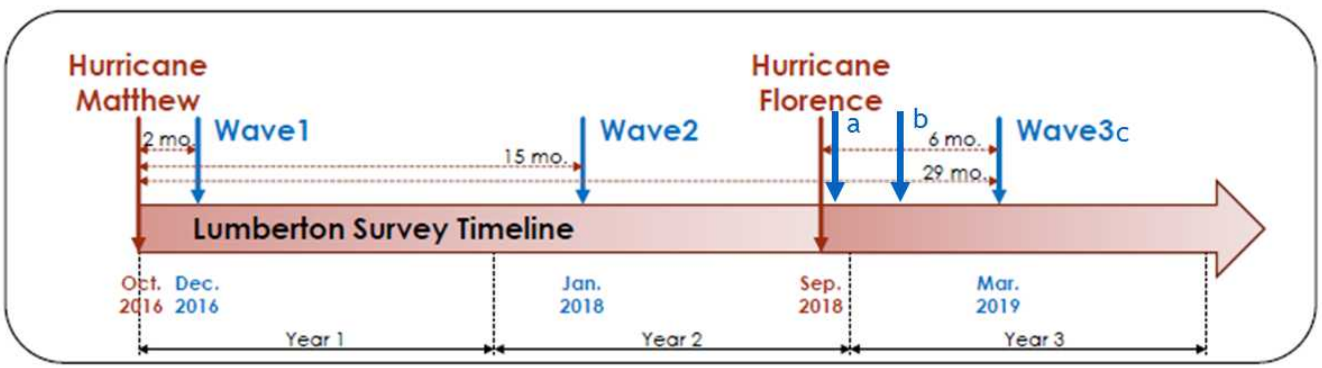
Lumberton



- Inland city in Robeson County, North Carolina.
- Diverse population of approximately 21,000 people.
- Catastrophically flooded in 2016 by Hurricane Matthew and again in 2018 by Hurricane Florence.
- The Center has completed five waves of data collection in Lumberton since October 2016.
- The intersection of physical and social vulnerability has been apparent in the differential impact, disruption, and recovery progress measured across housing, business, and education sectors.

Lumberton Field Study

- Each wave has specific objectives: to measure initial damage and disruption or recovery progress, capturing interdependencies along the way.
- Survey the same businesses and households each time
- Perform interviews with key personnel at the schools, city, and state.



Lumberton Field Study Modeling

Models built from Field Study data

- Empirical building fragility models
- Population dislocation model
- Business interruption model
- Business recovery model (regression)
- Housing recovery model (regression)
- Public housing trajectory model (regression)

Models validated with Field Study data

- Residential flood-based damage states
- Probabilistic building fragility models
- Intrinsic functionality restoration model
- Flood simulation model
- Synthetic population model
- Community sampling methodology
- Housing recovery model (predictive)
- Mitigation and policy levers

Community Model

- Detailed information about the buildings within and around the Lumberton community was collected
- Data was collected through a detailed navigation of these building using Google Street Map View
- Spatial analysis of the collected building data was conducted in a GIS environment

1-Building material
2-Number of stories
3-Building occupancy
4-Building use
5-Building archetype
6-Foundation type
7-First-floor elevation
8-Ground elevation
9-Building area
10-Attached garages
11-Maintenance status

Omar M. Nofal, and John W van de Lindt. 2020. "Probabilistic Flood Loss Assessment at the Community Scale: A Case Study of 2016 Flooding in Lumberton, NC." Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering, 6(2):1-15 https://doi.org/10.1061/AJRUA6.0001060

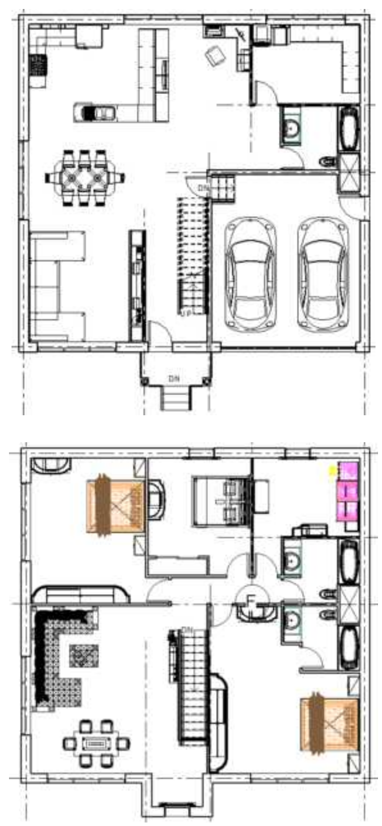
Vulnerability Model

- Portfolio of 15 building archetypes was developed to model the different building occupancies
- These archetypes are minimized such that they cou represent a community with acceptable accuracy
- These archetypes were assigned to each building within Lumberton

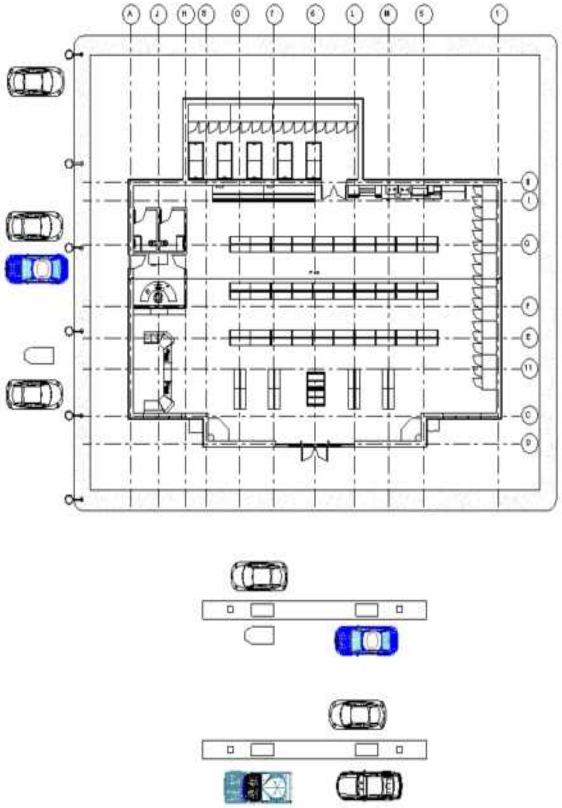
Omar M. Nofal, and John W van de Lindt. 2020. "Minimal Building Flood Fragility and Loss Function Portfolio for Resilience Analysis at the Community-Level." Water, 12(8), 2277 https://doi.org/10.3390/w12082277

Vulnerability Model

- A single variable and multi-variate flood fragility and loss analysis methods are developed
- This was done be breaking down the building into components
- The resulting component failure matrix is used to develop a fragility and loss function for the whole building



Vulnerability Model



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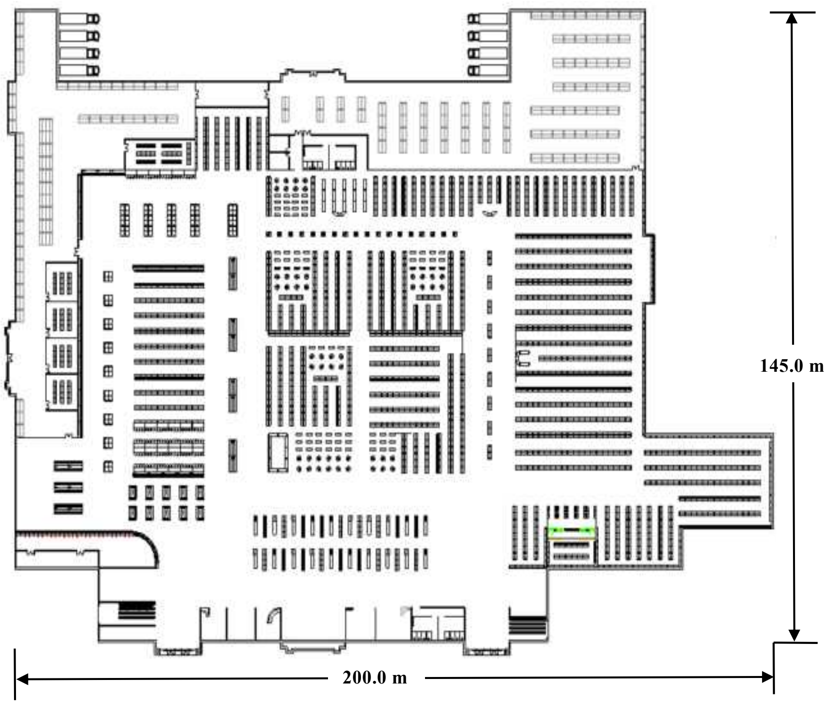

