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Impactos da verticalização urbana induzida pelo turismo na ventilação de Meia Praia, SC

Impacts of tourism-related urban verticalization on ventilation in Meia Praia, SC, Brazil

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Resumo

A intensa turistificação de Meia Praia, em Itapema-SC, promoveu, na última década, profundas transformações no dossel urbano da Avenida Nereu Ramos, com significativa verticalização e adensamento, gerando um perfil de rugosidade crescente e a configuração de cânions urbanos. Este trabalho avalia os impactos dessas transformações na ventilação urbana, comparando os cenários de 2012 e 2025 por meio de simulações CFD no ANSYS Fluent, a partir de modelos tridimensionais de um recorte urbano representativo. Os resultados demonstram fragmentação do fluxo de ar, concentração do escoamento em poucos corredores viários, redução da permeabilidade ao vento nas quadras internas e aumento de zonas de estagnação, com potencial implicação ao conforto térmico. Propõe-se, como contraponto, a adoção de recuos proporcionais à altura das edificações, pilotis e interrupções nos embasamentos, podendo melhorar a permeabilidade ao vento e qualidade ambiental. A pesquisa contribui para questionar o modelo de desenvolvimento urbano orientado exclusivamente pela valorização fundiária, propondo diretrizes de ventilação urbana aplicáveis ao planejamento de cidades litorâneas turísticas.

Palavras-chave: Ventilação urbana. Cânion urbano. Simulação CFD. Verticalização. Urbanização turística.

Abstract

Over the last decade, the intense touristification of Meia Praia in Itapema, Santa Catarina, has promoted profound transformations in the urban canopy of Avenida Nereu Ramos, including significant verticalization and densification. These changes have generated an increasing roughness profile and the formation of urban canyons. This study evaluates the impact of these changes on urban ventilation by comparing 2012 and 2025 scenarios using CFD simulations in ANSYS Fluent based on three-dimensional models of a representative urban section. The results show fragmented airflow, wind concentration in a few street corridors, reduced wind permeability in inner blocks, and increased stagnation zones, without environmental

considerations. The study highlights setbacks proportional to building heights, pilotis, and interruptions in continuous podiums as strategies to improve wind permeability and environmental quality. This research challenges the urban development model that focuses solely on increasing land value and proposes guidelines for urban ventilation applicable to the planning of coastal tourist cities.

Keywords: Urban ventilation. Urban canyon. CFD simulation. Verticalization. Tourist urbanization.

INTRODUCTION

Contemporary urbanization, particularly in the context of financialization, has produced landscapes that are increasingly oriented toward income generation and promote the erasure of local ways of life [1]. In coastal areas such as the coast of Santa Catarina, tourism intensifies this process by fostering urban development primarily oriented toward leisure, relaxation, and entertainment. This dynamic often degrades the urban landscape through the promotion of a commodified aesthetic that privileges visual spectacle over environmental quality, cultural heritage, and local identity [2-4].

In Itapema, Santa Catarina, this process intensified following the opening of BR-101, which has driven tourism and real estate appreciation since the 1980s, accelerating construction and verticalization [5], [6]. In this context, the Meia Praia neighborhood has experienced intense urbanization along the waterfront and in adjacent areas. Over the past few decades, this area, which was previously occupied by private vacation homes, has experienced significant densification and verticalization [7].

An analysis of the current urban planning instruments and regulations reveals an established typology in the urban fabric: high-rise buildings with massive, continuous base structures supporting vertical towers [8], [9]. These bases can exceed 20 meters in height. There is no fixed limit on the total height of buildings. The maximum height is determined by solar geometry (shading cone) combined with the Transferable Development Rights mechanism. The serial arrangement of these buildings along the street favors the formation of urban canyons.

Tourism-related real estate development has increased building height and density in Meia Praia, potentially affecting local wind permeability, heat removal, and pollutant dispersion [10–12]. Furthermore, urban environments have progressively been affected by climate change, which alter wind regimes and airflow velocity patterns [13]. Due to these issues, urban wind environments have received increasing attention from the scientific community.

