City Texture and Urban Resilience

CSHub Topic Summary | March 2020

MIT CONCRETE SUSTAINABILITY HUB

Reshaping Urban Resilience

Hurricanes are the most damaging of natural disasters: since 1980, they have inflicted nearly $1 trillion in damages in the U.S. By 2075, though, their average annual damage cost will likely rise by nearly 40% due to climate change and coastal development. Meeting this challenge demands greater resilience. America, however, isn't constructing nearly enough resilient buildings.

This is, in part, due to the inadequacy of the nation's building codes—the minimum construction standards mandated by governments. Currently, these codes don't consider how a building's local context—specifically, the arrangement of neighboring buildings—may increase its hazard risk. This local arrangement of buildings is known as city texture.

To reinvigorate building codes and better predict and mitigate hazard damage, researchers at MIT have developed a new approach to urban resilience that rapidly quantifies city texture to estimate hazard risk. This same city texture framework has proven useful for studying other urban phenomena such as the urban heat island effect.

City Texture Influences Wind Loads

Scientists have long studied the effects of urban morphology on wind flow. Much of their attention has focused on the urban canyon effect.

The urban canyon effect occurs when wind flow between buildings creates pockets of high and low pressure—much like air traveling over and under an airplane wing. This pressure differential generates heavy wind loads that can pry off roofs and damage structures.

While current building codes account for urban canyons in an approximate fashion, they don't consider how surrounding canyons collectively influence the wind loads a building might experience. As a result, they assume a building's drag coefficient—or a measure of the force exerted on the building by wind due to that building's shape—is fixed.

In practice, this is not the case: The direction of the wind and arrangement of adjacent structures can dramatically alter a building's drag coefficient. By investigating city texture, CSHub researchers have begun to more accurately capture these drag coefficients. Their research will allow stakeholders to implement stricter building codes and design more resilient communities.

Figure 1. A dramatic example of an urban canyon above Montgomery Street in San Francisco, California. Credit: Minesweeper / Creative Commons

77 Massachusetts Ave, 1-372, Cambridge, MA 02139 | cshub@mit.edu | cshub.mit.edu

Calculating City Texture

To model the effect of city texture on wind loads, researchers began to quantify city texture using a technique from materials science called the radial distribution function (RDF). While this tool traditionally looks at the densities of atoms in materials, here the RDF is applied to measure the average number of neighboring buildings surrounding any given building. To calculate city texture, the RDF is then combined with the average square footage of neighboring buildings exposed to wind.

Once quantified, city textures were then organized by their resemblance to the atomic structures of crystals, liquids, and gases (**Figure 2**). Crystal cities, like Chicago, displayed greater order. Liquid cities, like Los Angeles, showed less order, while gas cities displayed the least order. Researchers found that cities with more ordered, crystalline textures displayed higher wind speeds and higher building drag coefficients that would lead to greater damage.

Case Study: Mexico Beach

MIT researchers studied the relationship between city texture and wind damage in several Floridian communities in the wake of major hurricanes. One case study looked at the community of Mexico Beach, which incurred catastrophic damage during Hurricane Michael in 2018 (**See Figure 3a**).