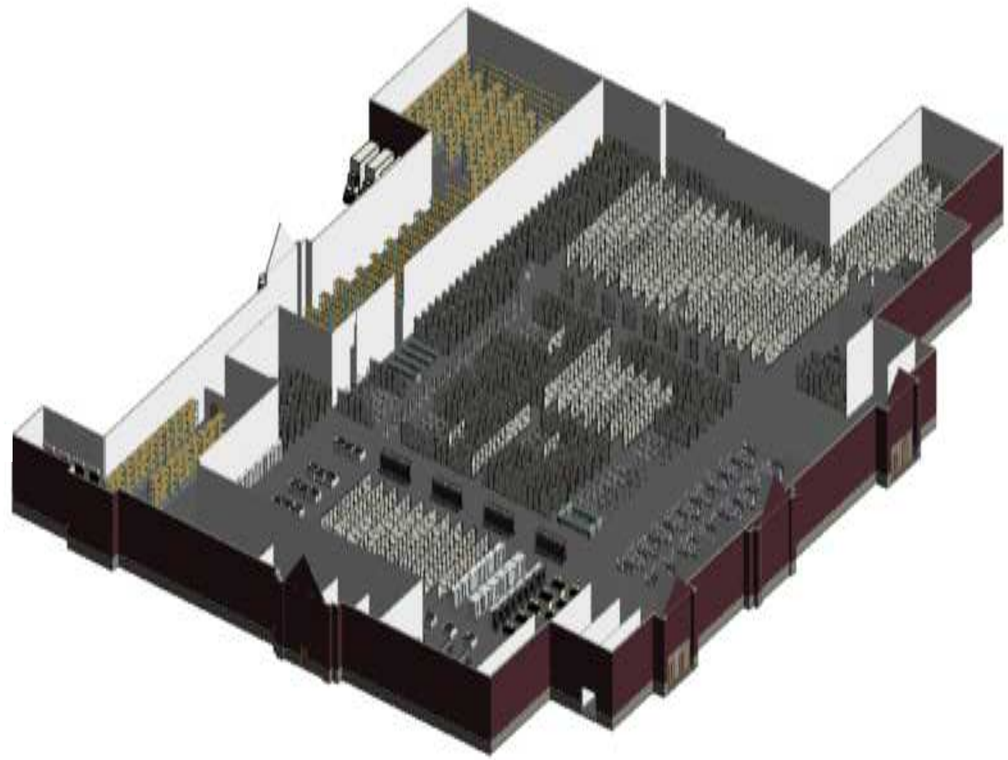

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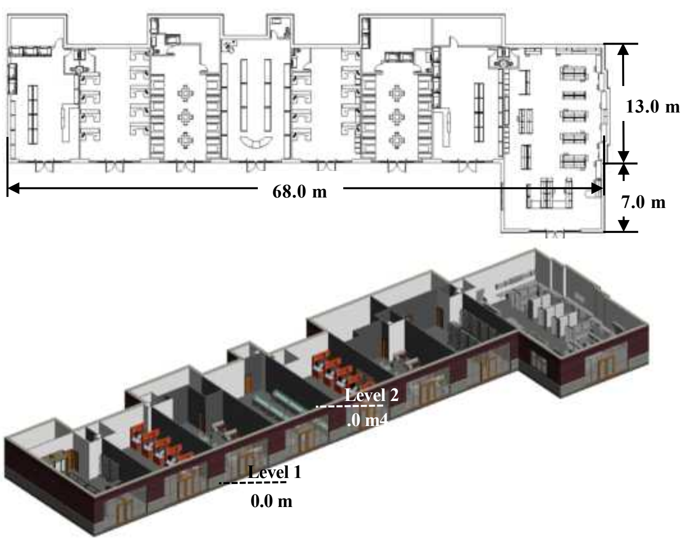
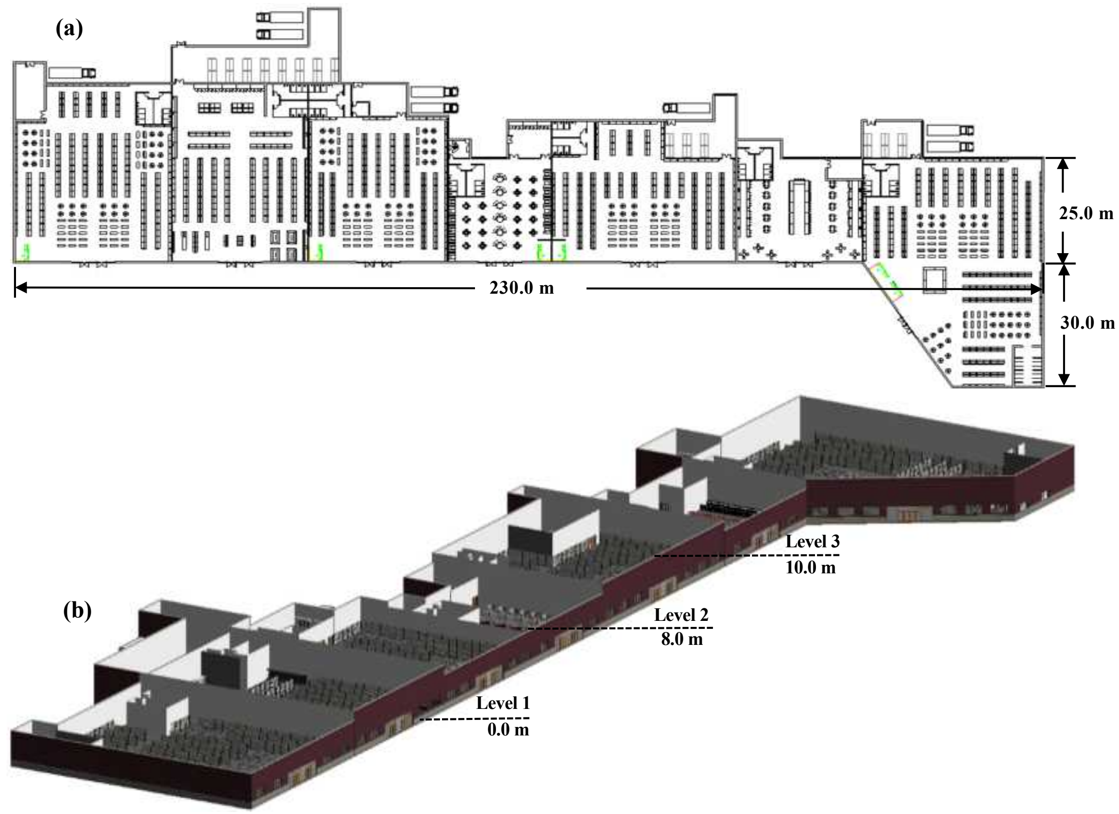
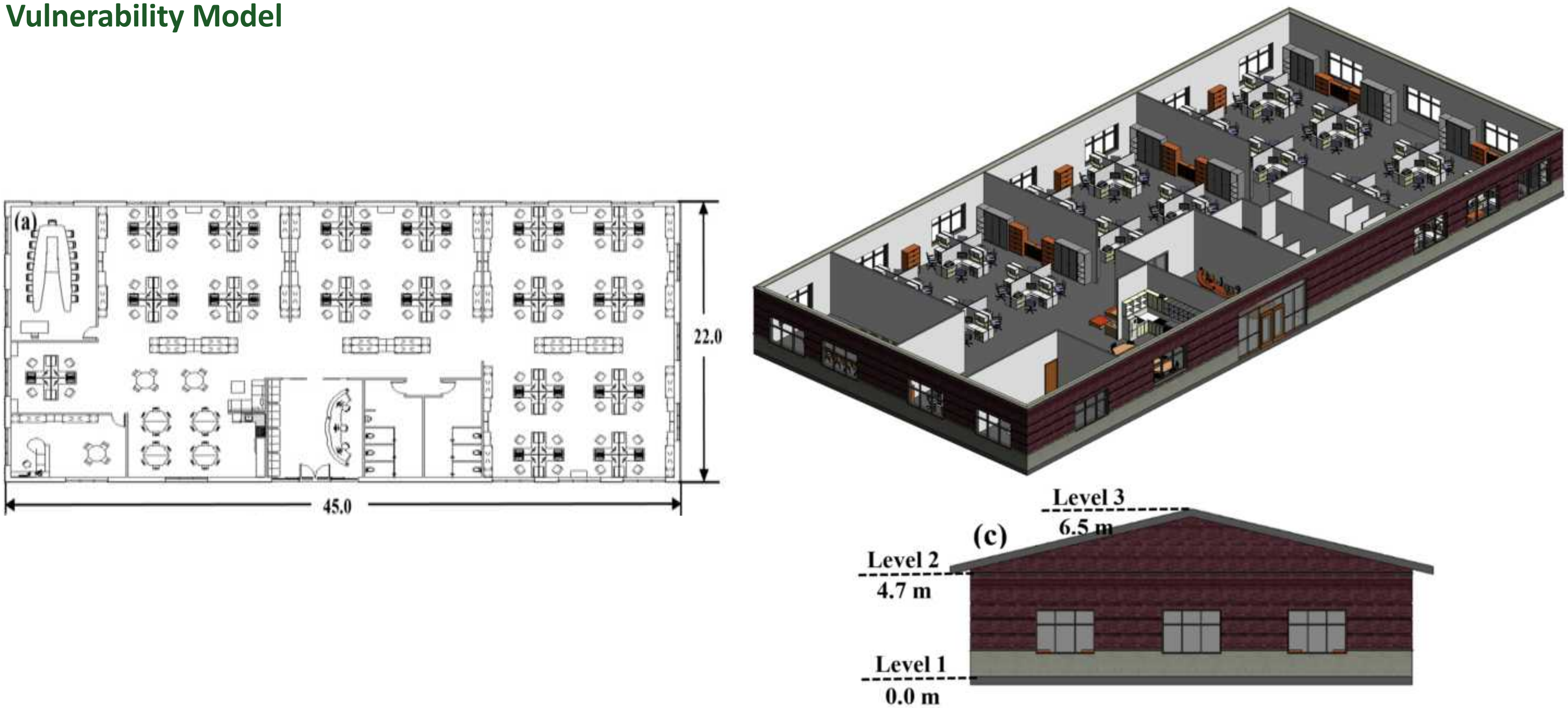
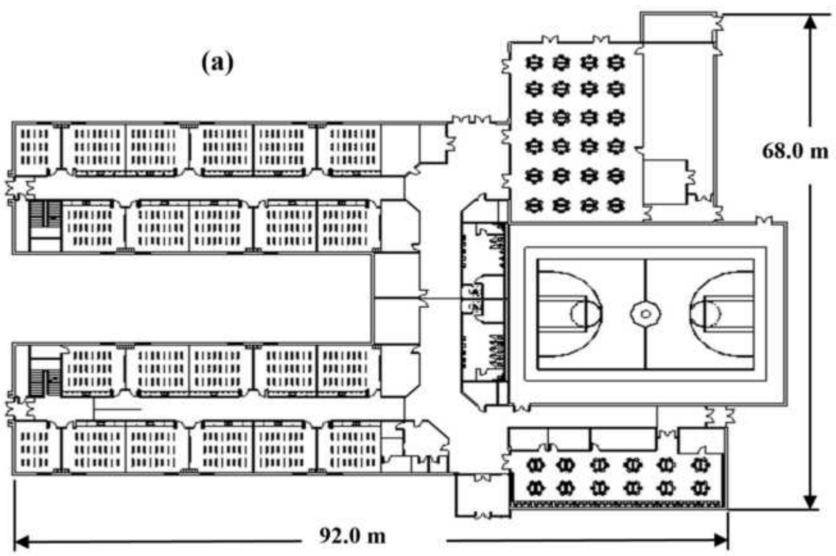


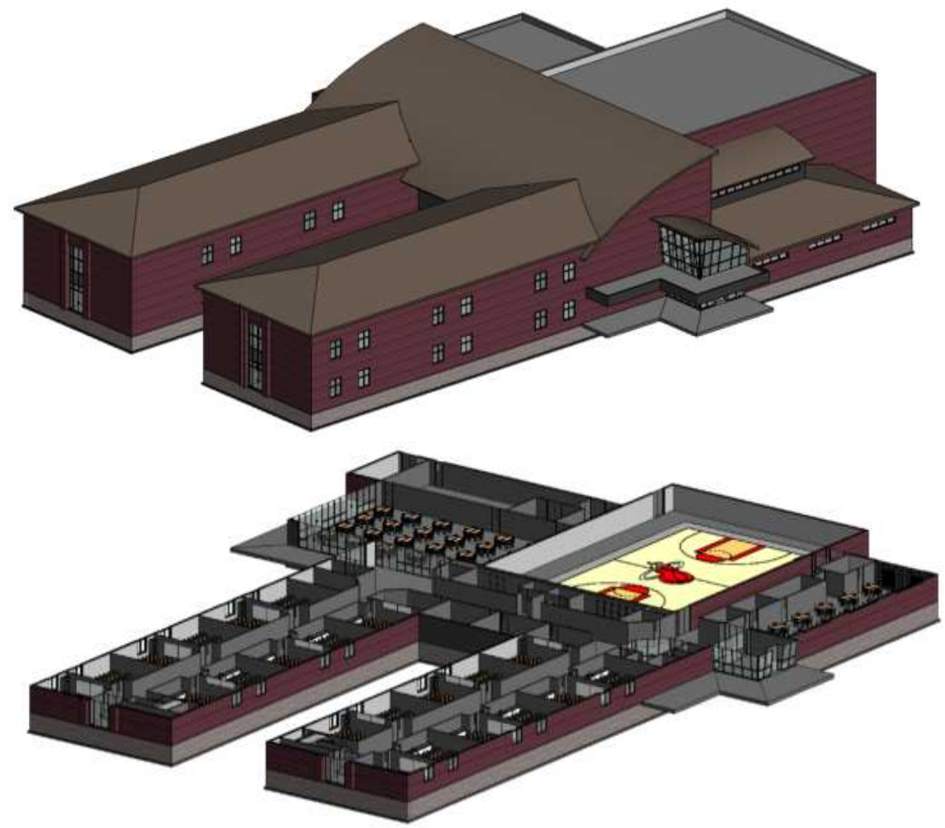


Vulnerability Model



Vulnerability Model





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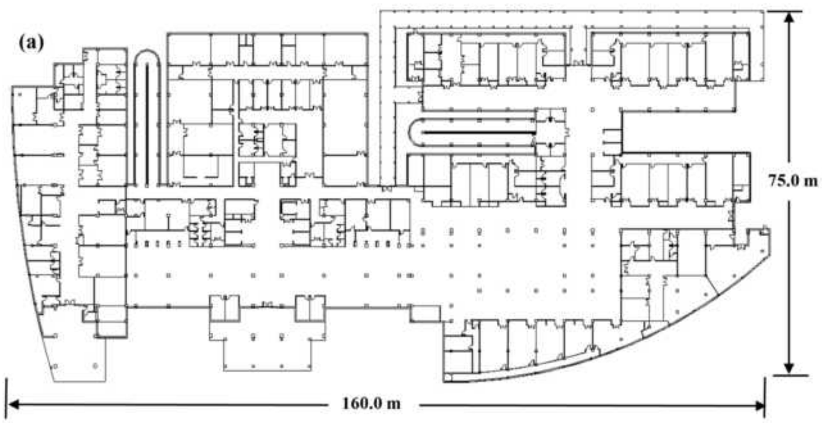

