Integrating Ecological Modeling into the 3D CAD System Rhinoceros

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Abstract: Architecture and ecology have been intertwined for centuries, reflecting the enduring need to harmonize built environments with natural processes. Addressing contemporary challenges such as global warming, urbanization, and biodiversity loss requires innovative design methodologies that incorporate ecological knowledge. This paper introduces a new approach to ecological modeling in Rhinoceros® (Rhino), realized through the new Rhino/Grasshopper plugin, RHINO.ECOLOGIC® (MCNEEL EUROPE 2025), that applies a voxel-based strategy to 3D models. By integrating the ecological *"Joschinski Model"* (JOSCHINSKI 2024), the plugin generates spatio-temporal maps of soil conditions, light availability, species distribution, biodiversity and biomass. Parametric and data-driven design principles enable architects and planners to customize simulations according to site-specific or project-specific constraints, facilitating more sustainable decisions early in the planning process. Preliminary tests with professional landscape architects confirmed the approach's feasibility, particularly when analyzing large-scale neighborhoods. Ultimately, this method offers a powerful computational tool for cultivating ecologically resilient and diverse urban landscapes, bridging the gap between computational design and ecology.

Keywords: Ecological modeling in 3D CAD, data-driven design, biodiversity and biomass simulations, Rhino/Grasshopper plugin, Rhino.Ecologic®

1 Introduction

The intricate relationship between architecture and ecology has evolved over centuries, manifesting in diverse sustainable practices across cultures and time periods, from ancient green roofs (*Newgrange* in Ireland 3200 BC) and terrace gardens (Mesopotamian ziggurats and Babylon's *Hanging Gardens of Semiramis*) to sophisticated irrigation systems (e. g., hydraulic irrigation systems of *Angkor Wat* 1150 CE) and vernacular traditions. These diverse examples, spanning continents and millennia, demonstrate the enduring role of ecology and architecture. The *American Environmental Justice Movement* of the 1960s revitalized ecological practices by embracing Indigenous knowledge, advocating for sustainable and equitable environments (BULLARD 1990, EHRLICH 1968). As the *Glass Box style* high-rise became the dominant architectural symbol of American cities in the 1970s, a growing awareness of nature spurred architects, environmentalists, and ecologists to explore sustainable design alternatives (STEPHAN 2022, MCHARG 1992).

Today, global warming, rapid urbanization, and, as result, drastic land cover changes and loss of natural ecosystems cause an increasingly dynamic and uncertain environmental future. Already poor environmental conditions in urban areas are exacerbated by urban heat islands, lack of green spaces, biodiversity loss, and pollution, and pose a serious threat to human well-being. This leads, for example, to rising healthcare costs due to increased respiratory, cardi-

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ovascular, and mental health issues (BUTCHART et al. 2012, NEEM et al. 2009). Governments and urban planners are striving to counteract these challenges by introducing new concepts in city planning that prioritize natural and green spaces, sustainable infrastructure, and climate-resilient designs. Furthermore, preserving plant biodiversity is crucial for mitigating the negative effects of climate change (ISBELL et al. 2011, MAESTRE et al. 2012). At the same time, urban areas are, at least for some species, excellent refugia preventing their extinction (GENTILI et al. 2024) – church towers are used by endangered Peregrine falcons in European cities (MAK et al. 2021), Carabid beetles are enclosed and protected on roundabouts (HELDEN & LEATHER 2004), and churchyards provide stable ecosystems for e. g., rare mosses, lichens, mushrooms, orchids and old trees (LÖKI et al. 2019). In light of these facts, the integration of ecological data into architectural design practices has become not only prudent but essential to promote sustainable urban development and enhance human well-being (GRIMM et al. 2008).

Among the emerging tools in this interdisciplinary space, species distribution models (SDM), are gaining currency as vital instruments for informing design, policy, and stakeholder decisions. These spatial models, which depict the geographical range and habitat requirements of individual species or communities, have long served as fundamental tools in conservation biology, biogeography, climate change research, and habitat or species management (GUISAN et al. 2000). As noted by J. ELITH et al., predicting species distributions has been central to diverse applications in ecology, evolution, and conservation science (ELITH et al. 2006). With the rapid advancement of geospatial technologies (GIS), remote sensing methods, and data modeling techniques the accuracy and applicability of species distribution mapping has been significantly enhanced (GUISAN et al. 2000, PHILLIPS et al. 2006). Today, SDMs can deliver nuanced, site-specific insights into habitat connectivity, climate resilience, and ecological health of species on a larger scale.

For the field of landscape architecture and urban planning, this development presents both an opportunity and a challenge. On one hand, fine-scaled SDMs can guide the design of landscapes and building envelopes in urban areas that are better aligned with existing biodiversity and more resilient to environmental pressures such as global warming, urbanization, and habitat fragmentation. On the other, integrating species distribution data into a design framework requires a recalibration of traditional workflows, a deeper understanding of ecological processes and the adoption of analytical methods that were once beyond the purview of many landscape architects and urban planners. This shift calls for collaborative approaches between architecture and ecological science (MCGRATH 2018, BIRKELAND 2020, CATALANO et al. 2020, VOGLER 2021, WEISSER et al. 2022).

