Solar Radiation Indices as Urban Planning Tools: Modeling And Application In Florianópolis

Renata Mansuelo Alves Domingos[1], Pedro Oscar Pizzetti Mariano[1], Fernando Oscar Ruttkay Pereira[1]

[1] Universidade Federal de Santa Catarina, Florianópolis (Brasil)

Abstract

This study proposes a generative methodology for urban form modeling guided by solar performance, applied to the continental area of Florianópolis, Brazil. The approach integrates parametric modeling, solar radiation simulation, and morphological analysis to explore how urban densification affects solar accessibility. Implemented in Rhinoceros 3D, Grasshopper, and Ladybug Tools, the workflow follows four stages, environment, selection, organization, and simulation, and evaluates four temporal scenarios (2003, 2013, 2023, and a projected future). Results show a progressive 64% reduction in total envelope radiation from 2003 to the future scenario, with façades being the most affected by shadowing. Generative simulations revealed that adjusting spacing, orientation, and height distribution can enhance solar exposure by up to 40% without reducing density. The methodology, still under experimental testing, demonstrates potential for integrating solar performance into volumetric planning, enabling compact yet climatically adaptive cities.

Keywords: Urban densification, photovoltaic potential, energy sustainability, solar accessibility, parametric design

1. Introduction

Urban environments are undergoing profound transformations due to the accelerated processes of densification, land scarcity, and vertical expansion that characterize contemporary cities. These dynamics have direct implications for environmental performance, particularly regarding access to solar radiation, a critical factor for both energy efficiency and urban comfort. In coastal and topographically diverse cities such as Florianópolis, southern Brazil, urban form has become a decisive variable in determining how solar energy interacts with the built environment. The capacity of buildings and open spaces to receive sunlight depends not only on latitude and climate but also on geometric characteristics such as height, spacing, orientation, and the spatial configuration of urban blocks (Zhao et al., 2023; Lan et al., 2022).

The relationship between urban morphology and solar accessibility has long been recognized as a key interface between urban planning and environmental performance. Studies have demonstrated that compact and high-density morphologies tend to reduce solar availability due to shadowing and self-obstruction effects (Godoy-Shimizu et al., 2021). Zhao and Gou (2023) highlighted that façade exposure to sunlight in mixed-use neighborhoods is strongly constrained by building height and street width ratios, while Lan et al. (2022) confirmed that lower and more evenly distributed urban fabrics exhibit higher solar potential and energy performance. These findings emphasize that spatial form is not a neutral variable but an active determinant of environmental behavior and urban sustainability.

In Brazil, where the tropical and subtropical climates provide abundant solar resources, this relationship gains strategic relevance. Yet, the morphological configuration of cities often undermines the efficient use of solar radiation. Research conducted in Salvador (Bastian, 2023) and São Paulo (Girotti et al., 2019) showed that unplanned verticalization leads to significant losses in solar exposure, up to 60% reduction in façade radiation, which negatively impacts photovoltaic generation and indoor comfort. Such patterns reveal the lack of integration between land use regulation and solar-oriented urban design, resulting in dense environments that fail to capitalize on one of the country's most valuable renewable energy assets.

Recent advances in computational design have opened new possibilities for bridging this gap. Parametric modeling and simulation platforms, such as Rhinoceros 3D, Grasshopper, and Ladybug Tools, have enabled

10.18086/swc.2025.08.21 Available at http://proceedings.ises.org

dynamic analyses of solar behavior at the urban scale. These tools make it possible to model realistic scenarios, simulate annual solar radiation on building surfaces, and visualize how morphological decisions affect energy potential across time and space (Zhang et al., 2024). The integration of these tools with geographic and climatic databases has transformed solar analysis from a post-design evaluation into a generative process capable of informing urban form creation.

This methodological evolution has given rise to the concept of performance-driven urban design, in which spatial form emerges as a function of environmental performance targets rather than purely geometric or economic constraints. Within this framework, solar radiation acts as a generative parameter, a quantifiable input guiding the organization, proportion, and orientation of urban blocks. Instead of using static density indicators such as the Floor Space Index (FSI) or Ground Space Index (GSI) merely as regulatory boundaries, the proposed approach treats them as flexible variables that can be optimized according to solar access criteria. Morphological relations derived from tools such as Spacemate (Berghauser Pont & Haupt, 2009) can thus be recalibrated based on environmental performance, enabling the formulation of design configurations that balance density, height, and solar efficiency.

