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Preliminary insights from review of surrounding effects on wind loading and vulnerability models

Ude E.J.[1], Sidhu A.[1], Nnamani E.N.[2], Ciucci, M.[3], Marino, A.[3], Hofer L.[1] Zanini M.A[1]

[1]*Department of Civil, Environmental and Architectural Engineering, University of Padova, Italy.*
[2]*Department of Civil, Environmental, University of Minho, Portugal.*
[3]*INAIL, Istituto Nazionale Assicurazione contro gli Infortuni sul Lavoro*

SUMMARY
Wind load on structures requires attention to the surrounding built and environmental effects. Neighbouring structures and terrain alter local wind pressures, so a building can be assigned a different damage outcome depending on how its surroundings are represented. This study presents preliminary findings from a structured review of relevant literatures representing built and surrounding conditions in wind loading or damage assessment. Result shows that explicit representation is the norm, with surrounding geometry resolved physically or numerically in most studies. What varies is the layout resolved and the scale at which resolution is abandoned. Most studies analyse idealised configurations rather than real building stock, and representation switches from resolved geometry to a prescribed terrain roughness parameter between portfolio and neighbourhood scale. Attention concentrates on shielding, interference, and spacing, with terrain, orography, and vegetation sparsely treated. The gap lies in carrying physically meaningful representation across that boundary, applied to real configurations.

Keywords: wind vulnerability, interference, urban morphology

1. INTRODUCTION

Wind hazards are a persistent component of the global disaster landscape. Storms account for 18% of all events recorded in the EM-DAT archive for 1900 to 2023, second only to floods (Delforge et al., 2025).

Recent frameworks estimate losses not for a single structure but across building portfolios, neighbourhoods, and regions, supporting decisions from insurance pricing to municipal mitigation planning. Assessment at these scales requires attention to the surrounding built and environmental conditions of each building. Neighbouring structures and terrain alter local wind flow through shielding and channelling, changing local pressure coefficients substantially relative to an isolated case (Chang & Meroney, 2003; Liu et al., 2018).

With respect to vulnerability modelling, the review by Walker (2011) emphasized that, engineering-based vulnerability models should include probabilistic wind-load estimation because of the nonlinear relationship between wind speed and load. Highlighting that this nonlinearity is influenced by (often non-homogenous) upstream terrain, nearby buildings, vegetation, wind direction, building orientation, and building geometry. For low-rise buildings specifically, these interference effects can either reduce or amplify roof suction depending on roof slope, building spacing, and position within a group (Chen et al., 2019). Meaning that the same building may be assigned a different damage outcome purely as a function of its neighbours.

While this interference and surrounding effect understanding is well established in the literature, its application for wind load on structures in a group or portfolio have been implemented with different approaches and/or at different scales. Particularly, various studies evaluate interference implicitly with prescriptive exposure terrain factors or explicitly by having them depend in one or

more of: geometry and layout of buildings, orography, spacing, wind angle and terrain etc at different scales.
This raises the question central to the present study: How are surrounding built and environmental conditions incorporated, applied, and validated in wind-induced vulnerability models, and what evidence gaps remain? This study reviews the relevant literature to address this question and reports the preliminary findings accordingly.

2. METHODS

This study adopts a structured and systematic review approach to collect and synthesize existing research relevant to the defined problem domain. Particularly, Boolean search strings combining wind vulnerability terms with interference/shielding/exposure terms were run in Scopus and Web of science and Engineering village. The retrieved records were screened by title/abstract then full text against predefined inclusion and exclusion criteria in line with relevance, scope, and alignment with the objectives of the study. Following the screening process, a subset of studies was retained for in depth examination and data extraction. Preliminary insights from 30 studies so far have been reported here. Key information extracted from these studies, including methodological characteristics, main findings, and reported research gaps among others.
The representation method is coded at three levels: CFD/Wind tunnel-resolved geometry, a shielding or interference factor, and a terrain roughness parameter.

3. PRELIMINARY RESULTS

The reviewed studies span 1984 to 2025, with four published before 2000. Twenty produce wind loading results without a damage or loss output, and ten produce fragility, vulnerability, or loss functions. Two thirds of the evidence on how surrounding conditions modify wind loading therefore stops at pressure or load coefficients.

3.1. Shielding dominates while vegetation and orography lag

Figure 1 shows which surrounding conditions are represented. Shielding and interference appear in 25 studies, and building spacing or urban morphology in 25. Wind directionality relative to the surroundings appears in 9, terrain and surface roughness in 7, orography in 2, and vegetation in 2. Attention is concentrated on neighbouring structures, with terrain, orography, and vegetation together accounting for 11 mentions across 30 studies. Vegetation appears only at city scale, and in both cases as an input to a roughness parameterisation rather than a modelled obstruction.