Studies indicate that for every 20-meter increase in building height, the wind velocity ratio decreases by 0.012 [14]. Although variations in building height increase horizontal and vertical wind speeds around taller structures, they reduce air permeability near shorter ones [15]. Furthermore, when examining airflow in street canyons with buildings of different shapes, lower pollutant concentrations were found at pedestrian level compared to streets with buildings of uniform shape [16].

The analytical complexity of urban environments cannot be fully replicated under experimental conditions [17]. Computational fluid dynamics (CFD) simulations are an efficient, systematic way to model wind environments across large areas. In this context, the objective of this study is to evaluate the impact of urban transformations in Meia Praia on natural ventilation through qualitative and quantitative analyses of

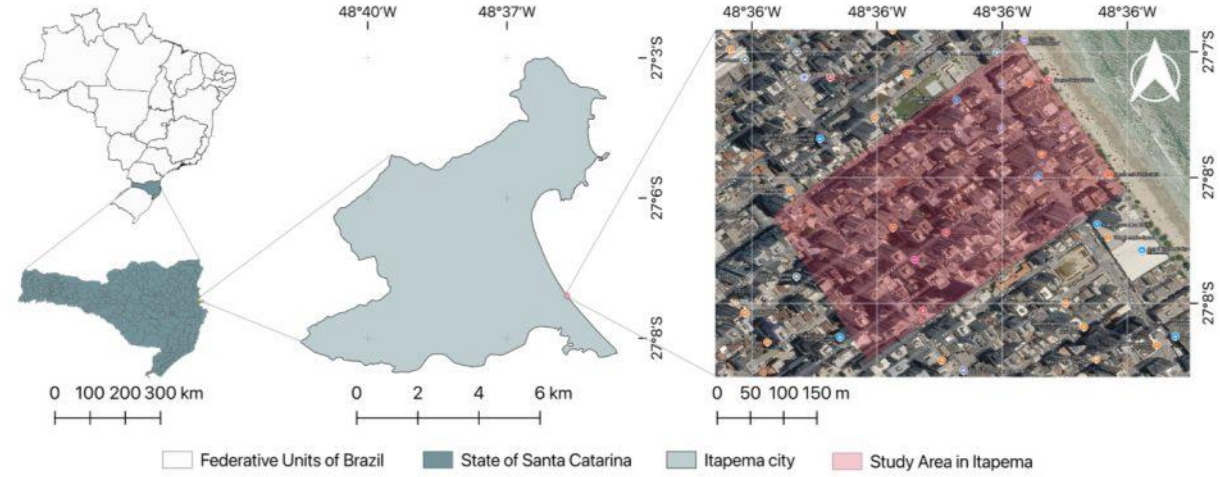
wind flow obtained from CFD simulations for the years 2012 and 2025. The research is characterized as an applied, exploratory, and comparative case study.

METHODS

TEMPORAL AND SPATIAL DELIMITATION

The study area is located in the municipality of Itapema, Santa Catarina, southern Brazil, at approximately 27°05'25" S and 48°36'41" W (Figure 1).

Figura 1: Location map of the study area, Itapema-SC, Brazil.



Source: the authors.

A section of the Meia Praia neighborhood was selected due to the significant urban changes observed in recent years. While the built environment near the waterfront showed few alterations, the blocks between Avenida Nereu Ramos and Segunda Avenida experienced significant landscape transformations (Figure 2).

Figure 2: Landscape transformation in Meia Praia: Rua 240 in 2012 (a) and 2025 (b); aerial images in 2012 (c) and 2025 (d).





Source: the authors, adapted from Google Street View and Google Earth, 2021 (Maxar Technologies) and 2025 (Airbus).

Two temporal scenarios were defined based on a visual analysis of Google Maps and Street View imagery: retrospective (2012) and current (2025).