While numerous studies have correlated existing urban forms with their solar potential, fewer have explored how urban form itself can be generated and optimized through solar simulation feedback. Zhang et al. (2024) emphasize that performance-based generation techniques can produce more energy-efficient urban morphologies when environmental variables are directly embedded into the design process. In this perspective, solar radiation is not merely evaluated, it becomes a driver for morphological synthesis, influencing spatial distribution, volumetric proportion, and the rhythm of built and open areas. Such approaches resonate with the paradigm of climate-adaptive urbanism, which seeks to integrate scientific modeling, environmental data, and urban policy into coherent planning instruments.

Florianópolis offers an ideal context to apply and test such a methodology. The city's ongoing verticalization process and its recent urban plan revision illustrate the tension between growth and environmental quality. The continental sector of the municipality, characterized by medium density and mixed land use, has undergone rapid morphological changes since the early 2000s. Over two decades, the area has transitioned from predominantly low-rise housing to high-rise residential and commercial buildings, generating significant variations in solar exposure. By modeling this evolution through parametric tools and comparing different temporal scenarios, past, present, and a projected future, it becomes possible to assess how changes in urban form have affected solar accessibility and, in turn, how alternative configurations could optimize solar utilization.

The proposed methodology in this study integrates morphological modeling, parametric simulation, and spatial analysis to generate and evaluate urban forms oriented by solar performance. Instead of merely measuring the solar potential of existing structures, the approach establishes a form-generation process in which building height, spacing, and footprint distribution are defined based on solar incidence criteria. The method allows the simulation of different density configurations within the same regulatory parameters, identifying which combinations of FSI, GSI, and building height achieve the most favorable balance between density and solar availability.

In this sense, solar radiation operates not as an outcome but as a design input. By transforming radiation data into a generative constraint, the method promotes a redefinition of how urban form can evolve under densification without compromising energy performance. The objective is to demonstrate that it is possible to formulate urban morphologies that simultaneously meet density demands and maximize solar accessibility, contributing to more sustainable and climate-resilient planning practices.

Therefore, this research aims to analyze the evolution of solar accessibility in Florianópolis and to propose a new methodology for urban form generation guided by solar performance. Through the integration of computational simulation and morphological analysis, the study seeks to establish a replicable framework that connects urban geometry and solar behavior, enabling planners and designers to create future cities that are not only denser but also energetically intelligent and climatically adaptive.

2. Methodology

2.1. Characterization of the Study Area

The methodological development was applied to a representative portion of the continental area of Florianópolis, southern Brazil. This sector, classified as a Mixed Service Area (AMS–10.5) according to the municipal zoning regulation, exhibits medium density, mixed land use, and a pronounced process of verticalization over the past two decades. Its urban dynamics capture the city's broader spatial challenges: irregular lot subdivisions, heterogeneous building heights, and limited open-space continuity. These features make it a suitable testing ground for developing and evaluating a solar-oriented generative approach to urban form.