While Species Distribution Models (SDMs) are powerful tools, they come with notable limitations. Beyond issues such as overfitting, interpretation errors, and other technical challenges (SOLEY-GUARDIA et al. 2024), SDMs are heavily reliant on high-quality data. Urban areas, being highly fragmented and often under sampled, present significant challenges in acquiring suitable data. The most significant drawback of SDMs, however, is their static nature as they provide only a snapshot in time. For example, an SDM might predict that a newly cleared brownfield site is unsuitable for honeysuckle due to nitrogen deficiency. However, nitrogen-fixing species like *Alfalfa* and other *Leguminosae* may establish on such sites, enriching the soil and enabling the growth of honeysuckle after a few years. Similarly, SDMs do not account for temporal processes, such as tree growth and the resulting shade that can inhibit the growth of nearby plants. These successional dynamics and biotic interactions are typically not captured by SDMs. In contrast, mechanistic models, e. g., *Biome4* (KAPLAN et al. 2003), explicitly represent the underlying biological, physical, or chemical processes that drive a system's behavior. Rather than relying solely on statistical correlations, mechanistic models simulate core mechanisms such as growth, competition, dispersal, and resource consumption, offering a more dynamic representation of system change over time. As a result, they are better suited for modeling temporal dynamics and ecological succession. However, mechanistic models tend to be more generalized and often lack the specificity needed to model individual species or specific sites accurately. The landscape-scale model *FATE-HD* (BOULANGEAT et al. 2013) bridges these gaps by combining SDM approaches with mechanistic modeling. This hybrid approach addresses both the temporal limitations of SDMs and the generality of mechanistic models. Nevertheless, *FATE-HD*, as a large-scale scientific tool, was not originally designed for urban planning purposes. Recently, JOSCHINSKI et al. adapted the *FATE-HD model* for urban (3-dimensional) environments, revising the code structure and input-output processes (JOSCHINSKI et al. 2024). Despite these advancements, the model lacked an API or GUI, which severely limited its practical usability.

This paper addresses how SDMs/ ecological models can act as catalysts for innovation in landscape architecture and urban planning. By integrating JOSCHINSKI et al.'s model into Rhinoceros® (Rhino), a 3D freeform modeling Computer-Aided Design (CAD) software developed by Robert McNeel & Associates in 1998 (MCNEEL & ASSOCIATES 1998), we present a novel computational design tool for conducting ecological analyses of 3D landscapes and building envelopes. Incorporating ecological modeling as an intrinsic component of the digital design process enables designers and architects to simultaneously address architectural requirements and accommodate the ecological needs of diverse living species during the early design process, thereby contributing to more holistic and sustainable design outcomes that support life and biodiversity in urban areas. Ultimately, the goal is to highlight the potential for SDMs and ecological models not merely as passive background data but as active frameworks for realizing more ecologically resilient, contextually responsive, and aesthetically attuned landscapes, urban environments, and building envelopes.

Our new Rhino/ Grasshopper plugin for ecological analysis, RHINO.ECOLOGIC® (2025), is aimed at landscape architects and urban planners with knowledge in Rhino and Grasshopper (MCNEEL 1998 & 2008), enabling them to integrate ecological analysis into their design processes, thereby promoting more sustainable and nature-friendly landscape and urban development. RHINO.ECOLOGIC® is capable to:

1) **Ecologically analyze 3D geometry models** of landscapes, urban areas and building envelopes. Outputs are spatio-temporal species distribution maps on buildings, urban and terrain models.
2) Generate **dynamic biodiversity maps** of potential species to inhabit the design space.
3) Output **geometry specific soil distribution** and **local illumination maps**.
4) Generate a **database of ecological data linked to 3D geometry models** with all values formatted for advanced data analyses methods such as **Machine Learning**.

In the following sections, we present step by step our developed methods (Section 2) for a successful integration of ecological modelling into a CAD system, demonstrate first results of ecological analyzed 3D models (Section 3), and lastly discuss and conclude our findings (Sections 4 and 5).

2 Methods

2.1 Recalibration of a Traditional Design Workflow

A traditional design workflow in landscape architecture often begins with site inventory and analysis, followed by conceptual sketching, iterative refinements, and the preparation of detailed construction documents, typically relying heavily on professional expertise, heuristic knowledge, and manual drafting techniques. In contrast, a computational and data-driven design workflow represents a paradigm shift, empowering designers to exploit advanced algorithms, parametric modeling, and real-time environmental data to inform more dynamic, iterative, and evidence-based decision-making throughout the design process. Thus, a **computational design approach** is pivotal to our research and development.

In response to these challenges, we developed a tailored computational workflow that integrates individual components into a computational framework, enabling advanced ecological analysis within the 3D CAD environment Rhino (Fig. 1). Key components of the workflow are the *Joschinski Model* as well as a series of custom developed *Environmental Models*. Our method dissects a complex problem into manageable components and organizes processes in such a way that data can flow through the system (Fig. 1). The output of our framework facilitates the generation of dynamic biomass maps for parametric 3D geometry models in Rhino and Grasshopper (VOGLER et al. 2023 & 2024).