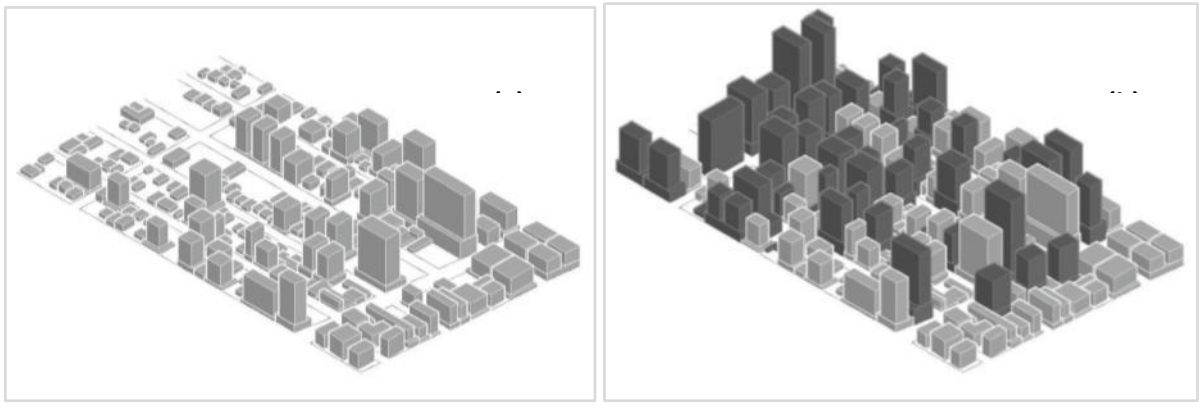
WIND CHARACTERIZATION OF ITAPEMA-SC

Two wind scenarios were selected for simulation: NE at 6.0 m/s and SE at 6.45 m/s. These scenarios were chosen based on data analysis from EPAGRI weather stations, which were used to characterize wind speed, and ERA5 reanalysis data, which were used to confirm predominant wind directions.

BUILDING GEOMETRY EXTRACTION

Three-dimensional geometric models corresponding to the years 2012 and 2025 were developed in AutoCAD (Figure 3). The horizontal perimeters of the blocks and buildings were extracted from the vector data provided by the Municipality of Itapema [18] and from the Google Earth imagery. Building heights were estimated using Google Street View.

Figure 3: Geometric models of the 2012 (a) and 2025 (b) simulation scenarios.



Source: the authors.

The geometries were simplified and arranged in an orthogonal layout to reduce computational cost without compromising the physical representativeness of the problem. This procedure is widely adopted in CFD studies of urban environments.

CFD SIMULATION

This study used ANSYS Fluent 2023 R1 to simulate urban wind flow conditions. For spatial discretisation, an unstructured tetrahedral mesh was employed, with local refinement applied near building surfaces and in regions where higher velocity and turbulence gradients were expected. The computational domain was defined according to well-established recommendations for urban atmospheric flow simulations, adopting distances of 6H upstream of the inlet, along the lateral boundaries, and above the domain, where H represents the height of the tallest building. The downstream region was extended to 12H to minimise artificial recirculation effects at the outlet boundary.

The boundary conditions were specified as follows: a velocity-inlet at the upstream boundary; a pressure-outlet at the downstream boundary; symmetry conditions at the lateral and top boundaries; and the ground and building surfaces defined as wall boundaries with a no-slip condition.

The numerical solution was based on the finite volume method applied to the Reynolds-Averaged Navier–Stokes (RANS) equations. The RNG k-ε turbulence model with Enhanced Wall Treatment was selected because it provides a suitable balance between numerical robustness, predictive accuracy, and computational efficiency for complex urban flows involving separation and recirculation[19].