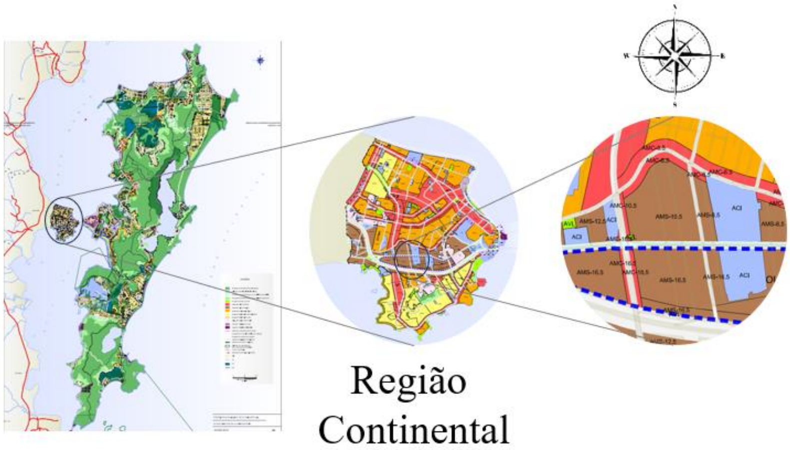

Figure 1: The continental area of Florianópolis

The area's morphology was reconstructed through a combination of field verification, aerial imagery, and the historical data available through 3D mapping tools. The morphological evolution was analyzed through four temporal scenarios, 2003, 2013, 2023, and a projected Future Scenario, each representing a distinct stage in the process of densification. While the first three scenarios reproduce existing configurations, the fourth was generated using the maximum buildable parameters permitted by the current Master Plan (2023 revision), enabling the exploration of the upper limits of urban density and its consequences for solar performance.

2.2. Generative Modeling Process

The generative modeling process developed in this study integrates parametric design techniques, solar radiation simulation, and morphological performance analysis in order to explore how different spatial configurations influence solar accessibility in high-density urban environments. Rather than evaluating fixed, pre-defined urban forms, the methodology proposes a dynamic and iterative workflow in which solar performance data actively guide the generation and adaptation of urban form. This allows the simulation of alternative spatial arrangements that maintain the same total construction potential while optimizing environmental quality.

All modeling and simulation procedures were conducted in Rhinoceros 3D, using the Grasshopper visual programming interface combined with Ladybug Tools. This parametric environment was chosen for its ability to integrate geometric modeling, environmental simulation, and data visualization into a single iterative process. The generative modeling workflow was structured in five interrelated stages: (1) definition of geometric parameters, (2) volumetric generation, (3) simulation of solar radiation, (4) performance evaluation, and (5) feedback and refinement.

The geometric foundation of the model was established using cadastral and regulatory information from the municipal zoning plan. Each lot was defined by its frontage, depth, and setback conditions, frontal, lateral, and rear distances, which correspond to the geometric parameters outlined in the city's Mixed Service Area (AMS–10.5) regulation.

To replicate realistic development patterns, individual lots with similar uses and dimensions were combined through a process of remembrancement, forming larger parcels that more accurately represent contemporary redevelopment practices in the study area. The resulting parcels ranged from approximately 1,400 to 1,500 m², closely matching the average lot size of recently built high-rise developments. These remembranced parcels served as the base units for volumetric generation.Additional geometric constraints were incorporated to reflect urban design conditions such as street width, sidewalk width, and corner subtractions, which affect shading and sky view factors. The height of each floor was standardized at 3.0 meters, consistent with typical local construction practices.

The second stage consisted of generating three-dimensional building volumes parametrically. For each parcel, the base footprint was extruded vertically according to a variable number of floors, from low-rise (1–3 floors) to mid- and high-rise typologies (up to 10 floors), consistent with the maximum heights permitted by zoning.

To test the effects of building placement and spacing on solar performance, the model introduced systematic variations in setbacks, orientation, and alignment. Lateral and rear setbacks were proportionally adjusted to building height, typically applying a ratio of height divided by five (H/5) to define the offset distance, which ensures that taller buildings are accompanied by wider open spaces. The algorithm also included corner subtractions and random orientation shifts of ±15°, creating more realistic irregularities in the built fabric.

Each configuration generated a distinct morphological typology while maintaining the same total floor area ratio (FSI). In this way, it was possible to compare the environmental implications of different urban forms — compact blocks, dispersed towers, linear alignments, or staggered arrangements — under equivalent density conditions. The resulting dataset of 3D models represents a series of plausible future morphologies for the study area, ranging from the historical pattern of 2003 to a projected high-density scenario.

The third stage involved annual solar radiation simulations for each generated morphology. Using the Ladybug Radiation Analysis component, the models were analyzed under real climatic conditions based on the SWERA (Solar and Wind Energy Resource Assessment) dataset for Florianópolis. The simulations accounted for all major components of solar radiation — direct, diffuse, and reflected — and calculated cumulative annual incident energy on every building surface, expressed in kWh/m². The results were visualized as color-coded heat maps applied to the 3D models, allowing immediate identification of areas with high or low solar exposure.