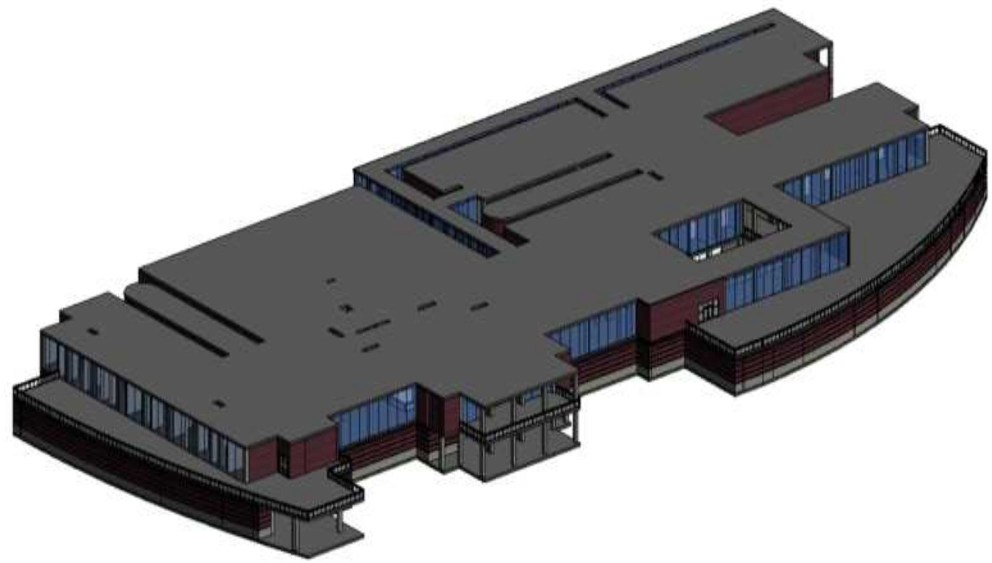

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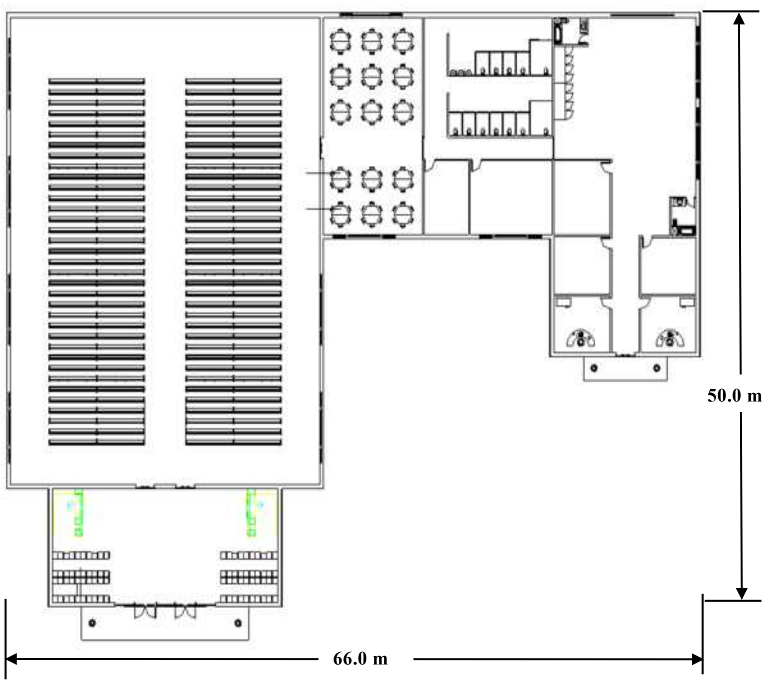
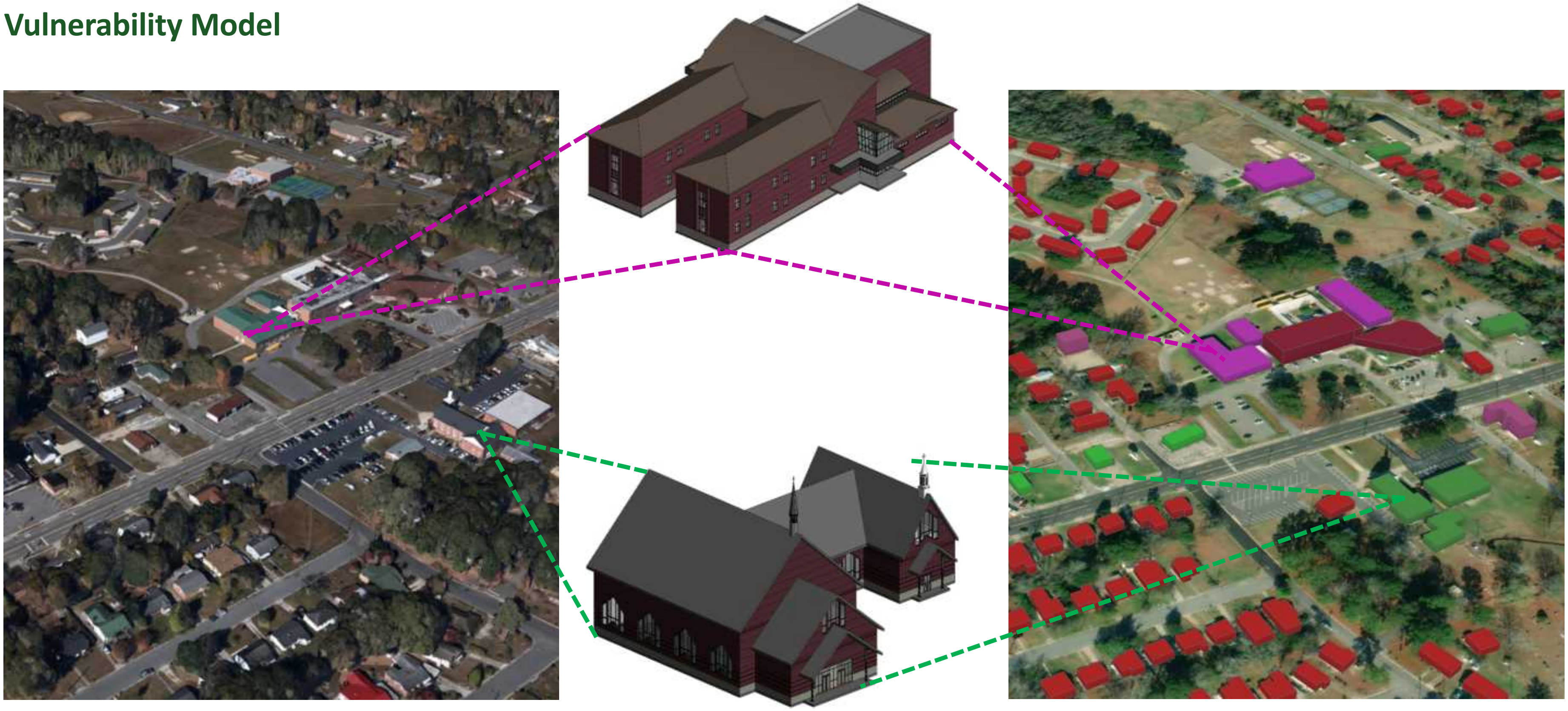


Vulnerability Model



Community Modeling: Mapping of the 15 building archetypes

Omar M. Nofal, and John W van de Lindt. 2020. “High-Resolution Approach to Quantify the Impact of Building-Level Flood Risk Mitigation and Adaptation Measures on Flood Losses at the Community-Level.” International Journal of Disaster Risk Reduction, 51, 101903

Exposure Modeling

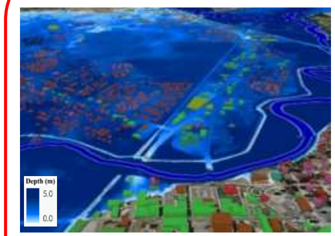
- The hazard map was then overlaid with the community model in a GIS environment to identify the flood hazard intensity at each building.
- Then, a risk analysis was conducted using the developed numerically flood fragility functions.