Pressure-velocity coupling was solved using the Coupled algorithm. Second-order spatial discretisation (Second-Order Upwind) was adopted for the momentum, turbulent kinetic energy (k), and turbulent dissipation rate (ε). Spatial gradients were computed using the Least Squares Cell-Based method, and pressure interpolation was performed using a second-order scheme. The explicit pseudo-transient relaxation factors were set as follows: pressure = 0.50; momentum = 0.50; turbulent kinetic energy = 0.75; turbulent dissipation rate = 0.75; and turbulent viscosity = 0.80.

To define the inlet velocity profile, a parametric expression representing the logarithmic Atmospheric Boundary Layer (ABL) profile was adopted [13], as given by the following equation:

$$U(z) = U_{ref} \cdot \left(\frac{z}{z_{ref}}\right)^{\alpha} \qquad \text{Equation 1}$$

where U_{ref} is the reference wind speed at a height of z_{ref}=10 m, and α=0.22 corresponds to Roughness Class C, representative of densely built urban areas.

The convergence criterion was set to 1×10^{-5} for all monitored residuals, including continuity, velocity components (x, y, z), turbulent kinetic energy (k), and turbulent dissipation rate (ε). Simulations were run for at least 500 iterations to ensure residual stabilisation before result analysis.

ANALYSIS OF THE RESULTS

Results are presented through qualitative and quantitative analysis of the flow fields obtained via numerical simulation. For the qualitative analysis, horizontal cross-sections were defined at 1.5 m or 21.5 m. The 1.5 m plane corresponds to the pedestrian reference height, while the 21.5 m plane lies above roof level, allowing characterization of airflow in the upper urban canopy.

For the quantitative assessment, vertical cross-sections were defined in the direction of the incident flow, identifying aerodynamic wake regions and leeward recirculation zones. Normalized wind velocity (U/U_(ref)) was extracted at eight sampling positions, four from the NE and four from the SE. The reference velocity U_(ref) was defined at 70 m, the height of the tallest building. Profiles were compared between urban scenarios from 2012 and 2025, investigating the impact of verticalization on wind flow.

RESULTS AND DISCUSSION

WIND DISTRIBUTION IN THE URBAN CONTEXT

The results suggest the urban transformation of Meia Praia affected the local wind distribution, especially in the streets perpendicular to Avenida Nereu Ramos. Figure 4a shows greater permeability in 2012 when lower-rise buildings reduced flow roughness. Prevailing velocities range from 2.5 to 5.1 m/s in these streets and areas. However, low-velocity zones already exist in blocks.

Regarding the horizontal plane at 21.5 m (Figure 4b), clear differences between the scenarios are evident. In 2012, the airflow was more evenly distributed over the urban canopy. Velocities were between 5.1 and 7.6 m/s near the waterfront and between 2.5 and 5.1 m/s within block interiors despite localized turbulence between buildings. By 2025, taller buildings generate greater spatial contrast. Accelerations between 7.6 and 10.2 m/s occur in areas with channeling effects, such as Rua 234. Meanwhile, other areas register velocities below 2.5 m/s due to wind shadows and reduced air renewal.