To ensure comparability between scenarios, the analysis was performed using a uniform grid resolution for the radiation mesh and a consistent north orientation corresponding to the city’s true azimuth. For each building, data were aggregated for three envelope components: (a) roofs, (b) façades, and (c) vertical walls facing different orientations. This disaggregation enabled a more detailed understanding of how morphology influences solar behavior.

Following the simulations, the solar radiation results were correlated with morphological indicators derived from the models. The parameters analyzed included building height, footprint area, spacing between volumes, lot coverage, and total built volume. The Floor Space Index (FSI) and Ground Space Index (GSI) were computed for each configuration, and their relationship with average radiation per square meter was plotted in Spacemate diagrams.

This stage provided a quantitative link between urban density and solar accessibility, revealing how changes in vertical and horizontal distribution affect radiation performance. The data showed clear non-linear correlations: compact configurations (high FSI, low GSI) consistently exhibited lower radiation availability than those with wider spacing or variable heights.

2.3. Visual Programming Structure

The visual programming structure developed for this research was organized into four sequential action sets: (1) environment, (2) selection, (3) organization, and (4) simulation — based on methodologies previously employed in computational studies of urban environments (Mariano, 2018; Mariano, 2018; Mariano, 2020). These stages operate in a cascade logic, where each subsequent action begins only after the previous one has been completed. This framework ensures a controlled and traceable workflow, allowing both analytical and generative operations within the same computational environment.

The programming was implemented using Rhinoceros 3D, version 8 (McNeel, 2014) under an academic license, together with its Grasshopper component (Rutten; McNeel, 2014) and the Ladybug Tools plugin suite (Roudsari; Pak, 2013). This integrated setup allows for the construction, simulation, and iterative refinement of three-dimensional urban models based on parametric rules. At the end of each sequence, the structure permits the execution of an additional action — either iterative, where the process can be autonomously modified, or generative, where changes in the domain values trigger new geometric or environmental configurations.

The programming logic developed for this article follows the same four-step sequence:

Environment:

This initial stage establishes the spatial and contextual framework for the analysis. A parametric environment is generated to accommodate the object of study and its surrounding urban fabric. The adjustable parameters within this stage include the lot frontage and depth (replicated across 14 neighboring parcels), the width of sidewalks, and the street width in front of the analyzed area. These variables define the basic morphological boundaries that influence solar exposure and shading conditions.

Selection:

In the second stage, the urban and dimensional parameters of the object are defined. This includes the setbacks of both the building base (podium) and tower, independently adjustable; the floor-to-floor height of each section; the number of podium levels; and the utilization coefficient (building exploitation index, I.A.). These parameters are assembled and modeled within the Grasshopper environment to construct the initial geometry of the simulated object.

Organization:

The third stage focuses on the geometric and non-geometric organization of the model. Here, the chosen exploitation index (I.A.) directly influences the spatial logic, since different volumetric cuts applied to the tower's footprint — such as corner subtractions and edge recesses — modify the overall projected area. These geometric changes are automatically cross-checked with the I.A. to ensure regulatory consistency: if the tower's projection area is reduced, additional floors may be added; conversely, larger projections may require fewer floors.

During this stage, the simulation parameters are also defined through Ladybug components, including the sensor grid resolution, simulation hours, resulting domain range, and false-color map scale. These settings ensure that each simulation iteration operates under consistent environmental conditions and data quality standards.

Simulation:

The final stage involves reviewing the overall programming structure and initiating the data generation process. In the proposed workflow, the outputs — consisting of cumulative solar radiation maps and numerical performance data — are organized and catalogued manually for post-processing. For this specific study, however, the final stage was connected to the Galapagos genetic optimization component (Rutten, 2025) within Grasshopper, initiating a generative optimization cycle aimed at maximizing the best-performing configurations in terms of solar radiation exposure.

This four-stage structure provides a systematic and transparent computational pipeline, capable of handling the entire process from model setup to environmental simulation and optimization. By operating in a cascade logic, it ensures the reliability of each stage while preserving flexibility for iterative adjustments.

Moreover, the inclusion of a genetic algorithm at the final stage introduces an adaptive dimension to the process: the simulation results can feed back into the modeling system, allowing autonomous alterations in geometry or parameter values. This makes it possible to identify not only the solar performance of a given configuration but also to generate new configurations optimized for radiation capture.