Omar M. Nofal, and John W van de Lindt. 2020. "High-Resolution Approach to Quantify the Impact of Building-Level Flood Risk Mitigation and Adaptation Measures on Flood Losses at the Community-Level." International Journal of Disaster Risk Reduction, 51, 101903

Flood Damage/loss Analysis

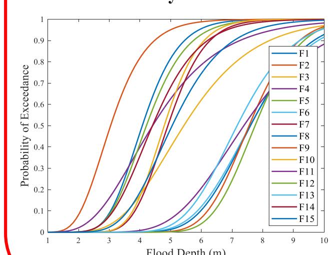
Community-Level Analysis

Hazard Model

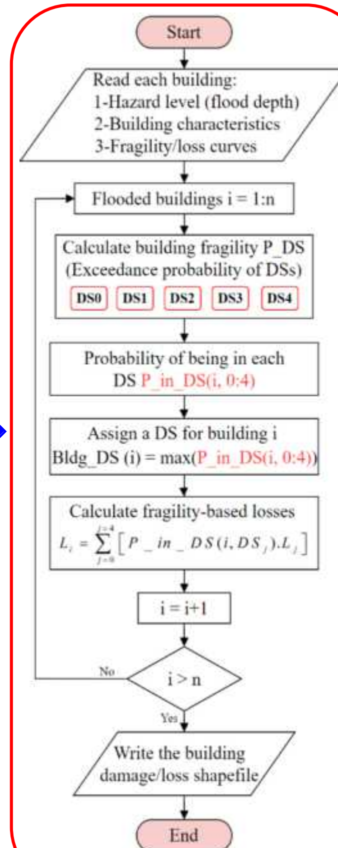


Exposure Model

Vulnerability Model



Building-Level Analysis



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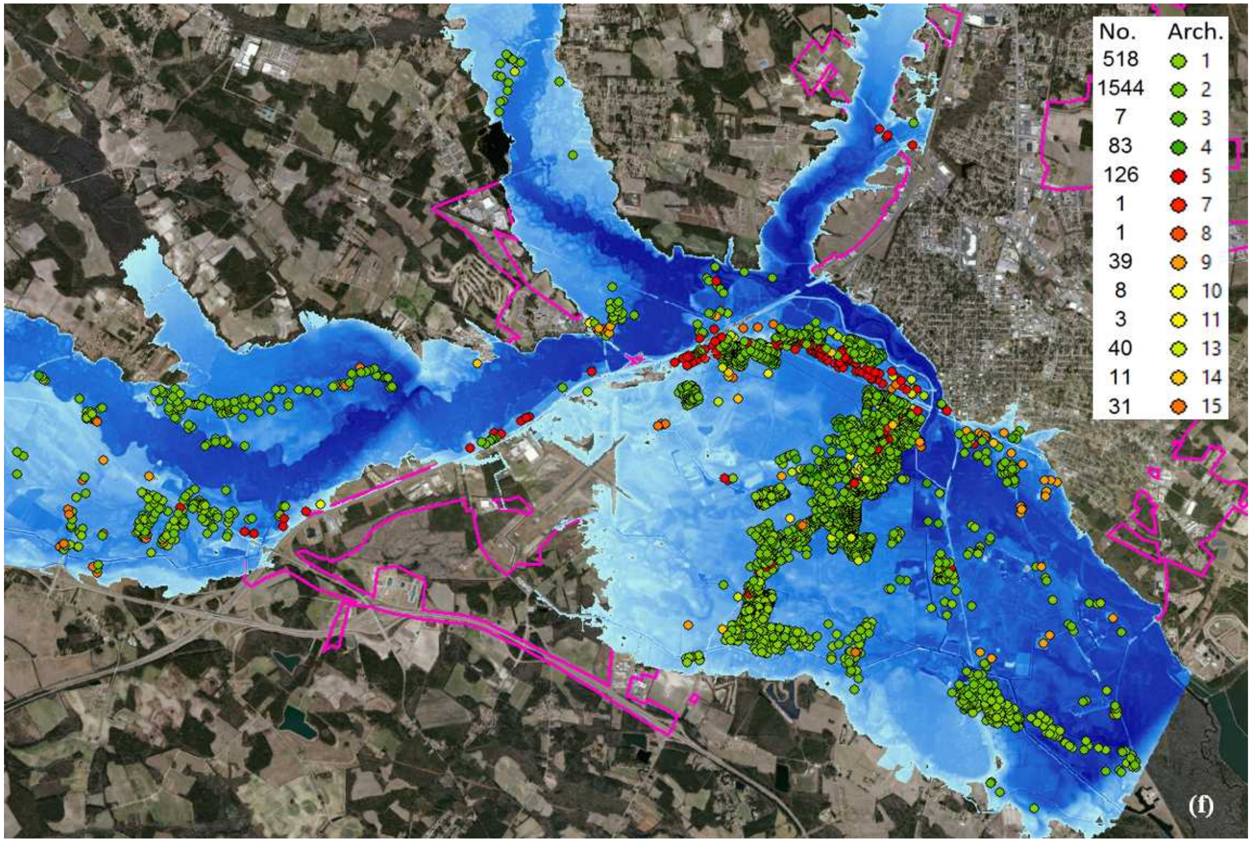
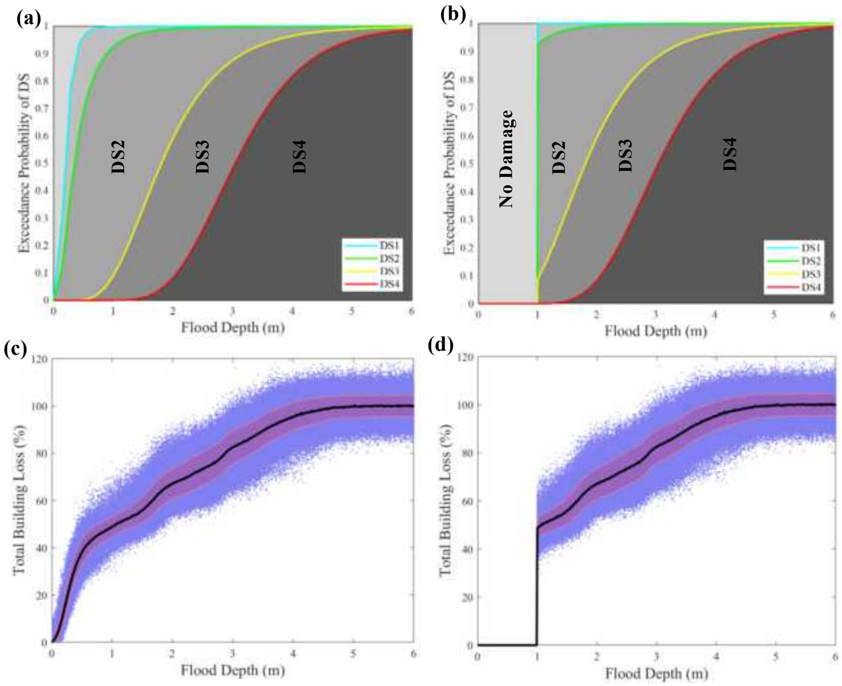
Vulnerability Model

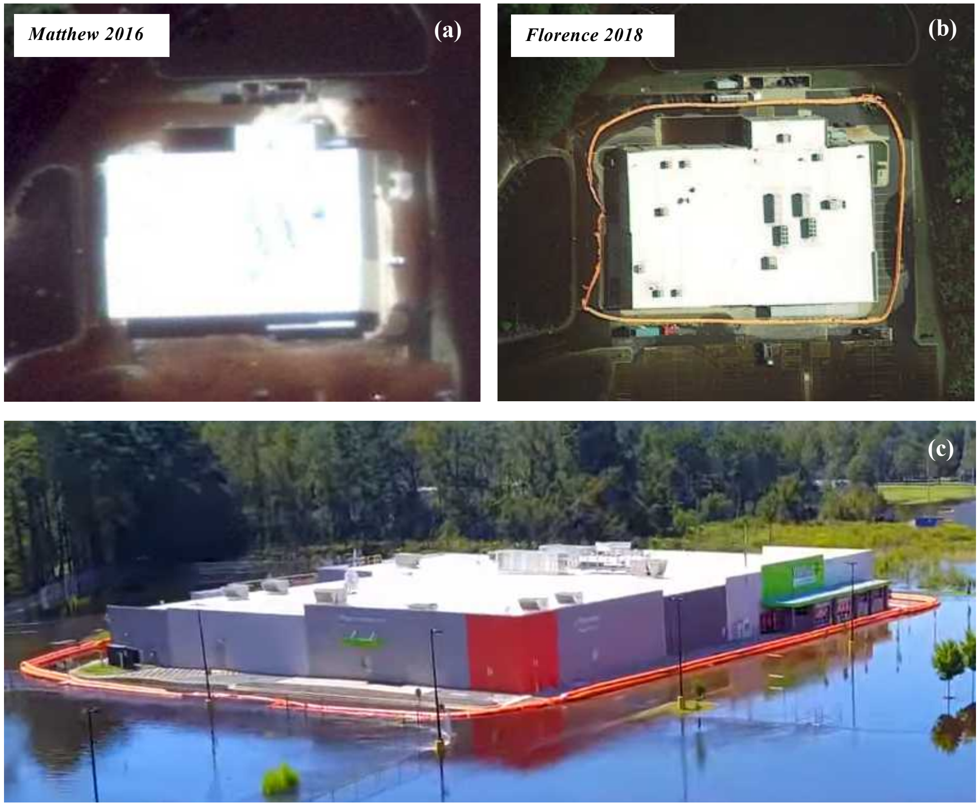
Archet ype	Building description
F1	One-story residential building on a crawlspace foundation
F2	One-story residential building on a slab-on-grade foundation
F3	Two-story residential building on a crawlspace foundation
F4	Two-story residential building on a slab-on-grade foundation
F5	Small grocery store/Gas station with a convenience store
F6	Super retail building (strip mall)
F7	Small multi-business building
F8	Super shopping center
F9	Industrial building
F10	One-story School
F11	Two-story School
F12	Hospital
F13	Community center (church)
F14	Office building
F15	Warehouse (small/large box)



Mitigation Analysis

Temporary barrier system



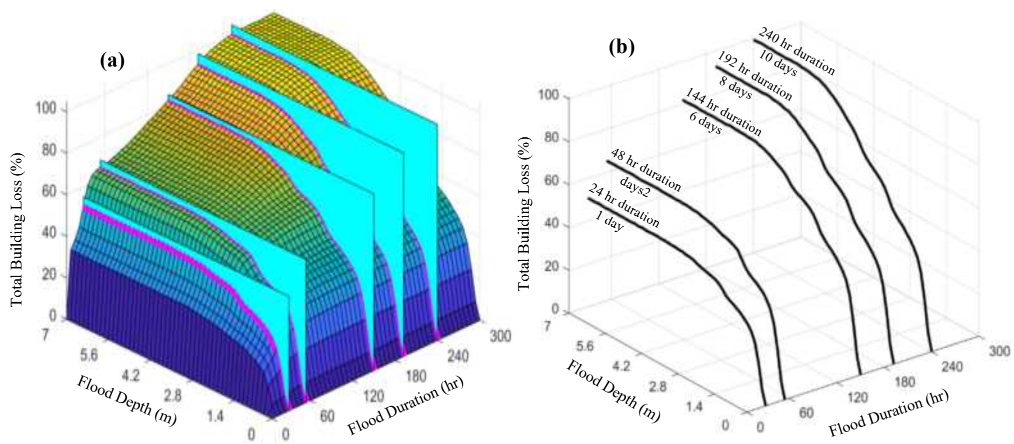


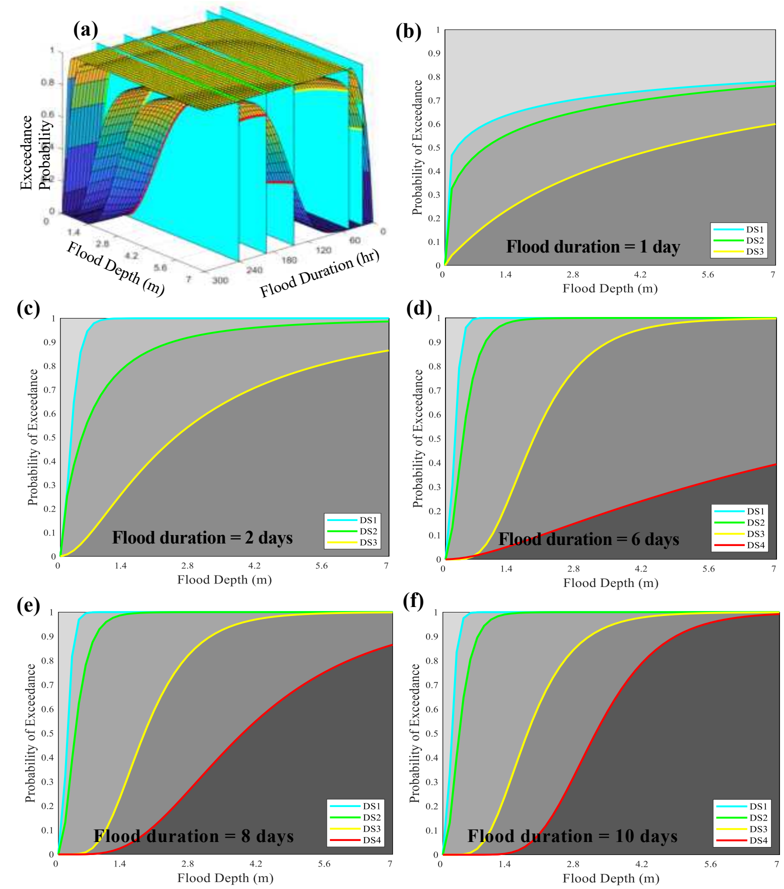
Omar M. Nofal, and John W van de Lindt. 2020. "High-Resolution Approach to Quantify the Impact of Building-Level Flood Risk Mitigation and Adaptation Measures on Flood Losses at the Community-Level." International Journal of Disaster Risk Reduction. https://doi.org/10.1016/j.ijdrr.2020.101903

Mitigation Analysis

Water pumps (The impact of flood duration)

- Flood fragility and loss curves were derived at different flood duration to account for different water pumping scenarios.





