Exploring What Better Cities Could Look Like

- A Surrogate-Assisted Urban Design Tool for Pedestrian Wind Comfort

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1 Problem

Pedestrian-level wind influences comfort, safety, and usability of streets and public spaces. CFD (computational fluid dynamics) provide detailed evaluations but are expensive and time consuming, limiting the number of urban layouts that can be tested during early phases.

2 Project Goal

Explore many feasible urban design configurations based on desired features and pinpoint the high performing candidates. Rather than finding one “best” design, we want to reveal multiple good solutions across different densities, and to output them within reasonable time and with competent accuracy on performance measures.

3 Methods

1. Generate designs from input with CMA-ME quality diversity optimizer
2. Predict wind speed and evaluate with pretrained surrogate model.
3. Convert predicted wind fields to wind-comfort score.
4. Quality diversity search places designs into an FAR versus plot-coverage archive and leaves only the highest-performing designs in each region.

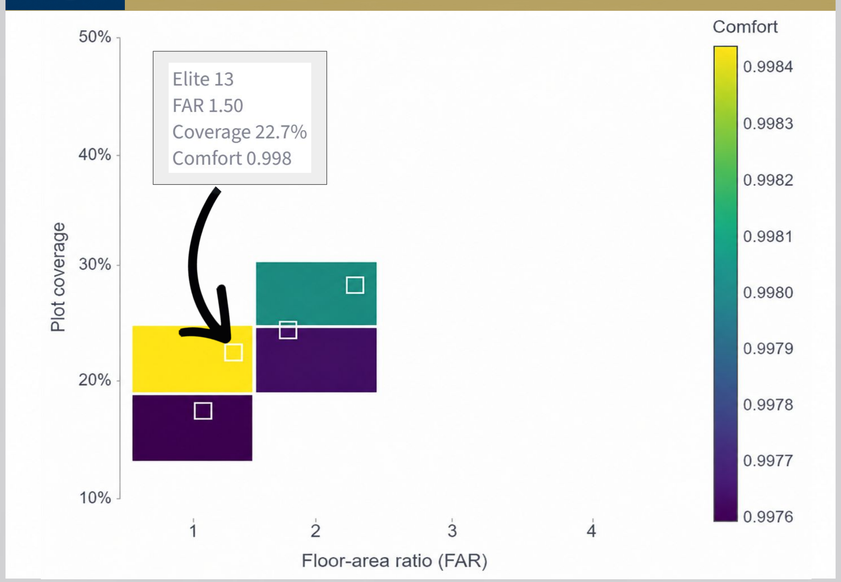
4 Testing

- Site - 150m x 150m
- Massing Grid - 3 x 3
- Maximum Floors - 14
- Candidates - 32
- Archive Bins per Axis - 10
- Wind Directions - 4
- Random Seed - 50

5 Metrics

Floor-Area Ratio	$\mathrm{FAR}(x) = \dfrac{\sum_{i=1}^{n} A_i N_i}{A_{\mathrm{site}}}$
Plot Coverage	$\mathrm{Coverage}(x) = \dfrac{\mathrm{Area}\left(\bigcup_{i=1}^{n} \mathrm{Footprint}_i\right)}{A_{\mathrm{site}}} \times 100\%$
Structural Similarity Index	$\mathrm{SSIM}(x,y) = \dfrac{(2\mu_x\mu_y + C_1)(2\sigma_{xy} + C_2)}{(\mu_x^2 + \mu_y^2 + C_1)(\sigma_x^2 + \sigma_y^2 + C_2)}$
Wind-Comfort Score	$q(x) = 1 - \sum_s p_s \left[f_{u,s}(x) + \lambda f_{d,s}(x) \right]$