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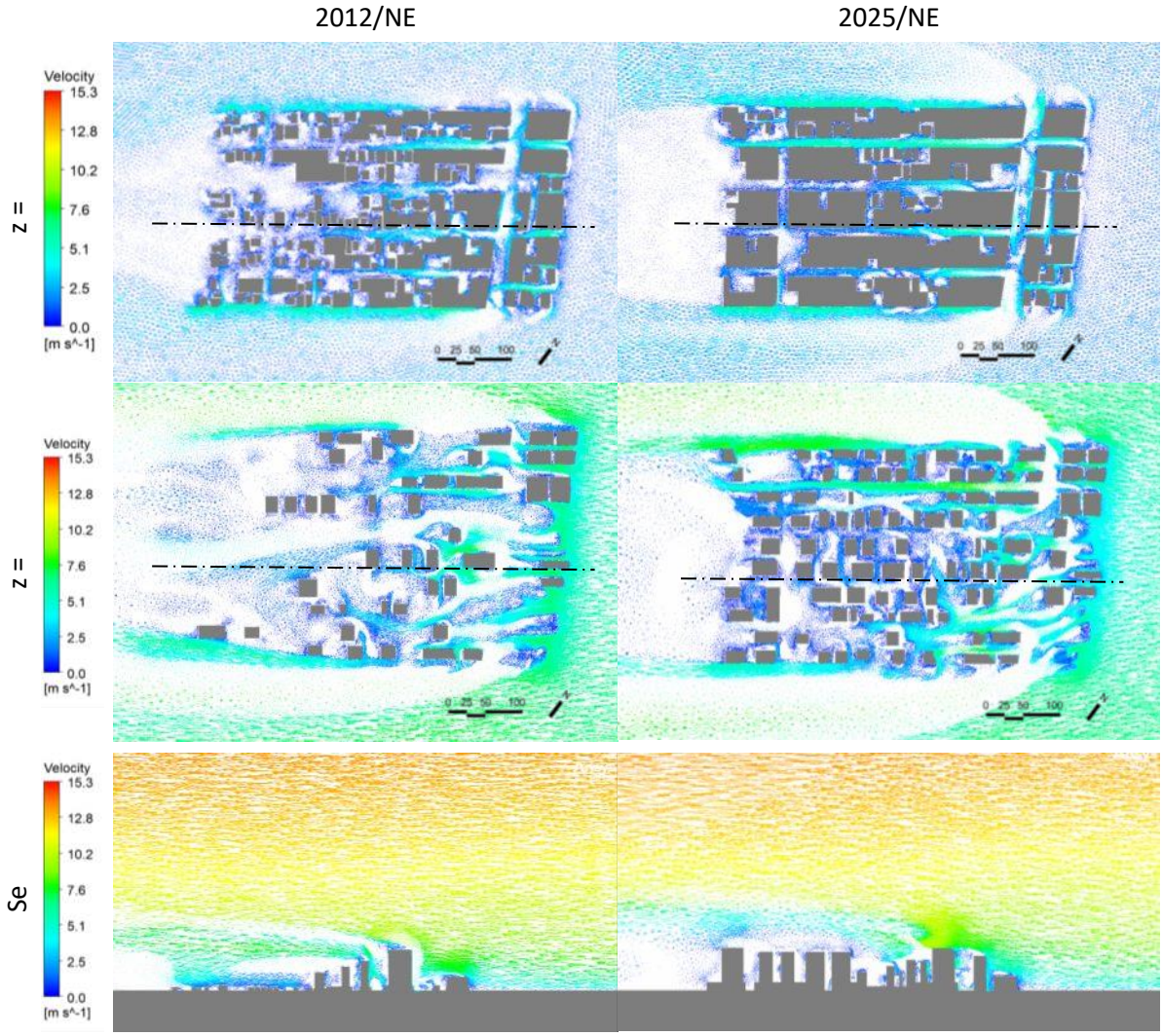
Figure 4: Air velocity fields for NE wind incidence at z = 1.5 m (a), z = 21.5 m (b), and vertical cross-section (c) for the 2012 and 2025 scenarios.