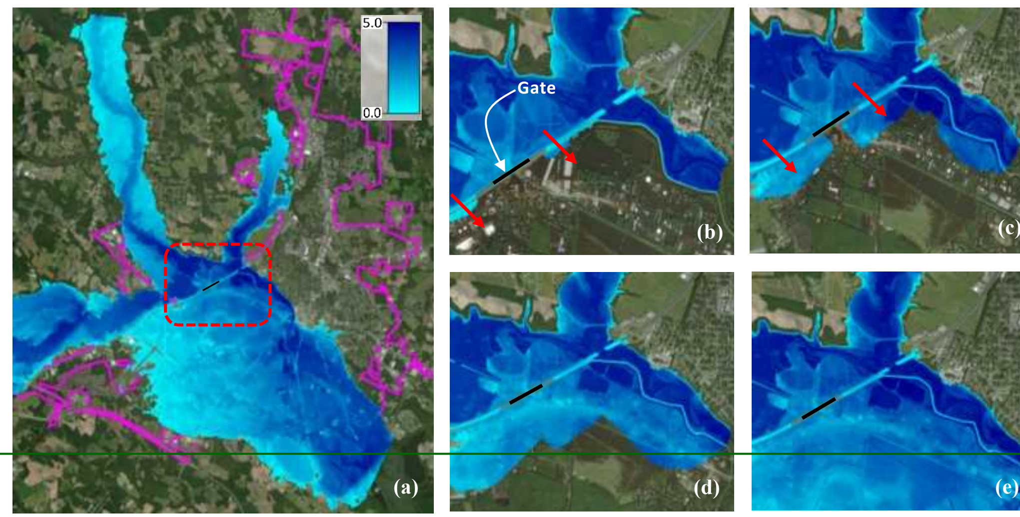
Omar M. Nofal, John W van de Lindt, and Trung Q. Do. 2020. “Multi-Variate and Single-Variable Flood Fragility and Loss Approaches for Buildings.” Journal of Reliability Engineering and System Safety, 12(8), 2277 https://doi.org/10.1016/j.ress.2020.106971

Mitigation Analysis

Community-level flood mitigation measures

1- Flood gates or temporary berms

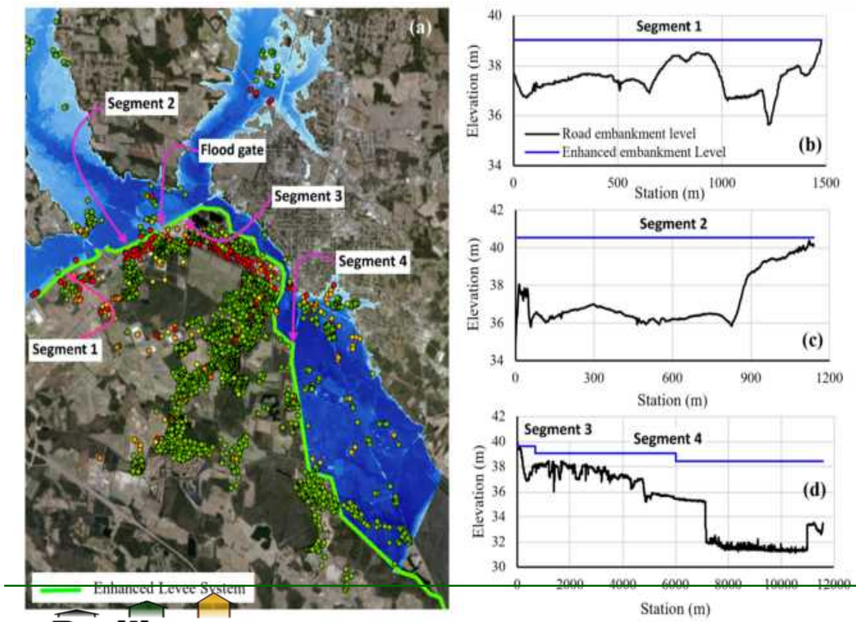
- The impact of constructing flood gate or temporary berm at critical locations was investigated for the example community of Lumberton.

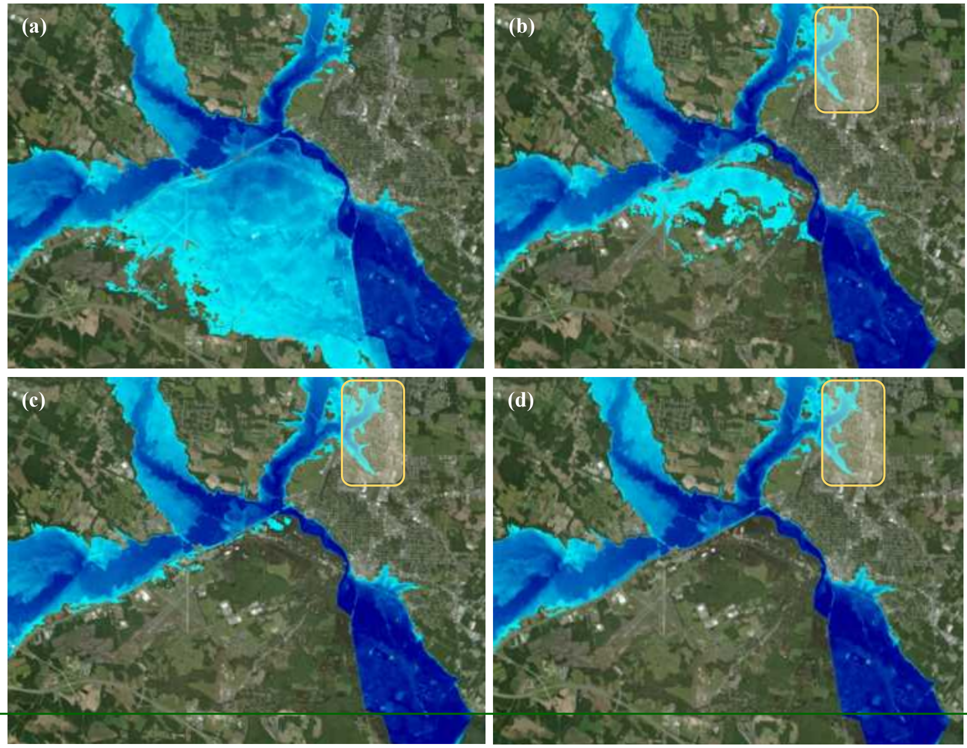


Mitigation Analysis

Community-level flood mitigation measures

2- Enhancing the current levee system



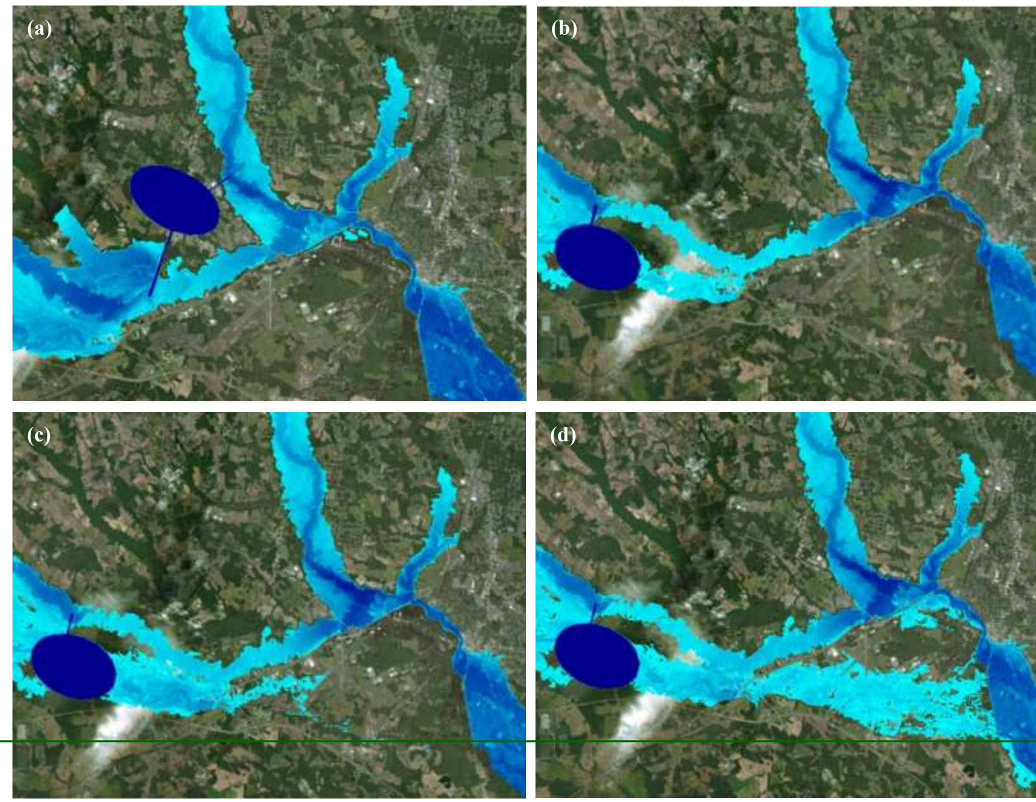


Mitigation Analysis

Community-level flood mitigation measures

2- Using retention/detention system

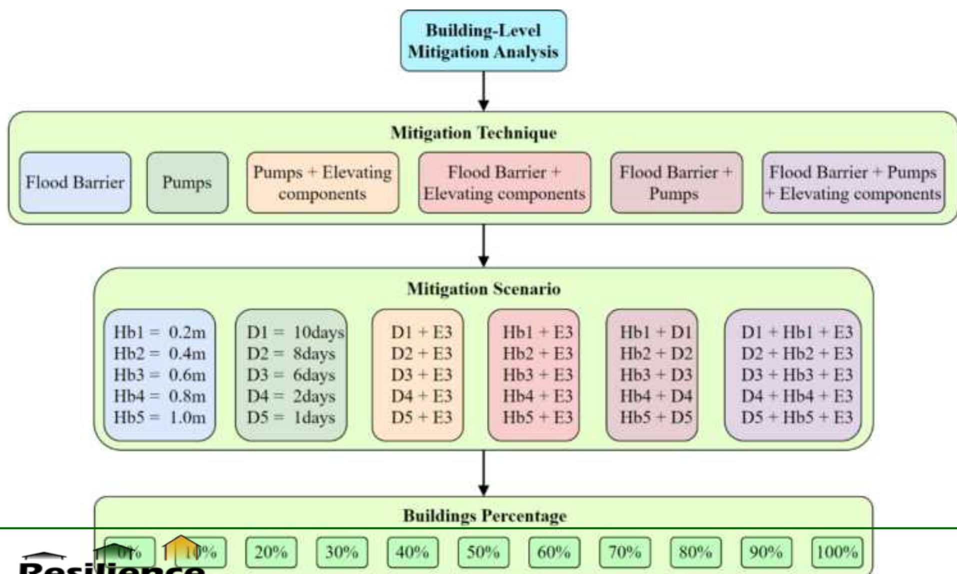
- The impact of using different retention systems in terms of different locations, and sizes was investigated.
- Additionally, a combination of using retention system along with other mitigation measures such as flood gate and enhancing the levee system was also investigated.
- Other exposure and vulnerability mitigation measures were also investigated.

