Generating Building-specific Fragility Curves

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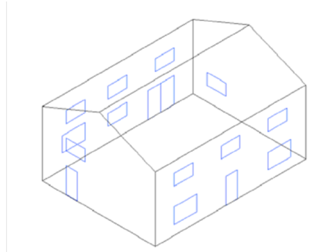
PROBLEM

Fragility curves represent a structure's likelihood of damage under a range of load levels—like those from natural hazards. They, therefore, help to set building code safety factors, resiliency ratings, and even insurance premiums. Unfortunately, there is no real standard for generating these fragility curves for wind loading.

FEMA's HAZUS hurricane model is the closest to a current standard for wind-load fragility curves. However, even this rigorous database generates curves for only *specific building types* by aggregating the curves of their components (e.g., windows, siding, roof)[1] (**see Figure 1**). Though useful, this aggregation approach limits the generation of customizable curves for unique buildings that deviate from the standard HAZUS types.



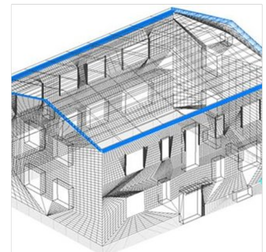
HAZUS model house geometry

Tabulated components

Component-level analysis

Aggregated representative

Assumed fragility curve shapes



Point-mass model

Discretized geometry

Streamlined analysis

Case-by-case model

Simulated fragility curves

Figure 1. A comparison between HAZUS component-based building models[2] and our molecular simulation inspired point-mass models[3]. Figures adapted from references 2 and 3.

APPROACH

We draw on tools from statistical physics to simulate the probability of failure for building components subjected to wind loading. Using a Monte Carlo molecular simulation, a building's components and their connections are broken based on the energy stored in each connection. This provides a damage inventory of broken connections of the building envelope.

We can then determine the probability of a given failure level relative to total possible failure. To confirm these probabilities, we simulate the whole range of connections—from no connections broken to a critical number of connections. This can be done on a component level and the building level. Damage states are defined using the existing HAZUS databases or by the future stakeholders.

WHY DOES THIS RESEARCH MATTER?

- Building-level fragility curves can be generated directly instead of by aggregating component curves.
- Stakeholders will be able to generate fragility curves for unique buildings.
- This approach presents the possibility of advancing beyond build-level to neighborhood and even city-level fragility curves.

FINDINGS

By inputting building geometry, the bill of materials, and geographic information, fragility curves can be generated for specific building composed of different materials. This approach is exemplified using a model 7-story building subjected to a wind-induced uplift pressure (see **Figure 2**.). Curves were generated for concrete and wood buildings. In the past, hurricane fragility curves for buildings have employed different distributions for building components. Our method makes no such assumption. Since we can't be sure of the curve's exact shape, this is a more realistic approach. More refined building simulations with more simulated connections and higher resolution of the load may yield normally distributed curves.

[1] HAZUS-MH Hurricane Wind Model Validation Study-Florida: Hurricanes Charley and Ivan HAZUS-MH MR-2", (2007)
[2] Multi-hazard Loss Estimation Methodology: Hurricane Model, Hazus-MH 2.1: Technical Manual p. 6-57.
[3] Dobelis, M., Kaļinka, M., & Borodiņecs, A. "The Capture of BIM Compatible 3D Building Model from Laser Scanner Data." The 17th International Conference on Geometry and Graphics (ICGG 2016): China, Beijing (pp. 4-8).

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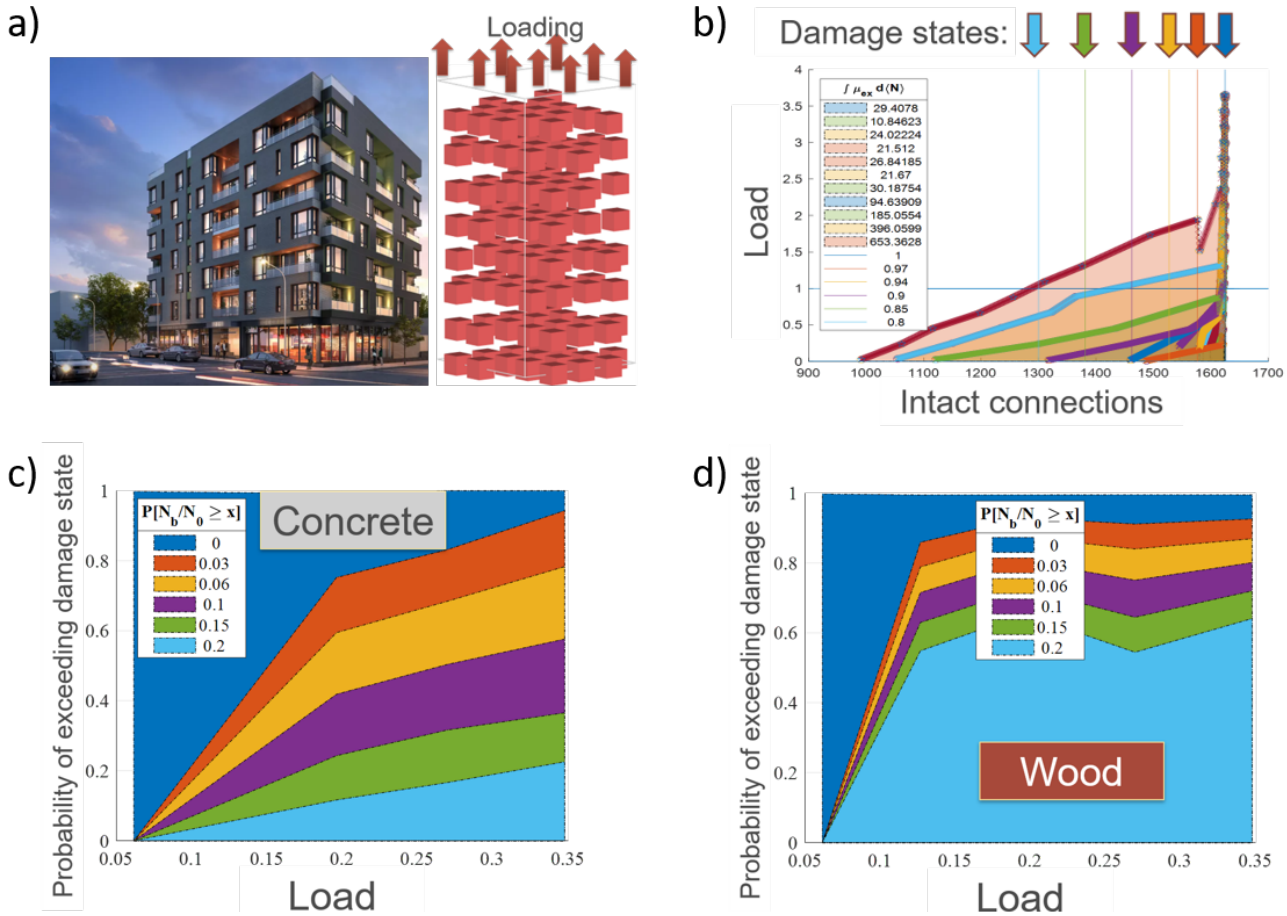

Figure 2. Constructing build-level fragility curves with molecular simulation-inspired tools. (a) The first step is defining the geometry and material properties of a discretized building model. (b) The second step is running simulations outputting energy (shaded areas of the graph) of for each damage inventory. (c and d) Finally, the steps can be repeated for different materials. Here, the concrete outperforms the wood, having lower probabilities of damage at every damage state. Damage states are defined as the percent of broken connections going from none, 0%, to extensive, 20%.

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