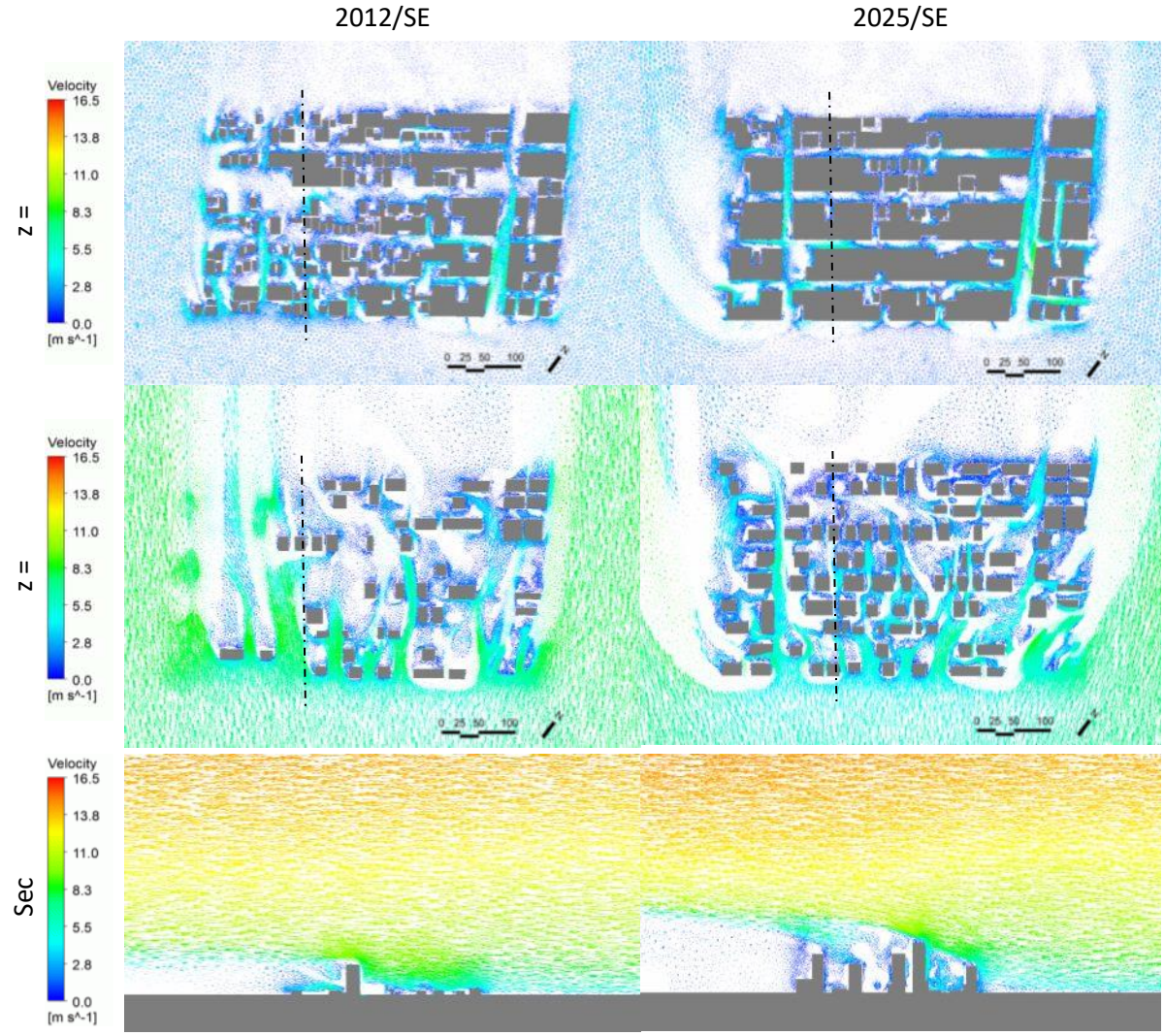
Source: the authors.

The vertical planes (Figure 4c) demonstrate the effect of verticalization on wind structure. In 2012, airflow exhibited greater continuity over the urban canopy. Velocities were between 7.6 and 12.8 m/s in the upper layer, and reduced values were observed near ground level, particularly on the leeward side, with velocities between 0 and 2.5 m/s. By 2025, taller buildings, especially near the waterfront, intensify flow blockage by forming windward barriers, aerodynamic wakes, and recirculation zones within block interiors. Despite localized accelerations between 5.1 and 7.6 m/s, ventilation at pedestrian level remains reduced and discontinuous.