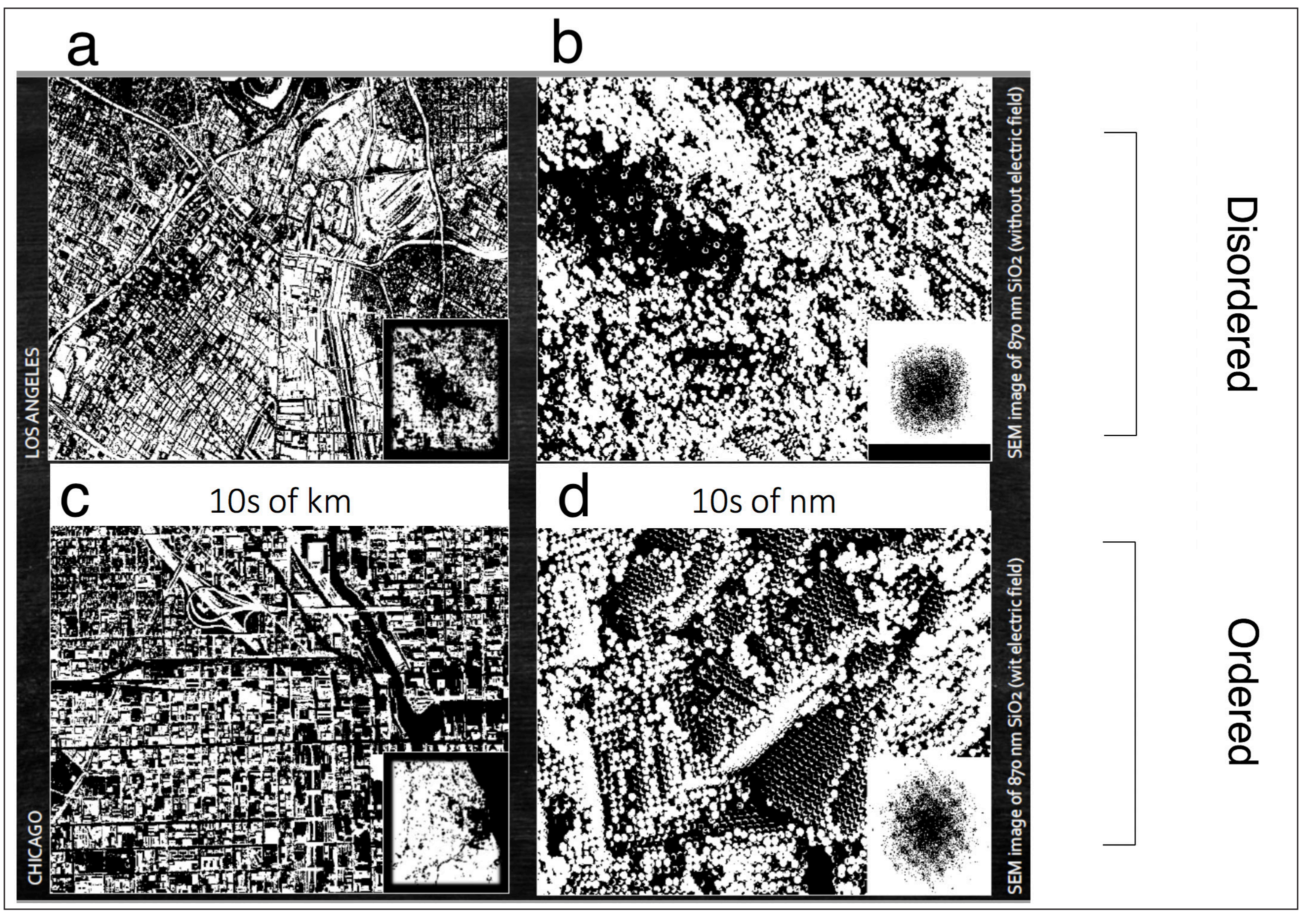

Figure 2. A comparison of between the textures of Los Angeles (**2a**) and Chicago (**2c**) and materials with analogous atomic structures (**2b** liquid, **2d** crystal).

