

## Impact of Urban Spatial Configuration on Massive Pedestrian Tsunami Evacuation through Agent-Based Modeling

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### INTRODUCTION & AIM

Current tsunami evacuation planning relies on static maps and average evacuation times, ignoring complex pedestrian behavior and underestimating risks in uncertain scenarios. This average-based approach fails to detect low-probability, high-impact events where specific urban spatial configurations trigger critical fatalities.

This research aims to identify and mitigate high-risk urban spatial configurations by analyzing critical evacuation time outliers in Las Brisas de Villa, Lima. By integrating the Social Force Model with high-performance computing, the execution of massive stochastic simulations reveal hidden vulnerabilities that traditional models fail to detect.

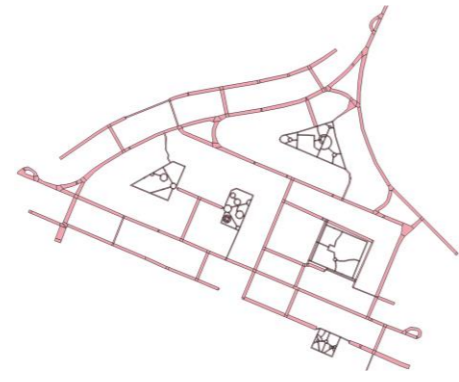
### METHOD

#### GIS AND CENSUS DATA

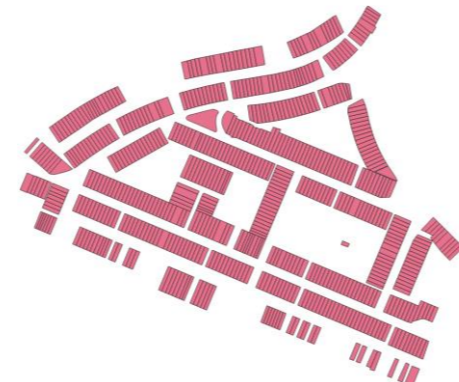
##### SATELLITE IMAGERY



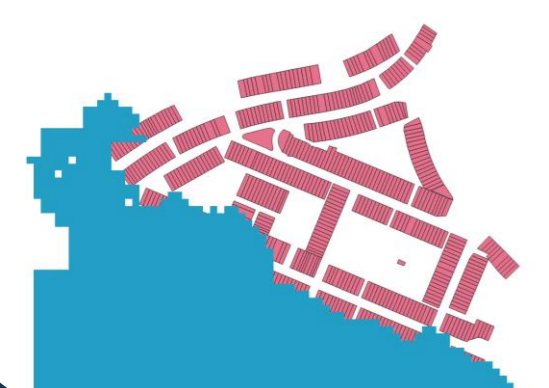
##### URBAN NETWORK



##### BUILDING



##### TSUNAMI SIMULATION



##### CENSUS DATA

Agents	Amount
Kids	333
Adults	689
Elderly	233
Total	1255

##### OBSTACLES



#### COMPUTATION

##### SOCIAL FORCE

$$\vec{f}_{ij} = \left[ A_i e^{-\frac{d_{ij}}{d_0}} + k_g(r_{ij} - d_{ij}) \right] \vec{n}_{ij} + \kappa_g(r_{ij} - d_{ij}) \Delta v_{ij} \vec{e}_{ij}$$