In terms of SE winds, the horizontal plane at 1.5 m (see Figure 5a) shows that in 2012, the airflow was not evenly distributed. It had some areas of acceleration between 2.8 and 5.5 m/s on the windward side and some areas of turbulence between buildings. Meanwhile, the areas inside the buildings had low circulation, with velocities between 0 and 2.8 m/s. For SE winds, the 2025 scenario intensified windward blockage and channeling along Avenida Nereu Ramos and Segunda Avenida, while interior blocks showed lower and more discontinuous airflow than in 2012.

At the 21.5-meter horizontal plane for southeasterly winds (Figure 5b), the 2012 scenario shows greater open airflow over the urban fabric. Prevailing velocities range from 5.5 to 8.3 meters per second (m/s) at the edges and along some corridors. Block interiors register values from 0 to 2.8 m/s, which are associated with low-circulation leeward zones. In 2025, wind speeds range from approximately 5.5 to 8.3 m/s on the windward side of buildings. The airflow exhibits a channeling effect with accelerated velocity. The presence of vortices between volumes and at block edges indicates greater flow discontinuity at this level, which is associated with flow deflection and height differences between buildings.

Figure 5: Air velocity fields for SE wind incidence at z = 1.5 m (a), z = 21.5 m (b), and vertical cross-section (c) for the 2012 and 2025 scenarios.



Source: the authors.

In the vertical planes (Figure 5c), the comparison illustrates the impact of verticalization on the flow structure. In 2012, the smaller scale of the windward buildings reduced flow blockage, allowing for greater wind continuity over the urban fabric. Velocities were between 8.3 and 13.8 m/s in the upper layer and between 0 and 2.8 m/s near the level of pedestrians. By 2025, the increased height of buildings intensifies pressure on windward facades and the barrier effect. This promotes

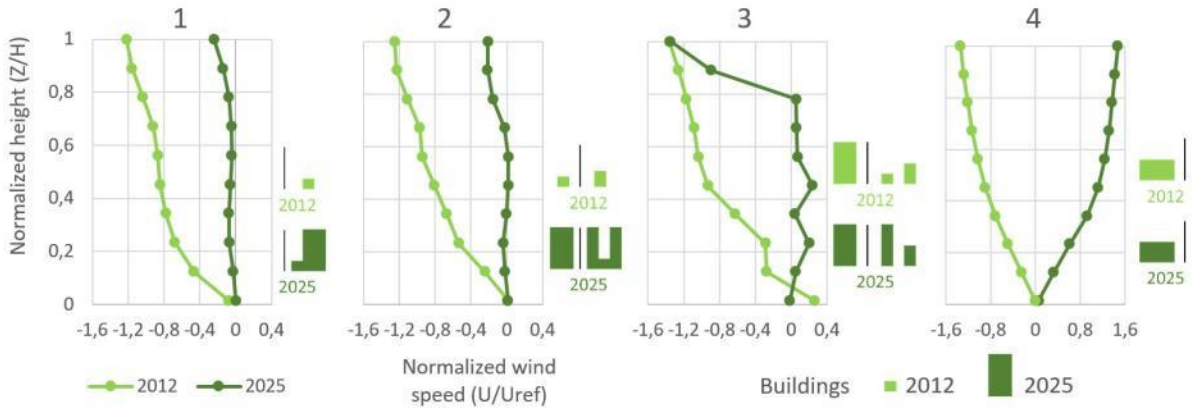
leeward eddies and low circulation within block interiors. While channeling accelerations between 5.5 and 8.3 m/s occur, near-ground airflow becomes more irregular and prone to stagnation.

Buildings near the waterfront hinder interior ventilation, especially at pedestrian level. In 2025, greater vertical building density intensifies the barrier effect and wind concentration along a limited number of street axes. Strategies that increase urban fabric permeability are relevant for air renewal and thermal comfort. Based on evidence from the literature, pilotis at ground level may promote more diffuse wind passage beneath buildings and reduce low-ventilation zones at pedestrian level.