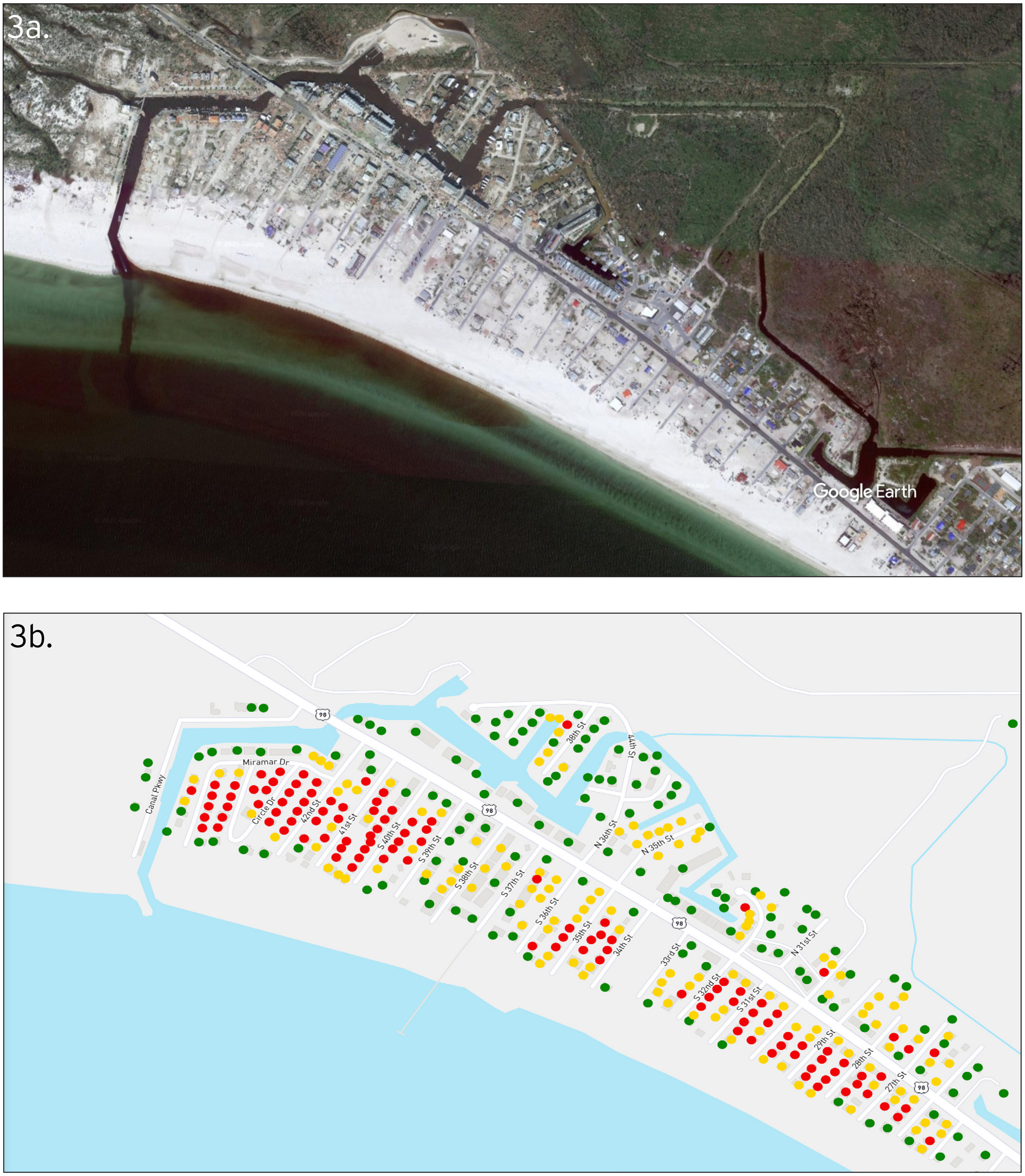

Figure 3. A comparison of the damage sustained by Mexico Beach in Hurricane Michael (**3a**) compared to the damage estimated by the city texture model (**3b**). Green dots indicate minimal damage, yellow dots indicate moderate damage, and red dots indicate severe damage or complete destruction.

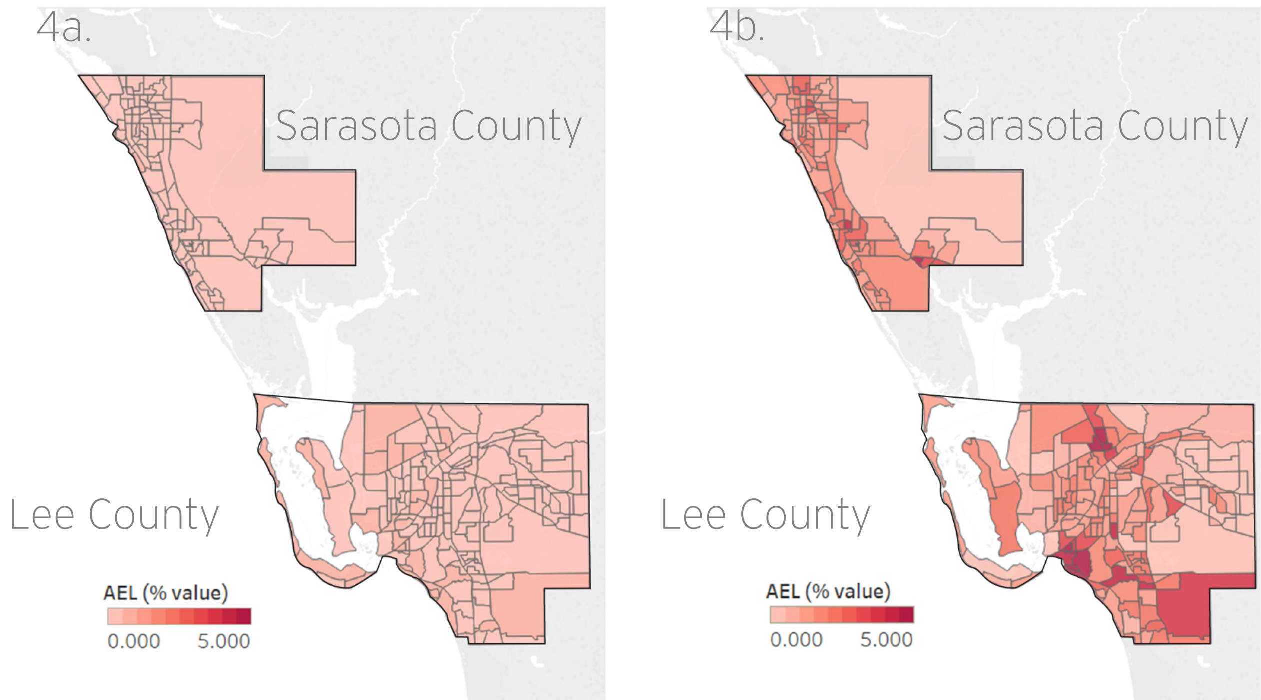

Figure 4. Average expected losses (AEL) for households during an extreme hazard event as a percentage of building value. **4a** is a conventional loss estimation while **4b** is a city texture informed loss estimation.