6 QD Archive

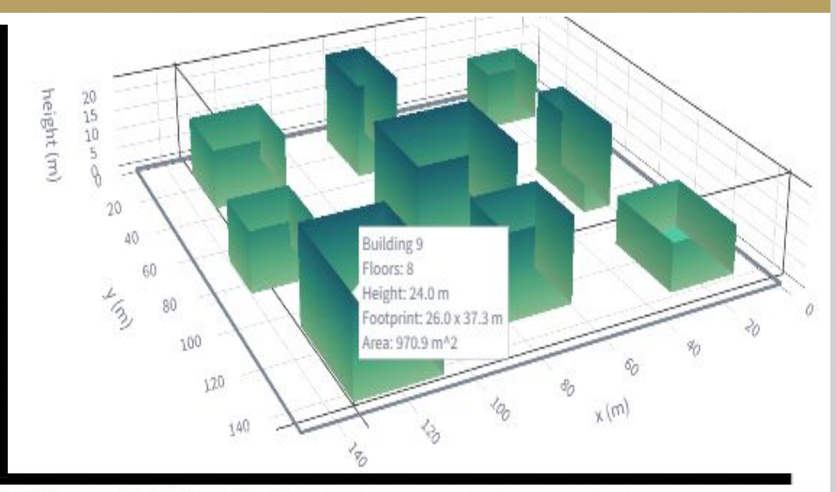


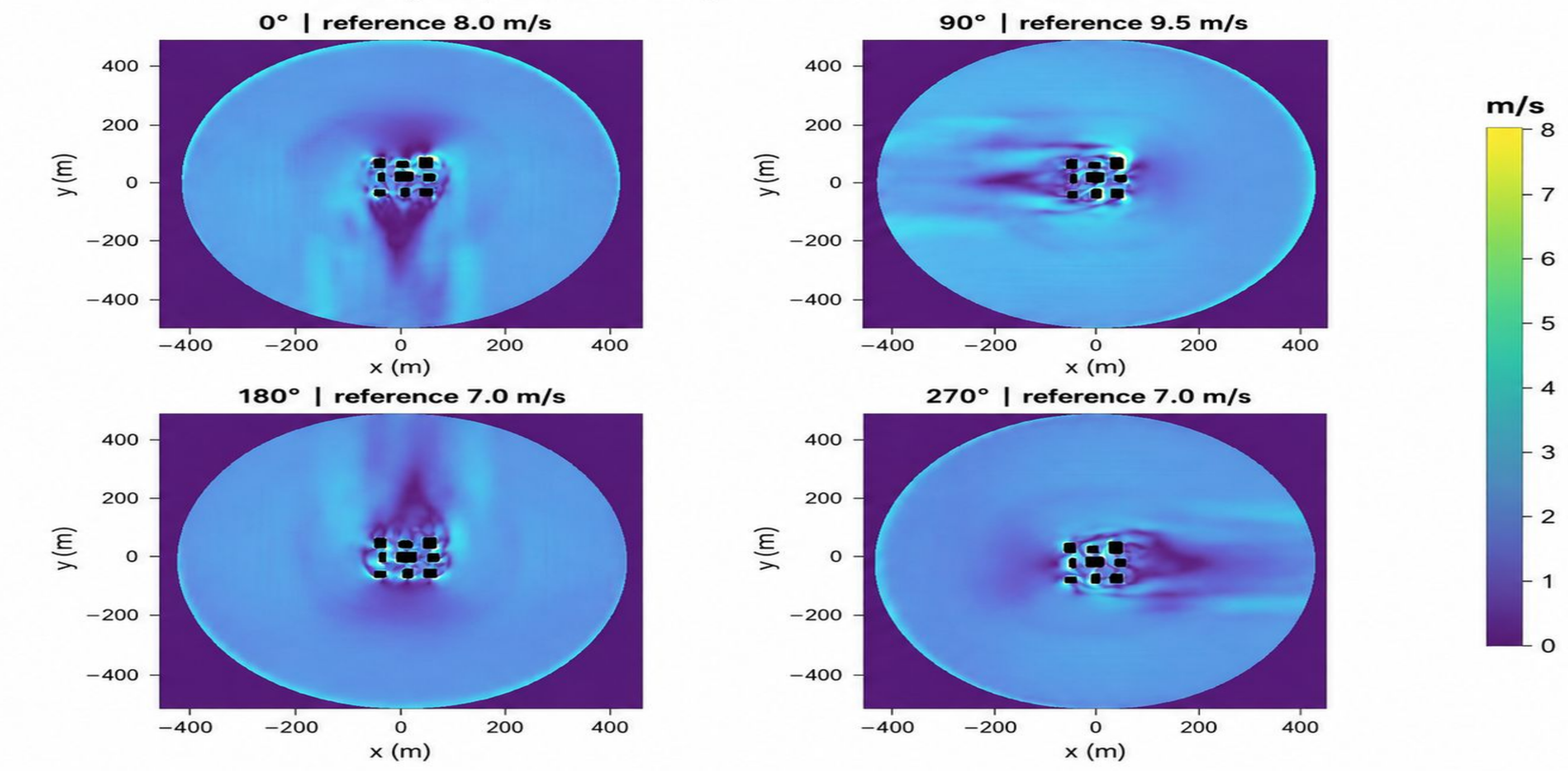
7 Candidate Elite

Elite 13

Comfort	FAR	Coverage
0.998	1.50	22.7%

Pix2Pix HD - Trained and validated with CFD Data on 1000 Geometries
Inference Time: 20 minutes (CPU)





8 Key Insights

- Workflow can generate and compare multiple feasible layouts
- Quality-diversity search reveals strong solutions across different densities and compare their overall comfort
- Different wind behavior can be observed from each designs

9 What’s Next?

- Explore more models
- Expand generator to more complex geometries
- Integrate more robust urban features such as building material, street width, and vegetations
- Go beyond predicting wind - energy consumption, outdoor thermal comfort

References: https://docs.google.com/document/d/1LApUX99VtBN7t5C24xDuvRP5kTOMiis9_qj8S7uk_8A/edit?usp=sharing