IMPACT OF HEIGHT VARIATION

The findings concerning the normalized vertical air velocity profiles are displayed in Figures 6 and 7, with reference to the NE and SE incident wind flow scenarios, respectively.

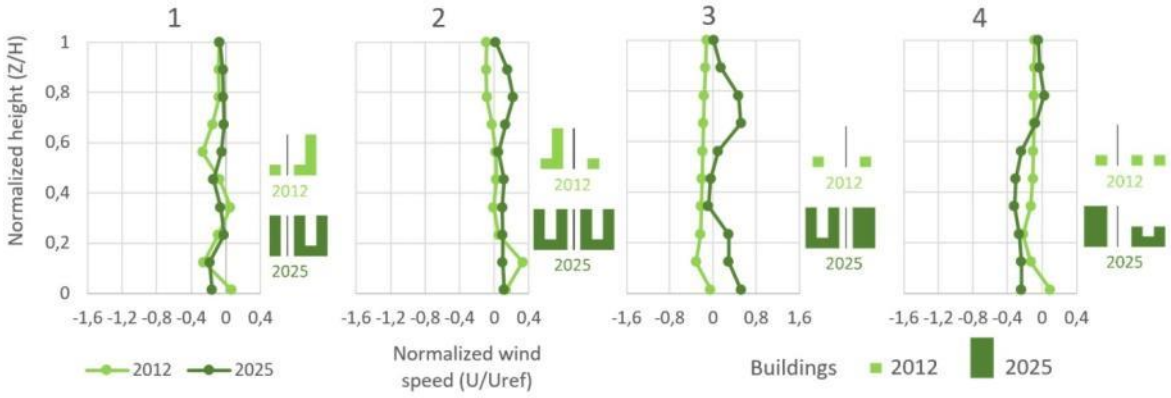
Figure 6: Normalized air velocity profiles at four locations for the NE incident wind condition, comparing the 2012 and 2025 urban scenarios.



Source: the authors.

For NE winds, profiles 1–3 show reduced near-ground recirculation in 2025, associated with flow deflection caused by new buildings and continuous podiums. However, recirculation shifted to higher levels, indicating a more vertically complex flow structure. This configuration may reduce air exchange at intermediate heights, with potential implications for heat removal and pollutant dispersion, which should be investigated in future studies [20]. Profile 4 shows a deep aerodynamic wake and flow reversal in 2025, whereas the 2012 scenario exhibited predominantly free flow.

Figure 7: Normalized air velocity profiles at four locations for the SE incident wind condition, comparing the 2012 and 2025 urban scenarios.



Source: the authors.

For SE winds, verticalization altered the recirculation patterns across all profiles (Figure 7). In 2025, profile 1 showed vortex dissipation, whereas profile 3 changed from a recirculation zone to an accelerated flow corridor. Profile 4 showed two local minima ($Z/H \approx 0.35$ and $Z/H \approx 0.56$), suggesting a two-layer recirculation structure consistent with patterns reported for narrow urban canyons [20]. Low near-ground velocities remained evident in the analysed sections.

CONCLUSION

In just over a decade, the intense occupation of Meia Praia transformed a waterfront of single-family residences into a verticalized environment of continuous base structures and tall towers. CFD simulations demonstrate the direct consequences for urban ventilation. The 2025 scenario showed greater fragmentation of airflow, concentration of airflow along a limited number of street corridors, and reduced wind permeability within interior blocks for both northeastern and southeastern wind directions.

Normalized vertical velocity profiles support this diagnosis. Dense verticalization displaced vortex structures to the upper levels. This configuration may reduce air exchange within the urban canopy, with potential implications for heat removal and pollutant dispersion that should be examined in future studies.

The results indicate that increased building height and continuity may reduce wind permeability and alter airflow distribution within the analysed urban section. Building height and setbacks should be considered together to improve wind permeability and support urban environmental performance. Meia Praia's current configuration highlights the need to incorporate wind permeability and urban environmental performance into planning and design decisions.

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DECLARATION

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