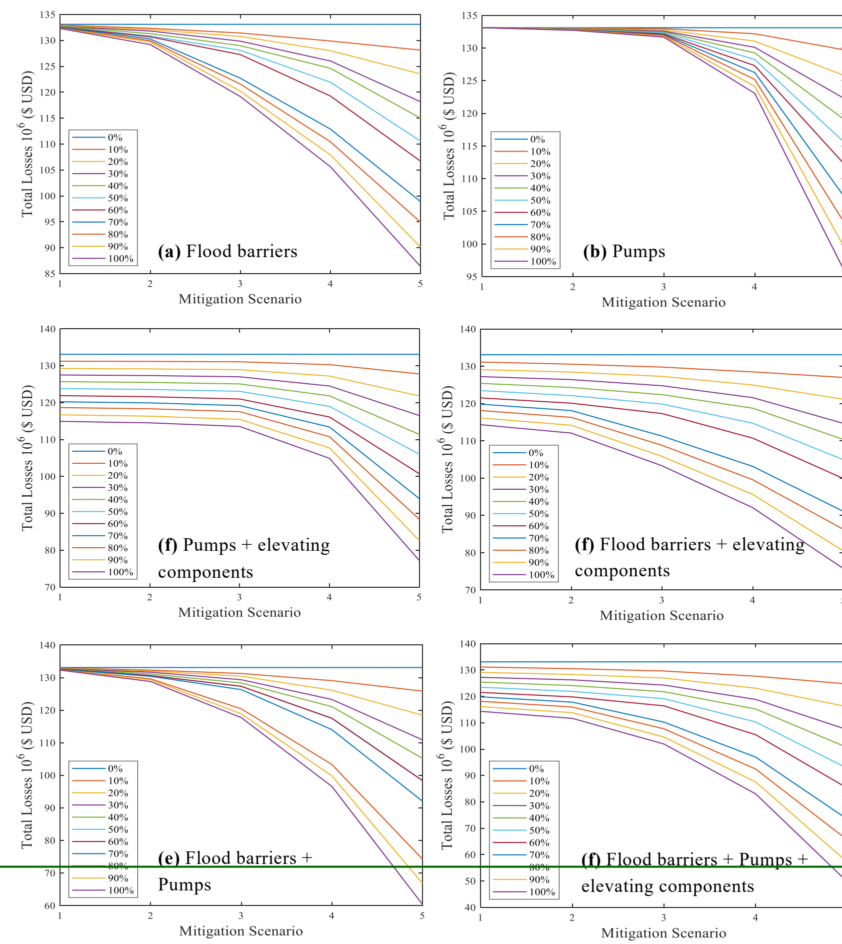


Mitigation and Adaptation Analysis

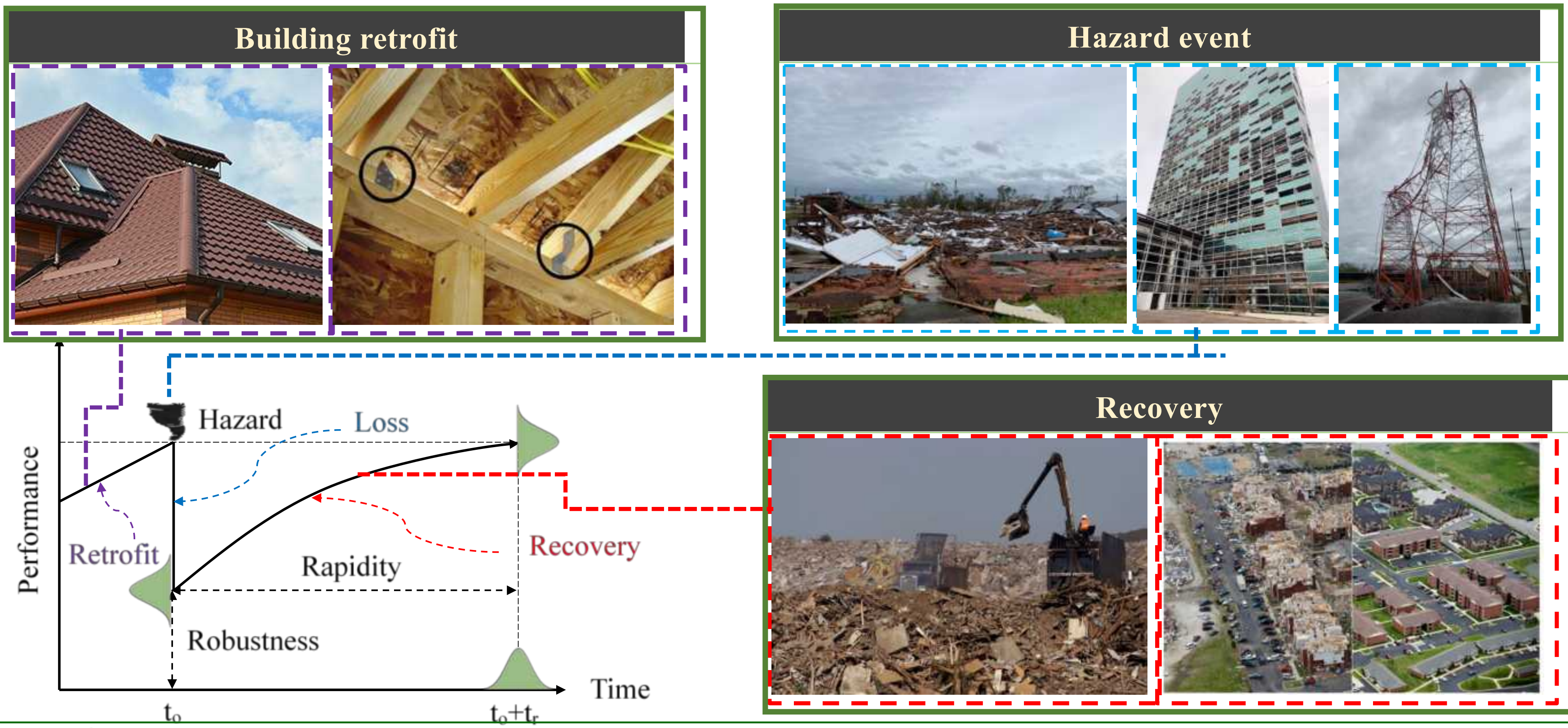
Building-level flood mitigation measures

- A combination of 330 building-level mitigation scenarios were applied for a select random number of buildings.





The Joplin Hindcast & Testbed as an Example of modeling community resilience



Wang. W(L)., van de Lindt, J.W., Rosenheim, N., Cutler, H., Hartman, B., Lee, J-S, and Calderon, D. (2020). "Effect of Residential Building Wind-Retrofit Strategies on Social and Economic Community Resilience Metrics". *Journal of Infrastructure Systems*, In Review

Background: City of Joplin, Missouri

Hazard (May 22, 2011 Tornado)

- ***EF5*** multiple-vortex
- Fatalities:***161***, Injured: ***1150***
- Costliest single tornado in US history
- US***$2.8*** billion

Built Environment

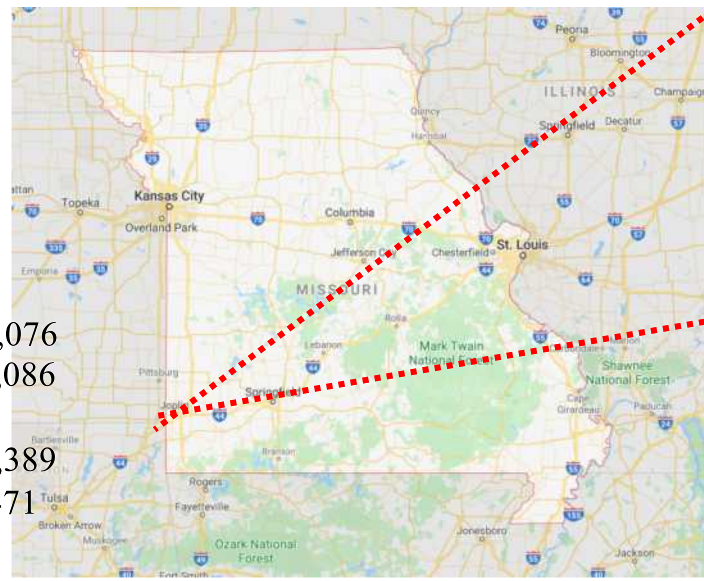
- Buildings
- Electric Power Network

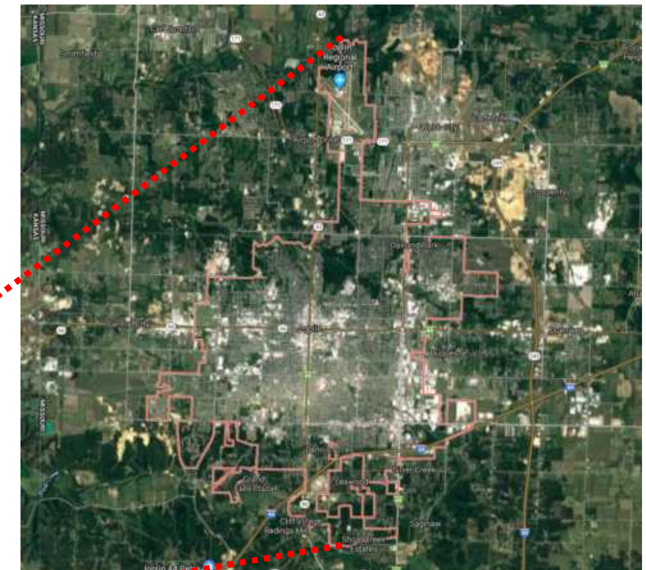
Socio-economics

Population: ***50,150***

- ➢ Owner-occupied: 27,076
- ➢ Renter-occupied: 21,086

- Housing units: ***23,322***
  - ➢ Owner-occupied: 11,389
  - ➢ Renter-occupied: 9,471
  - ➢ Vacant 2,462