Using the city texture of Mexico Beach, their model reliably predicted the drag coefficients of the community's structures and the damage those structures were likely to experience (**See Figure 3b**). These modeled drag coefficients strongly reflected the actual damage inflicted upon the community and often exceeded the maximum drag coefficient specified by building codes—which may explain why the damage in Mexico Beach was so extensive.

A Better Estimation of Hazard Damage

In 2017, Hurricane Irma devastated regions of the Gulf Coast, inflicting $52 billion in damages. However, these losses were not distributed evenly. Florida's Lee County, for instance, experienced a significantly greater level of damage than its neighbor Sarasota County.

To explain these variations in damage, researchers applied their city texture model to those counties. In a case study, they estimated annual expected losses induced by hurricanes using a conventional approach as well as with a texture-informed one that incorporated city texture into wind loads.

Using a conventional approach, they found that annual expected losses for each county were virtually the same, with losses well below 1% of the value of homes (**Figure 4**). In high-risk areas, losses amounted to 0-4% of annual household income (**Figure 4a**).

However, after calculating the impacts of city texture on individual homes in each county, disparities emerged. Researchers found that Lee County possessed a more crystalline texture than Sarasota, which was reflected in its greater level of damage: When incorporating city texture into wind loads, annual expected losses grew from less than 1% of the value of homes to up to 9% in Lee County and up to 6%

77 Massachusetts Ave, 1-372, Cambridge, MA 02139 | cshub@mit.edu | cshub.mit.edu

in Sarasota County. For half of homes, losses stayed below 1% of the building value; for a quarter, losses were magnified by factors up to 3; for the most severe impacts, losses were magnified by factors up to 6 (**Figure 4b**). In high-risk homes, repairs amounted to 4-30% of annual household income.

The disparities captured by the city texture model can provide insight into the variation in damages that occurred during Hurricane Irma. More fundamentally, the model demonstrates the extent to which current methods fail to predict the true impact of hazards and leave many communities unprepared.

Streamlining and Improving Hazard Mitigation

The city texture model has the potential to streamline and strengthen hazard mitigation practices. Traditionally, estimating wind loads requires highly accurate, yet time consuming and expensive, simulations. The city texture model can compensate for those limitations. It would allow stakeholders to quickly locate the most vulnerable areas up front and then apply simulations to just those high-risk locations. Using this approach, it would be possible to rapidly identify cities, neighborhoods, and buildings with high susceptibility to wind loads and incentivize resilient retrofits.

For developers and planners, the model could inform the construction of communities with more resilient textures as well as the development of building codes tailored to the texture of each structure.

The city texture model may also incentivize homeowners to improve the resilience of their structures. Though hazard mitigation practices reduce hazard losses and save owners money over a building's life, many remain unaware of these cost and safety benefits. By using city texture to calculate hazard costs, homeowners would be better informed of the extent of their risks and be encouraged to implement resilient construction that could keep them safe and save them money.

The next step for researchers is to increase the precision of the model by accounting for how various building shapes and the presence of surrounding objects, such as trees, may affect city texture. Since the collapse of structures during a hazard event may alter city texture, the model will eventually account for how those losses may influence the hazard risk of surrounding buildings.

Key Findings

- Wind loads depend on the orderliness of a city's texture: The more grid-like a city's texture, the greater wind loads it will experience.
- Current methods fail to capture the full extent of hazard risk by disregarding the impact of city texture on wind loads.
- The city texture model can streamline hazard mitigation by rapidly estimating wind loads and identifying vulnerable areas for retrofit.

Related Links

- Break-even Mitigation Percent Dashboard
- Research Summary: Life Cycle Costs of Hazard Resistant Buildings
- Research Brief: Community-Informed Building-Scale Resilience Assessment

Citation:

Manav, I.B., Roxon, J. (2019) The role of pavements in meeting GHG reduction targets, MIT CSHub, Research brief, Volume 2019, Issue 6.

This research was carried out by CSHub with sponsorship provided by the Portland Cement Association and the Ready Mixed Concrete Research & Education Foundation. CSHub is solely responsible for content.