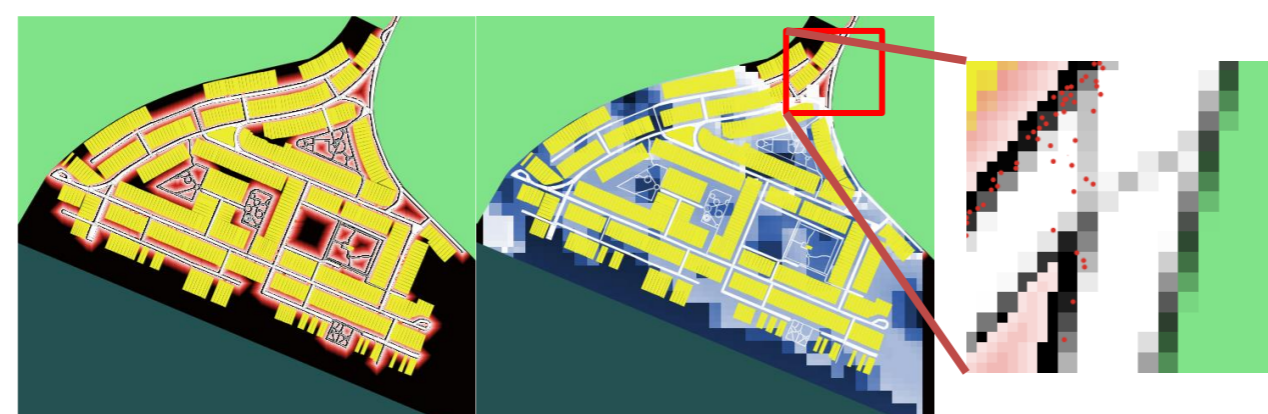
##### BREADTH-FIRST

$$D[v] = \min_{u \in N[v]} \{D[u] + w[u, v]\}$$

##### MILLING TIME

$$D(t) = 1 - e^{-\frac{t}{\tau}}$$

#### MULTIPLE EVACUATION SIMULATION



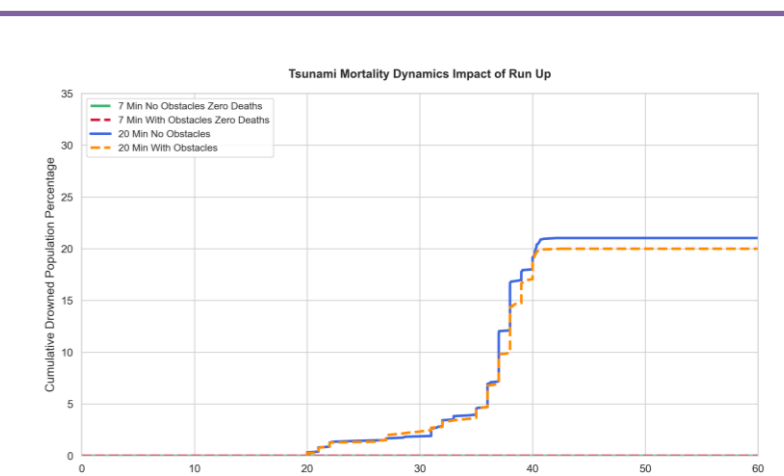
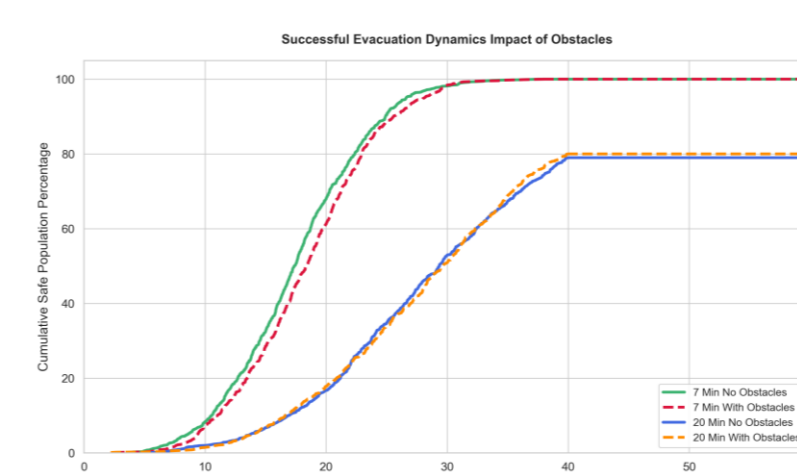
### RESULTS & DISCUSSION

#### SCENARIOS OVERVIEW

Stochastic evaluation of 500 simulations under 4 distinct scenarios:

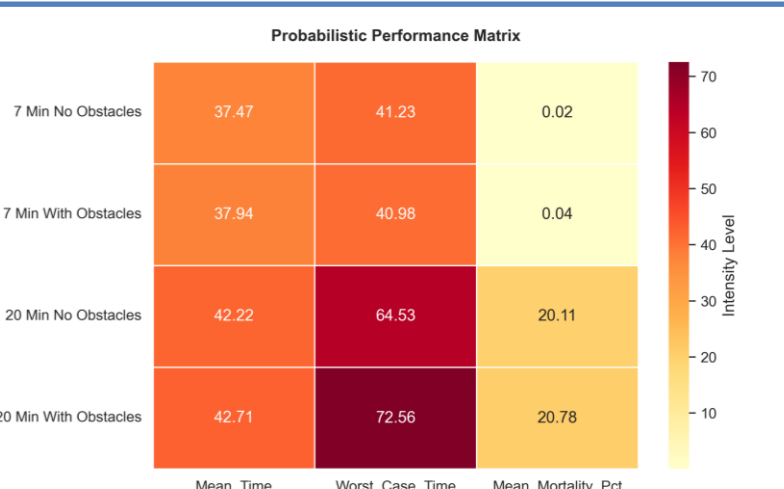
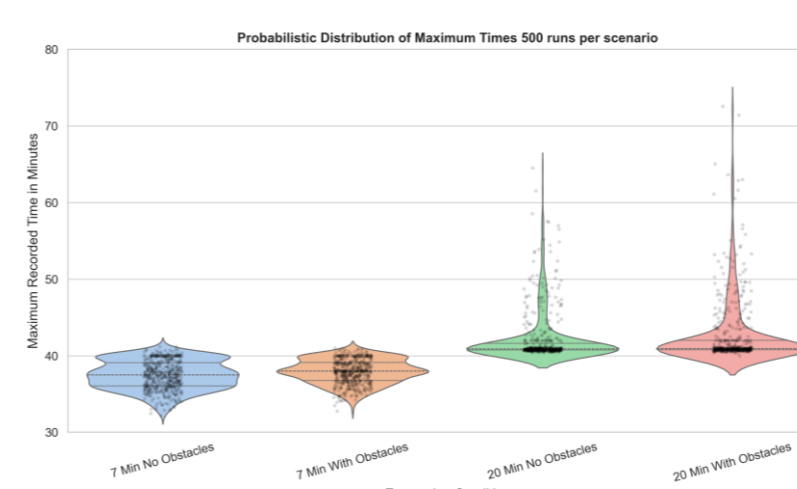
- Scenario 1: 7 minutes reaction | No obstacles
- Scenario 2: 7 minutes reaction | With obstacles
- Scenario 3: 20 minutes reaction | No obstacles
- Scenario 4: 20 minutes reaction | Obstacles

#### Evacuation & Mortality Dynamics



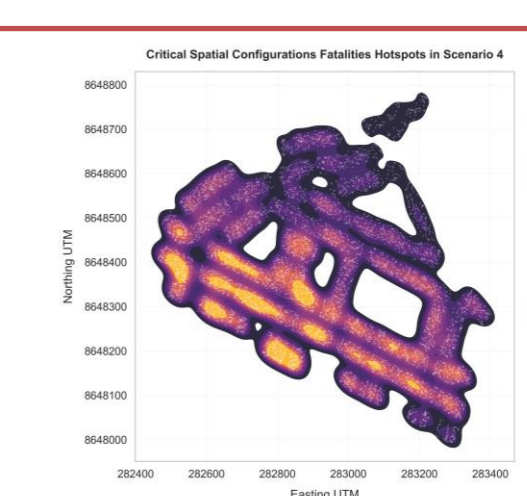
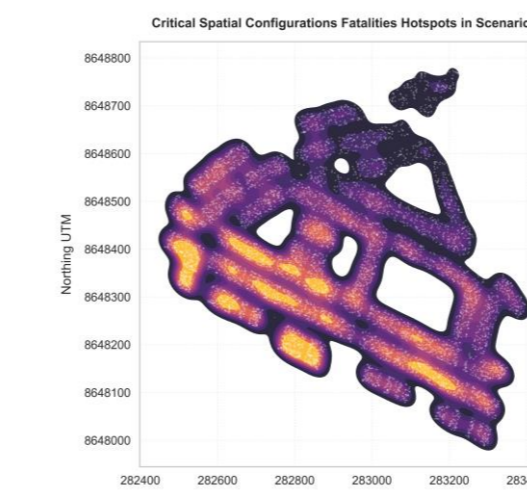
- A 20-minute reaction time leads to systemic evacuation failure.
- Obstacles severely delay the evacuation pace.

#### Outliers Analysis & Evacuation Times



- Obstacles increase maximum evacuation times pushing outlier populations beyond survival limits.

#### Dangerous Urban Configurations



- Hotspot analysis reveals the areas with the highest fatality concentration based strictly on outlier scenarios.
- The core critical zones remain constant.

### CONCLUSION

- Massive stochastic simulations successfully identify hidden urban vulnerabilities that traditional average based models fail to detect.
- Fatality risks are driven by specific critical spatial configurations rather than simple proximity to safe zones.

### FUTURE WORK

- Include floating population dynamics such as tourists and beach visitors to assess additional severe risk scenarios and different tsunami simulations.

### ACKNOWLEDGMENTS

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