Ultimately, the visual programming structure serves as the core operational mechanism of the generative methodology proposed in this study. It enables the translation of complex morphological and environmental relationships into programmable logic, facilitating the exploration of design scenarios that reconcile urban density with solar efficiency.

3. Results and discussion

3.1. Urban Growth and Morphological Transformation

The selected study area, located in the continental sector of Florianópolis, has undergone substantial morphological transformation over the last two decades. Between 2003 and 2023, the total built-up area increased by approximately 55%, while the proportion of high-rise buildings (above seven floors) rose from 2% to nearly 30% of the total constructed volume. In the projected future scenario, modeled according to the current municipal zoning parameters, this share is expected to reach almost 80%, indicating an evident process of verticalization and densification.

This transformation resulted not only in an increase in the overall built density but also in a marked reduction of open-space continuity, generating more compact urban blocks with higher obstruction coefficients. The morphological evolution observed in the simulated models (2003, 2013, 2023, and Future) reveals a clear trend toward the replacement of low-rise residential typologies by mixed-use towers occupying consolidated plots or newly remembranced lots. The remembrances modeled in the generative process demonstrated that typical block recompositions, averaging 1,400–1,500 m², could accommodate buildings of up to ten stories under the existing zoning rules, creating volumetric compositions that significantly alter the local solar geometry.

The three-dimensional simulations illustrate that the progressive densification leads to a proportional reduction in sky view factors and in the exposure of façades to direct sunlight. In 2003, low-rise buildings (one to three floors) dominated the landscape, ensuring wide access to solar radiation on roofs and upper façades. By 2023, however, the increase in medium-rise and high-rise constructions caused a notable reduction in solar exposure, with large shadow patterns extending over neighboring lots and streets. In the future scenario, characterized by the full exploitation of the construction potential allowed by zoning, vertical volumes overshadow nearly 60% of the ground surface during winter months, drastically modifying the local solar microclimate..

3.2. Evolution of Solar Radiation Availability

Quantitative analysis of solar radiation on building envelopes shows a consistent decline in available solar energy per square meter of built surface across the four temporal scenarios. When comparing 2013 to 2003, total annual radiation incident on the envelopes decreased by approximately 7%. Between 2013 and 2023, this reduction intensified to about 15%. The projected future configuration presents a dramatic decline of nearly 64% in relation to the 2003 baseline.

This downward trend reveals a direct relationship between morphological densification and solar accessibility. In the 2003 model, average annual radiation values on building envelopes reached 1,800–2,000 kWh/m² for one- to three-story typologies. In 2013, these values dropped to around 1,600 kWh/m², while in 2023 they fell further to approximately 1,200 kWh/m². The future scenario exhibits the lowest exposure levels, with average values below 700 kWh/m² in high-rise typologies.

The results demonstrate that the loss of solar radiation is not uniform across building components. Roof surfaces maintain the highest levels of solar exposure throughout all scenarios, while façades experience the most severe reductions due to shadowing and mutual obstruction. In the future configuration, roofs of low-rise buildings still receive up to 2,000 kWh/m² annually, whereas façades of high-rise towers record less than 400 kWh/m². The generative simulation thus evidences the asymmetric impact of densification, where the upper layers of the urban fabric retain favorable radiation levels while the vertical surfaces, essential for daylighting and photovoltaic integration, become progressively deprived of sunlight.

A closer look at the height-dependent variation of solar access indicates that the transition from low- to mid-rise structures produces the steepest losses. The increase from one to two floors leads to an average 50% decrease in available radiation, while the difference between two and three floors corresponds to a further 15% reduction. Between three and four floors, the decline becomes more accentuated again, reaching 40%. From five stories upward, radiation values tend to stabilize, with minor variations between eight and ten stories, suggesting that the upper height range of the urban profile operates under a relatively constant but reduced solar regime.

3.3. Spatial Distribution and Morphological Correlation

The integration of solar data with morphological parameters (FSI, GSI, building height, and coverage ratio) allows a more comprehensive interpretation of these results. When plotted in the Spacemate diagram, the relationship between density and solar availability follows an inverse and nonlinear trend. Blocks with FSI values below 1.5 (low density and wide spacing) present average radiation levels between 1,800 and 2,000 kWh/m². Intermediate configurations (FSI 2–3) show values ranging from 1,000 to 1,600 kWh/m², whereas high-density typologies (FSI above 4) drop to approximately 500–600 kWh/m².