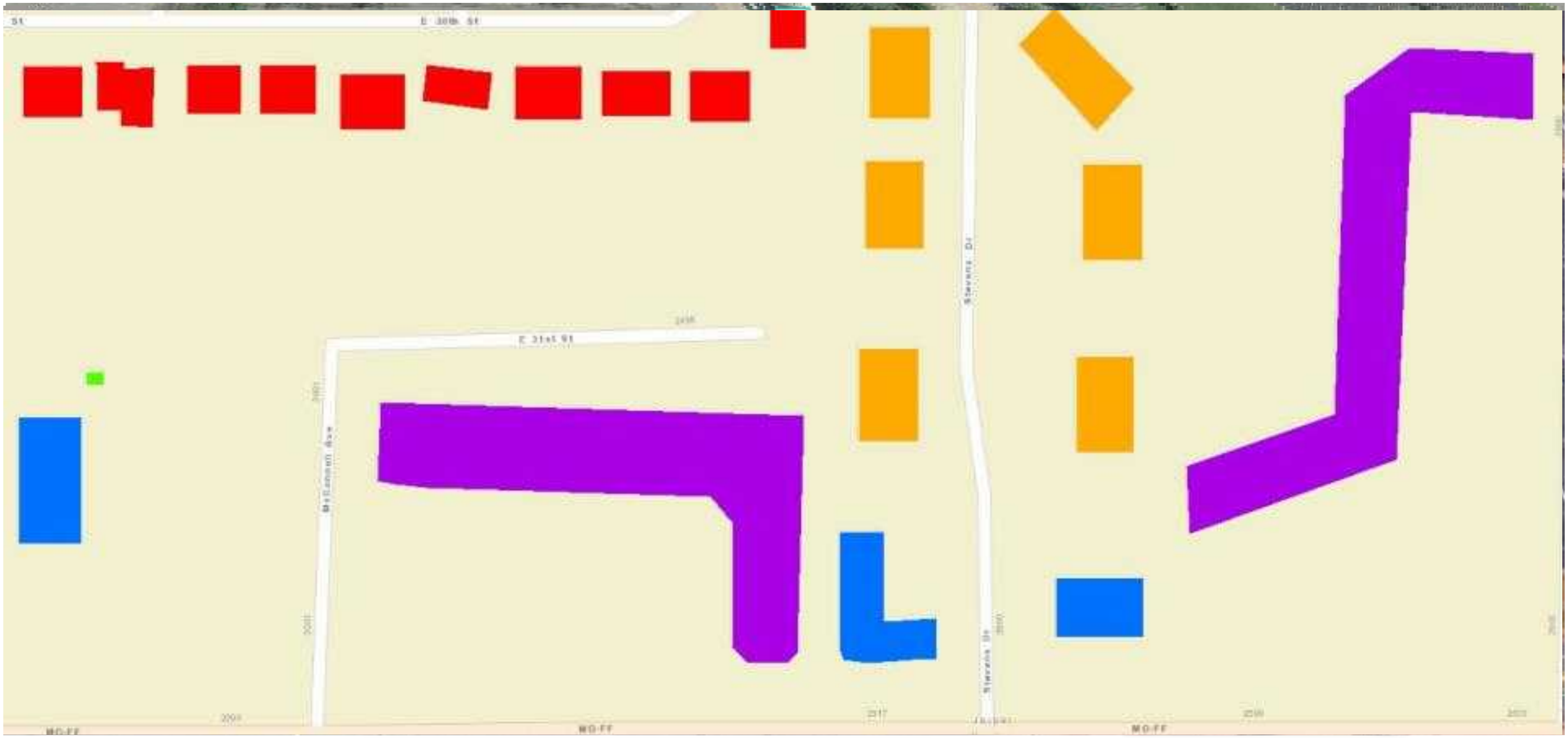
Joplin

Missouri

ARCHETYPE BUILDINGS

Building type	Building description
T1	Res. wood bldg. - small rectangular plan - gable roof - 1 story
T2	Res. wood bldg. - small square plan - gable roof - 2 stories
T3	Res. wood bldg. - medium rectangular plan - gable roof - 1 story
T4	Res. wood bldg. - medium rectangular plan - hip roof - 2 stories
T5	Res. wood bldg. - large rectangular plan - gable roof - 2 stories
T6	Business and retail building (strip mall)
T7	Light industrial building
T8	Heavy industrial building
T9	Elementary / middle school (unreinforced masonry)
T10	High school (reinforced masonry)
T11	Fire / police station
T12	Hospital
T13	Community center / church
T14	Government building
T15	Large big-box
T16	Small big-box
T17	Mobile home
T18	Shopping center
T19	Office building

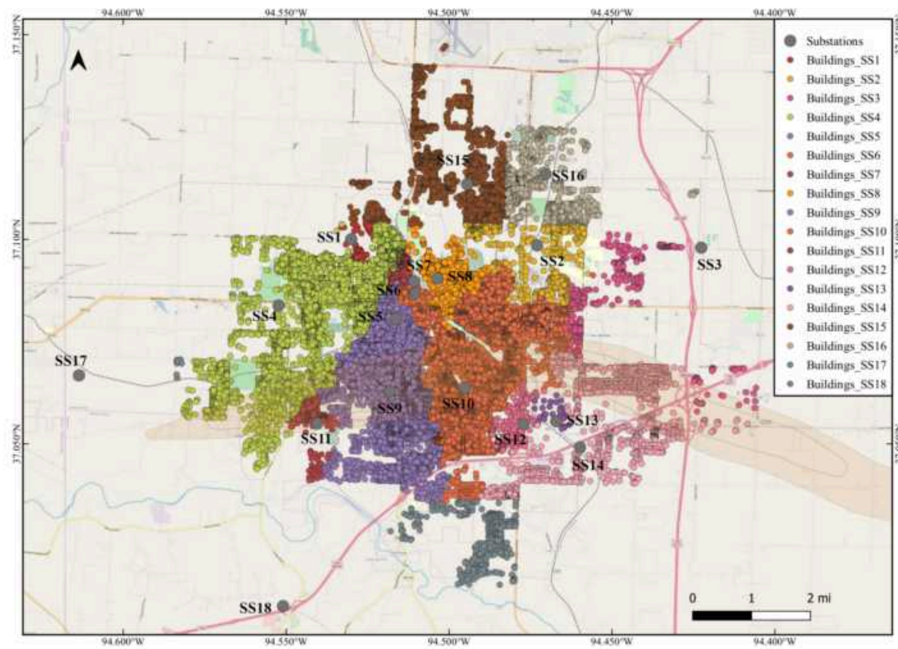
Masoomi, H., Ameri, M.R., and van de Lindt, J.W. (2017). "*Wind performance enhancement strategies for wood-frame buildings*." Journal of Performance of Constructed Facilities.


E 30th St
E 31st St
Stevens Dr

Functionality due to Physical Infrastructure Damage

Probabilistic; Uncertainty propagated fully through the analyses

Building failure probability from MCS



Buildings situated in the substation service areas

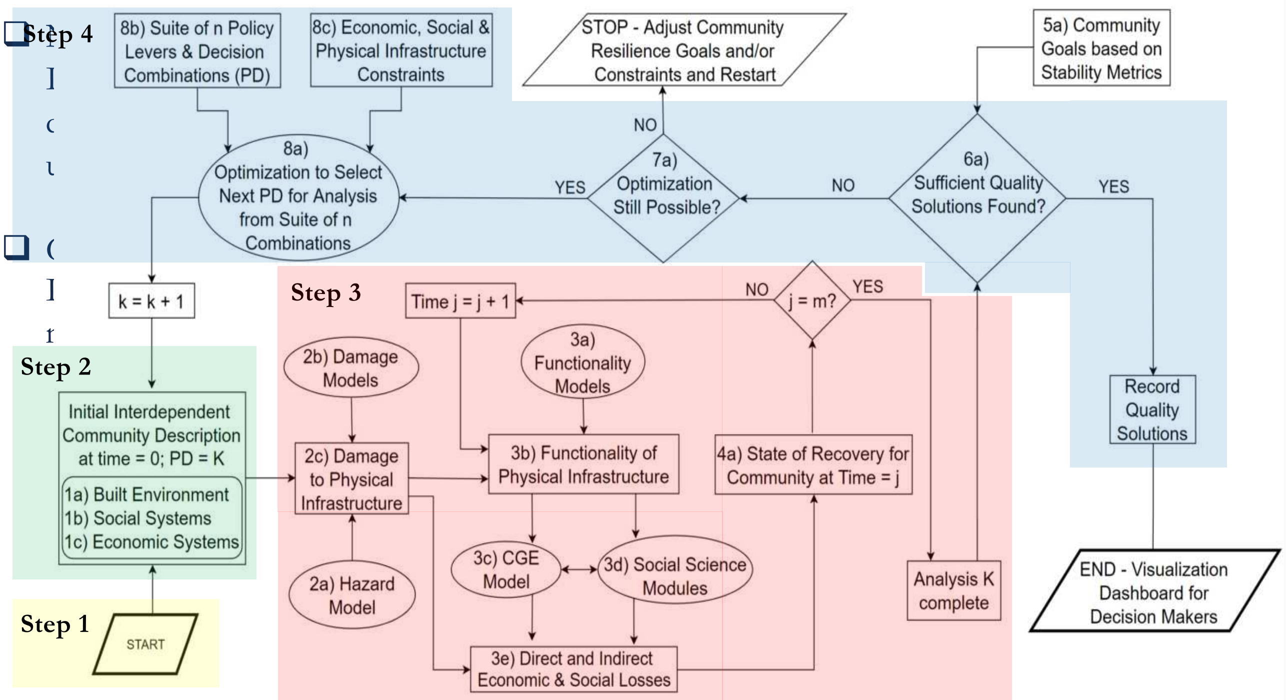
Wang. W(L)., van de Lindt, J.W., Rosenheim, N., Cutler, H., Hartman, B., Lee, J-S, and Calderon, D. (2020). “Effect of Residential Building Wind-Retrofit Strategies on Social and Economic Community Resilience Metrics”. *Journal of Infrastructure Systems.*