3.2. Explicit representation dominates

Four representation methods appear. Wind tunnel-resolved geometry is used in 16 studies and CFD-resolved geometry in 10, so 24 of 30 resolve the surrounding geometry physically or numerically. A shielding or interference factor is used in 5, and a terrain roughness parameter in 4. Only 3 studies rely on a roughness parameter alone, and only 1 combines a resolved representation with one. Explicit treatment is therefore the norm. The geometry resolved is mostly invented: 21 of the 30 studies use idealised layouts against 9 site-specific ones, and the imbalance is concentrated at portfolio scale, where 17 of 21 studies analyse generated configurations.

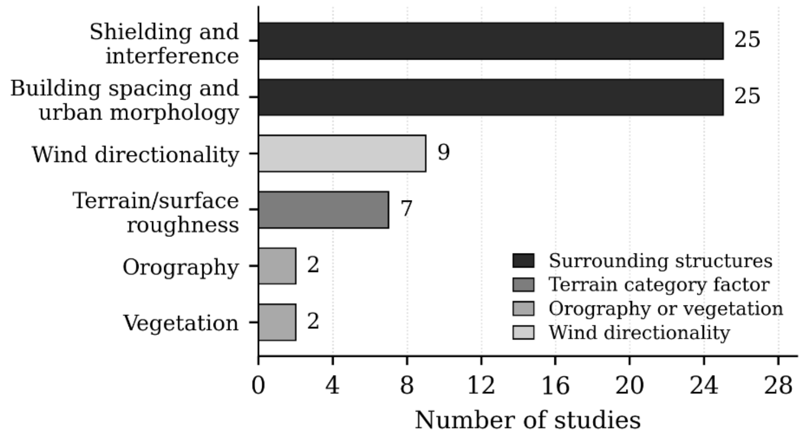

Figure 1. Local exposure factors represented across the reviewed studies.

3.3. Balancing scale and fidelity

Figure 2 maps representation method against scale of assessment. The reviewed studies occupy a narrow range, with 21 at building portfolio scale, 5 at building scale, and 2 each at neighbourhood and region. Two blocks emerge and they do not overlap. Geometry-resolved methods, tunnel and CFD, appear only at building and portfolio scale, apart from a single CFD study at neighbourhood scale. The terrain roughness parameter appears only at neighbourhood and region, and never at portfolio scale or below. The shielding or interference factor sits entirely at portfolio scale. Representation therefore switches from resolved geometry to a prescribed surface property between portfolio and neighbourhood scale.

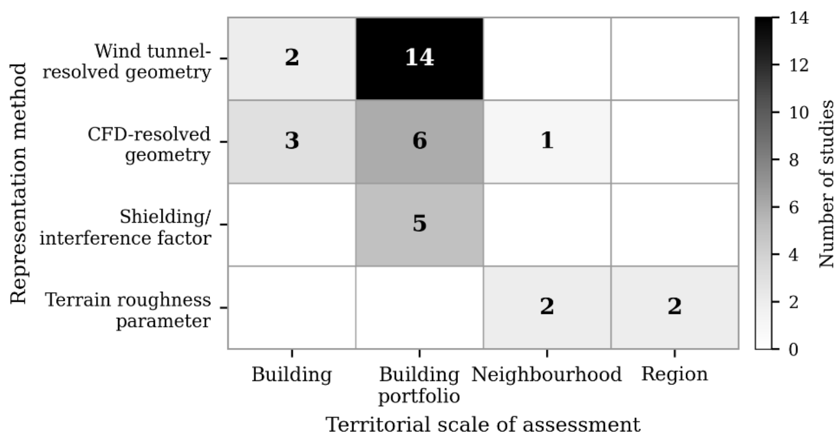

Figure 2. Representation method by territorial scale of assessment.

3.4. Reported limitations

The reviewed studies converge on four constraints. Idealised and uniform layouts are repeatedly flagged as unrepresentative of real building stock, with authors noting that identical shapes do not reflect complex real-world configurations (Jiang et al., 2023). Configurations are narrow, restricted to fixed arrangements, single densities, or limited wind directions, which limits generalisation beyond the tested case (Kim et al., 2013). Computational cost blocks scaling, with community-scale simulations reported to run for days (Nofal et al., 2022). At larger scales the constraint shifts to input data, where national land-use datasets provide coarser resolution than state-level sources (Vickery et al., 2006).

4. CONCLUSION

Surrounding built and environmental conditions are explicitly represented across most of the reviewed studies, with geometry resolved physically or numerically in the majority. What varies is the layout being resolved and the scale at which resolution is abandoned. Most studies analyse idealised configurations rather than real building stock, and representation switches from resolved geometry to a prescribed terrain roughness parameter between portfolio and neighbourhood scale, with a single study spanning that boundary. Attention also remains narrow, concentrating on shielding, interference, and spacing, with terrain, orography, and vegetation sparsely treated. The reviewed studies attribute these limits to idealised layouts, restricted configurations, computational cost, and coarse input data at larger scales. Closing this gap requires exposure-aware vulnerability frameworks that carry a physically meaningful representation of surrounding conditions across that boundary, applied to real rather than generated configurations.

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