These correlations demonstrate that the volumetric efficiency of compact urban forms, although advantageous from a land-use perspective, leads to significant energetic inefficiencies in terms of solar gain. The findings support the hypothesis that morphological parameters commonly used in urban regulation, such as maximum height and lot coverage, are insufficient to ensure environmental performance. Instead, the integration of solar criteria into the generative process enables a more balanced outcome, achieving comparable density levels while preserving favorable radiation exposure.

The generative models developed for the future scenario provide further insight into this relationship. By varying the spatial distribution of the same total built volume, it was possible to generate configurations with improved solar performance without reducing density. In particular, increasing the average spacing between towers by 6–8 meters or adjusting their relative orientation to optimize solar capture resulted in radiation gains of up to 25% in envelope exposure. Similarly, introducing graduated height transitions between adjacent plots reduced shadow lengths, improving sunlight penetration into lower façades and open spaces. These results illustrate the potential of performance-based generation as a planning strategy to reconcile urban compactness with solar efficiency.

3.4. Spatial Distribution and Morphological Correlation

The generative methodology applied in this study demonstrates that solar performance can effectively serve as a guiding variable in urban form design. By iteratively simulating and evaluating morphological variations, it becomes possible to identify forms that optimize solar accessibility without compromising regulatory density limits. The experiments indicate that even within the existing planning framework, substantial improvements can be achieved by adjusting building arrangement and block composition.

For example, configurations maintaining a similar total floor area but redistributing built mass horizontally, through staggered building placement or volumetric gradation, showed radiation levels up to 40% higher than those obtained from compact, uniformly vertical blocks. Such outcomes suggest that solar-oriented generation should inform not only design practices but also urban policy instruments. If solar performance is embedded into the parameters that define permissible forms, urban planning can evolve from a static regulatory mechanism into a dynamic, performance-based system.

It is important to note that this generative methodology is still undergoing experimental testing and refinement. The process aims to move beyond traditional two-dimensional representations of urban density, usually expressed as floor area ratios or land occupation rates, and to explore density as a three-dimensional volumetric condition. By evaluating the buildable volume rather than only the buildable area, this approach introduces a new way to balance spatial and environmental efficiency. The capacity to simulate and visualize volumetric potential allows planners to identify where voids within the urban fabric can be strategically created to enhance solar access and ventilation, while maintaining the overall constructive density established by zoning regulations.

In this sense, the method proposes a transition from the notion of “how much can be built” to “how built form can be distributed in space.” This volumetric logic opens possibilities for creating lighter and more permeable urban morphologies, capable of reconciling compactness with environmental quality. The generation of strategic voids, courtyards, setbacks, and open corridors, not only mitigates shading conflicts but also improves daylight penetration and microclimatic comfort. Therefore, the preliminary results of this ongoing testing phase suggest that a volume-based assessment of urban density may represent a viable pathway toward integrating solar performance, spatial quality, and densification objectives within the same regulatory framework also like de Figure X.