Architecture

Research to practice: communities & stakeholder engagement…

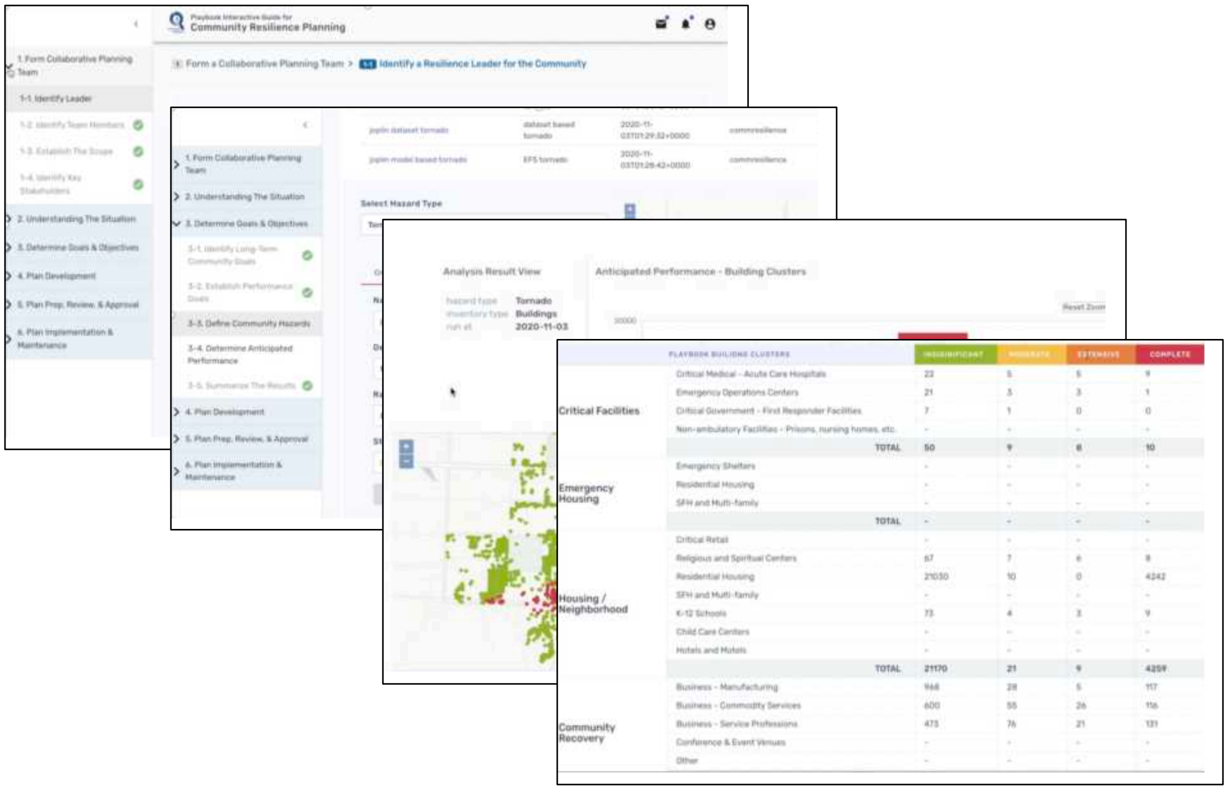
- The NIST Community Resilience Planning Guide
- NIST CR Playbook
- IN-CORE powers the analysis behind the playbook steps
- Community users can develop resilience plans & try alternative mitigation strategies or policies

Integrating the NIST CRPG Playbook with IN-CORE



Steps 5 and 6 will be added as part of IN-CORE web interface

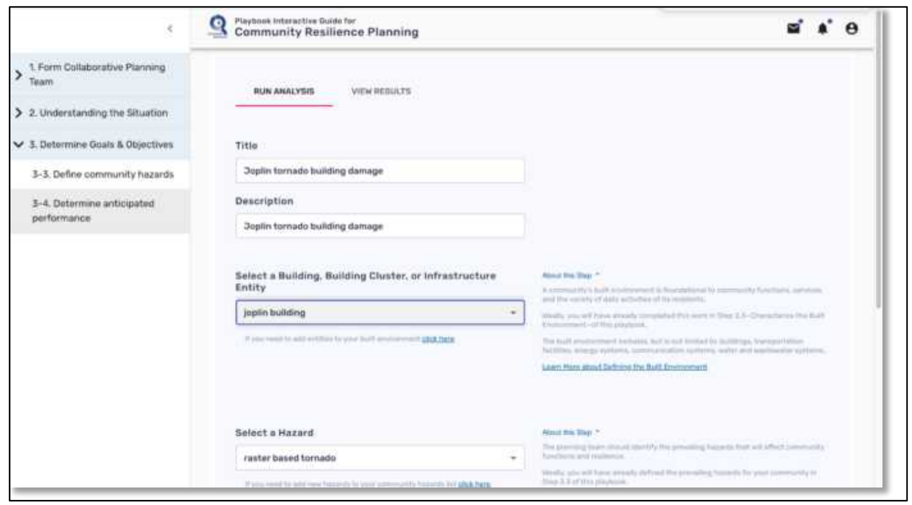
Integrating the NIST CRPG Playbook with IN-CORE



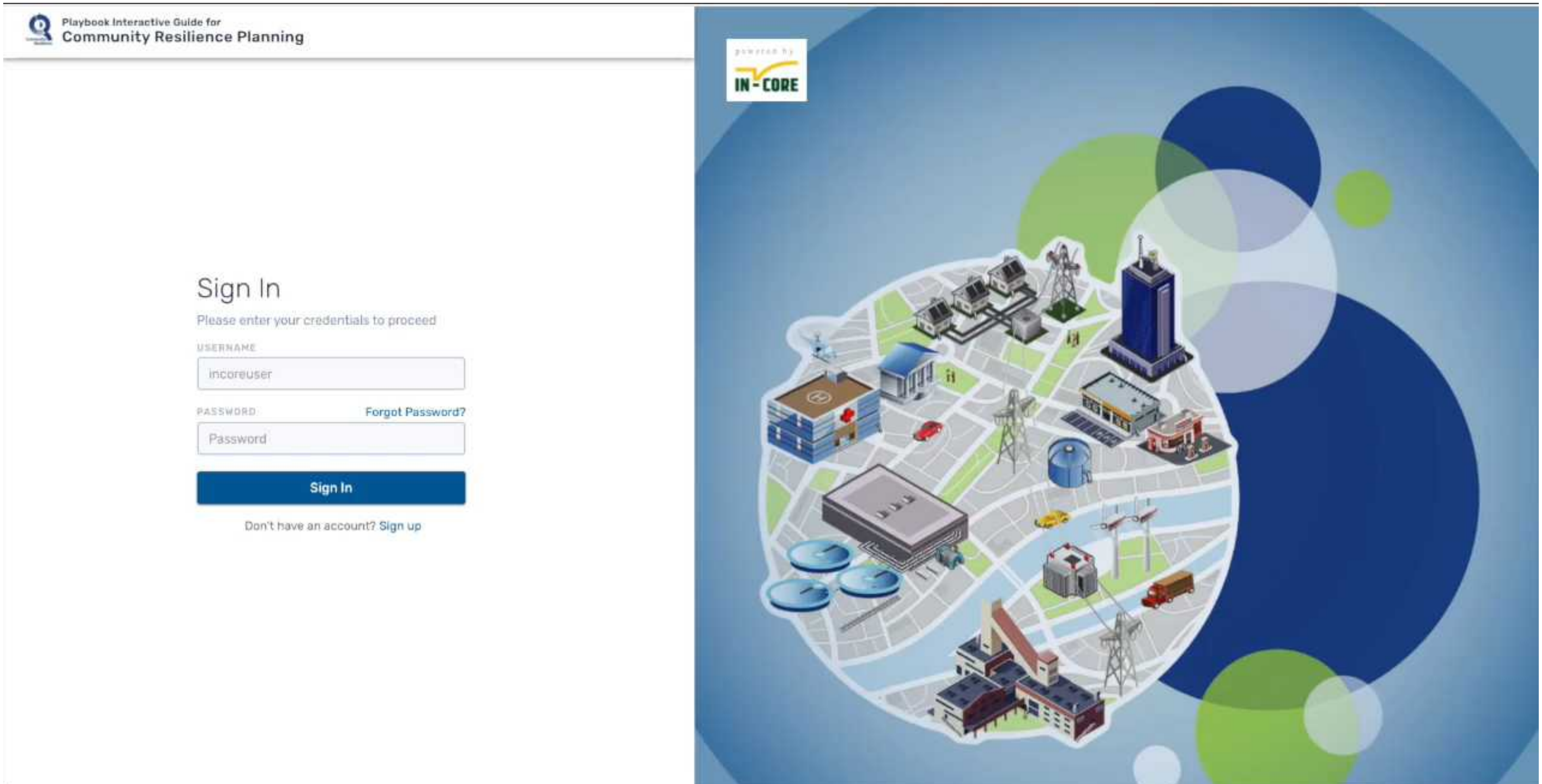
Prototype: Playbook Interactive Guide for Community Resilience Planning

- Purposes of the development efforts
  - Starting web application version of NIST CR Playbook
  - Integration of NIST CR Playbook and IN-CORE
  - IN-CORE use by communities via web application
- Prototype Developments
  - Web user interface design of Playbook Interactive Guide for Community Resilience Planning
  - Integration of IN-CORE with the web application
- Prototype is functioning but not fully implemented

Prototype: Playbook Interactive Guide for Community Resilience Planning



Resilience


Playbook Interactive Guide for
Community Resilience Planning
Sign In
Please enter your credentials to proceed
USERNAME
incoreuser
PASSWORD
Forgot Password?
Password
Sign In
Don't have an account? Sign up
powered by
IN-CORE

Next Steps for the community App

- Continue to build out
  - housing unit allocation analysis
  - population dislocation analysis
- Add User interface and interaction for
  - Step 3-1: Identify long-term community goal
  - Step 3-2: Determine desired performance goals for buildings and infrastructure systems
- Any community, any tornado, e.g. Moore, OK, could be modeled
- Other hazards – flood and seismic

Where the rubber hits the road: policy

- Translation of good research to good practice requires stakeholder engagement to
  - Listen to what is needed by communities
  - Enable useful and usable tools
  - Provide visualization to explore outcomes effectively
- Improving resilience at the community level requires
  - The ability to compare policy options using costs, direct and indirect losses
  - Measuring the effects on social institutions (e.g. schools, hospitals, services)

Community Partnerships: A two way street

- Three initial communities:
  - Joplin, MO
  - Galveston, TX
  - Salt Lake City, UT
- Three more planned
- Provide feedback on refinement of Web App for IN-CORE
- Team will model community and provide planning support

Some Expected (Hoped) Impacts to Resilience Practice

- The ability to reasonably estimate the impact of a hazard on the physical infrastructure, local economy, and social institutions and services; before anything has happened, i.e. planning
- The ability to try "what if" scenarios and explore changes in design codes, land use policy, capacity changes to institutions, etc.
- The ability to plan investment strategies over a longer time horizon that typical
- Remember – resilience and therefore (even simulated) recovery is a process!

Conclusions

- Resilience analysis requires modeling from before, during, and after a hazard event such as a flood, hurricane, or tornado; physical and non-physical systems

- Practical application of theoretical resilience concepts to facilitate actionable strategies requires partnerships, communication, and useful and usable tools

- Challenges remain but with partnerships are solvable

Some Big Challenges Remain

- Ensuring broad enough applicability of the tools, e.g. IN-CORE web app
- Modeling common policy options effectively
- Enabling effective resilience metrics that can be measured and are meaningful to communities

- What is optimal from an engineering and scientific standpoint is NOT (necessarily) what is optimal for communities
  - The reason for the partnerships
  - Engage, listen, iterate!

Thank you!

The Center for Risk-Based Community Resilience Planning is a NIST-funded Center of Excellence; the Center is funded through a cooperative agreement between the U.S. National Institute of Standards and Technology and Colorado State University (NIST Financial Assistance Award Numbers: 70NANB15H044 & 70NANB20H008). The views expressed are those of the presenters, and may not represent the official position of the National Institute of Standards and Technology or the US Department of Commerce.

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A special thank you to Lisa Wang and Omar Nofal, Ph.D. students at CSU, for their contributions of the tornado and flood example analysis and slides, respectively.

Special thank you to InteRaCT and FIU colleagues for arranging my seminar.

Resilience

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