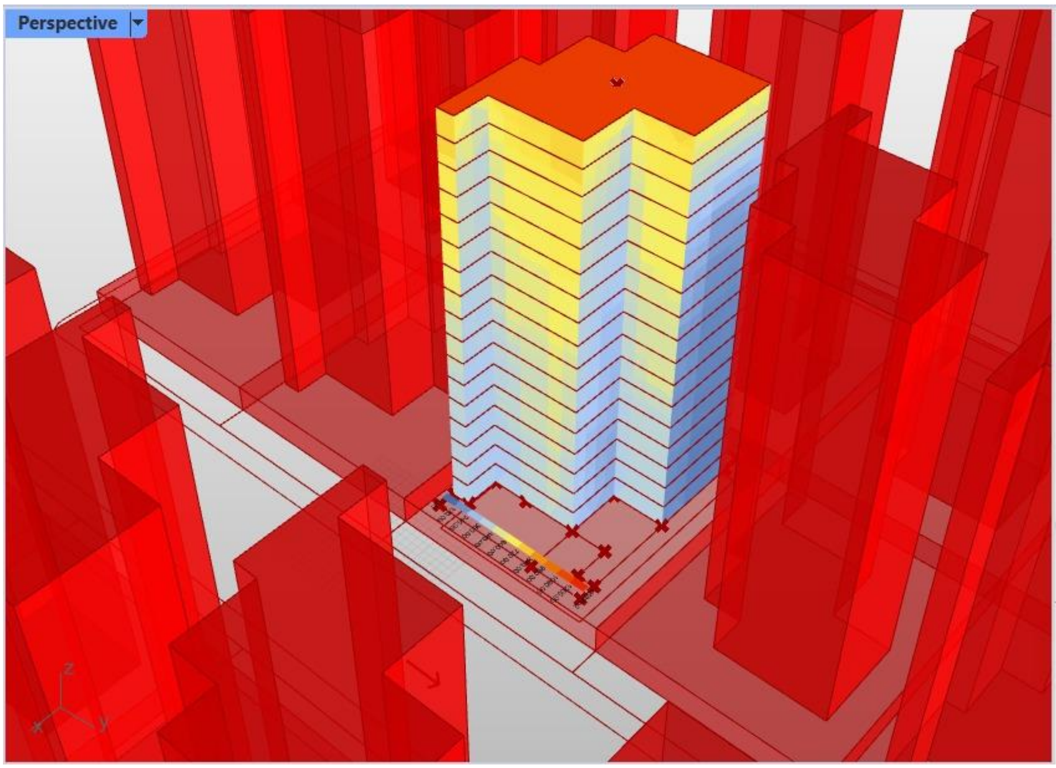

Figure X: Perspective of one of the models with high radiation in the envelope

These findings align with the emerging international trend toward performance-oriented planning, which integrates environmental simulation and urban governance. The results achieved for Florianópolis illustrate that morphological design guided by solar behavior can significantly enhance energy potential and mitigate the adverse effects of densification. More importantly, they demonstrate the feasibility of applying generative modeling as a planning support tool capable of visualizing, quantifying, and optimizing solar access before construction occurs.

4. Final considerations

The results of this research reinforce that solar radiation can be a fundamental variable for guiding urban form generation. The proposed methodology demonstrated that performance-based modeling, when coupled with iterative simulation, enables the creation of dense yet environmentally efficient morphologies. By analyzing four temporal stages of urban growth in Florianópolis, it was possible to identify a consistent and quantifiable relationship between verticalization and the reduction of solar accessibility, both on building envelopes and in public spaces.

The study highlights that the generative approach remains under development, but its experimental phase already indicates practical potential for urban design and planning. By employing a volumetric interpretation of density, the process enables designers and planners to assess how the buildable volume can be distributed in space rather than merely how much area can be built. This conceptual shift opens new possibilities for creating urban fabrics with strategic voids — setbacks, courtyards, and open corridors — that enhance solar access, daylight quality, and natural ventilation while preserving the same constructive capacity defined by zoning regulations.

The integration of a genetic optimization component, Galapagos, added an adaptive dimension to the process, allowing automatic identification of configurations that maximize solar exposure. These results show that generative simulation can serve as a decision-support tool for performance-oriented planning, bridging the gap between environmental modeling and regulatory practice.

In the case of Florianópolis, the methodology offers a potential framework for revising local urban parameters under a climate-adaptive perspective. By embedding solar behavior into the design and approval processes of new developments, municipalities could move toward more resilient, energy-efficient, and equitable cities.

Future work will focus on expanding the generative model to incorporate additional environmental layers, such as daylight autonomy, natural ventilation, and thermal comfort, and to test its scalability across different morphological and climatic contexts. Ultimately, the study contributes to advancing a performance-driven paradigm in urban planning, where form generation is guided not only by density or land use but by the energetic and climatic performance of the city itself..

5. References

Bastian, A.V., 2023. Morfologia Urbana e a Geração de Energia Solar Fotovoltaica em Salvador. PhD Thesis, Universidade Federal da Bahia, Salvador, Brasil. Accessed 10 Sep. 2025.

Berghauser Pont, M.Y.; Haupt, P.A., 2009. Space, Density and Urban Form. TU Delft, Delft University of Technology. Accessed 13 Sep. 2025.

Florianópolis, 2023. Lei Complementar nº 739, de 2023. Altera a Lei Complementar nº 482, de 2014 (Plano Diretor de Florianópolis) e consolida seu processo de revisão. Prefeitura Municipal de Florianópolis. Available at: https://leismunicipais.com.br. Accessed 31 Jan. 2024.

Girotti, C.; Marins, K.R.C.; Lara, A.H., 2019. Análise da morfologia urbana para maximização de geração de energia fotovoltaica no Belenzinho, em São Paulo. Ambiente Construído, 19(4), p. 7–22. DOI: 10.1590/s1678-86212019000400340. Accessed 15 Sep. 2025.

Godoy-Shimizu, D.; Steadman, P.; Evans, S., 2021. Density and morphology: from the building scale to the city scale. Buildings and Cities, 2(1), p. 92–113. DOI: 10.5334/bc.83. Accessed 15 Sep. 2025.

Lan, H.; Gou, Z.; Hou, C., 2022. Understanding the relationship between urban morphology and solar potential in mixed-use neighborhoods using machine learning algorithms. Sustainable Cities and Society, 87, 104225. DOI: 10.1016/j.scs.2022.104225. Accessed 2 Aug. 2025.

Mariano, P.O.P.; Pereira, A.T.C.; Vaz, C.V., 2018. Avaliação luminosa de elementos de fachada com características fractais. Parc Pesquisa em Arquitetura e Construção, 9(1), p. 3–18. DOI: 10.20396/parc.v9i1.8650255. Universidade Estadual de Campinas. Accessed 10 Sep. 2025.

Mariano, P.O.P., 2018. Processo de projeto paramétrico de elementos de fachada com características da geometria fractal. 189 f. Master’s Dissertation – Programa de Pós-Graduação em Arquitetura e Urbanismo, Projeto e Tecnologia do Ambiente Construído, Universidade Federal de Santa Catarina, Florianópolis. Accessed 10 Sep. 2025.

Mariano, P.O.P. et al., 2020. Autonomous parametric process for daylight simulation applied to the proposal of a daylighting of buildings performance tool. In: SIGraDi 2020 – 24th Conference of the Iberoamerican Society of Digital Graphics, Medellín: SIGraDi, pp. 534–539. Accessed 10 Sep. 2025.

McNeel, R.; Associates, 2014. Rhinoceros 3D Modelling Software, Version 5. McNeel & Associates, Seattle, USA. Accessed 12 Sep. 2025.

Roudsari, M.S.; Pak, M., 2013. Ladybug: a parametric environmental plugin for Grasshopper to help designers create an environmentally conscious design. In: 13th Conference of International Building Performance Simulation Association (BS2013), Chambéry, France. Proceedings of BS2013, pp. 3128–3135. Accessed 12 Sep. 2025.

Rutten, D.; McNeel, R.; Associates, 2014. Grasshopper 3D, EULA. Available at: www.grasshopper3d.com. Accessed 12 Sep. 2025.

Tomasetti, T., 2019. TT Toolbox for Grasshopper. CORE Studio. Available at: http://core.thorntontomasetti.com/colibri-release/. Accessed 12 Sep. 2025.

Zhang, X.; Wang, X.; Du, S.; Tian, S.; Jia, A.; Ye, Y.; Gao, N.; Kuang, X.; Shi, X., 2024. A systematic review of urban form generation and optimization for performance-driven urban design. Building and Environment, 253, 111269. DOI: 10.1016/j.buildenv.2024.111269. Accessed 01 Sep. 2025.

Zhao, H.; Yang, R.J.; Liu, C.; Sun, C., 2023. Solar building envelope potential in urban environments: A state-of-the-art review of assessment methods and framework. Building and Environment, 244, 110831. DOI: 10.1016/j.buildenv.2023.110831. Accessed 6 Sep. 2025.

Zhao, K.; Gou, Z., 2023. Influence of urban morphology on façade solar potential in mixed-use neighborhoods: Block prototypes and design benchmark. Energy and Buildings, 297, 113446. DOI: 10.1016/j.enbuild.2023.113446. Accessed 05 Oct. 2025.