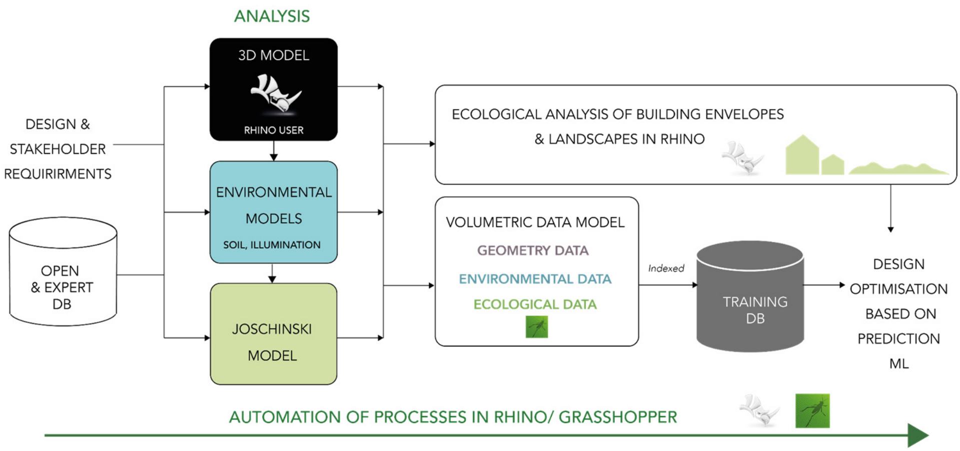

Fig. 1: Data Flow Diagram (DFD) for the integration of an ecological model into Rhino (© MCNEEL EUROPE 2025)

By refining the traditional workflow and applying a computational, data-driven system, we achieved a systematic integration of architectural, environmental, and ecological analyses, enabling early-stage feedback on the suitability of landscape and building envelope designs for supporting non-human species. By making use of Rhino and Grasshopper as open development frameworks, ecological modeling becomes an **intrinsic part of the design decision-making process**, allowing for the assessment of existing landscapes and building envelopes within urban environments (VOGLER et al. 2023). The following section demonstrates in detail how ecological data is integrated alongside environmental data into a computational and data-driven design process (Section 2), resulting in our new Rhino/ Grasshopper plugin, RHINO.ECOLOGIC®, for ecological analysis of building envelopes (Section 3).

2.2 Integrating Ecological Models into Rhino

Multiple CAD systems are widely utilized by planners and architects. However, we selected the Rhino development platform for our highly customized tool due to its open architecture, comprehensive API, and seamless integration with scripting languages such as Python, C#, and VB.NET (MCNEEL 1998). Furthermore, its robust user community and broad cross-disciplinary applications in computational design and engineering, and fabrication make it an ideal platform for developing specialized plugins that cater to diverse industry requirements (CANIZARES 2024). Additionally, its compatibility with a variety of design and analysis tools allows for rapid prototyping, iterative refinement, and direct integration of complex data such as ecological or environmental inputs directly into the architectural design process.

In the first step, we needed to identify an appropriate model that suited our purposes. To progress beyond the current state-of-the-art of using species distribution models (SDMs), we opted for an open-source C++ program (JOSCHINSKI et al. 2024). The *Joschinski model* simulates plant community dynamics in urban environments and is based on BOULANGEAT'S validated *FATE-HD* Model[1] (BOULANGEAT et al. 2014). BOULANGEAT'S Model is a spatially explicit ecological model that simulates plant community dynamics and species distributions under varying environmental conditions. It is based on an SDM approach, but additionally incorporates processes such as competition, dispersal, disturbance and demographic changes to project how vegetation communities may shift in response to factors like climate change or habitat modification. Ecological data primarily exist in two-dimensional (2D) raster formats at the scale of a country or larger region, and terrestrial simulations generally do not incorporate a vertical dimension (e. g., FATE-HD, RangeShifter, Landis). Consequently, the challenge lies in adapting these models to function at much smaller scales and in three dimensions (3D), enabling the simulation of ecosystems on both terrain & urban models as well as on building envelopes (Fig. 2).

Like its predecessor, the *Joschinski Model* applies a two-step approach: first, a filter identifies where each plant group (species or other groupings) could potentially grow, and then a mechanistic module simulates plant growth within each grid cell. The model operates at an annual time step and at a much smaller spatial scale of $1m^2$, simulating plant development over the lifespan of a building. The model tracks the presence, abundance, and maturity stages of each plant group in each grid cell over time, capturing germination, recruitment, growth, aging, competition for light, disturbance (e. g., management, animals), seed dispersal, and mortality. Ultimately, it produces spatially and temporally varying distributions of plant biomasses and biodiversity. Its restructured architecture facilitates modularization, maintainability, and the integration of environmental inputs such as soil type, soil depth and light conditions (JOSCHINSKI et al. 2024). To simplify the parameterization process, species sharing similar traits (growth, lifespan, etc.) can be grouped into Plant Functional Groups (PFGs) and treated as identical (CALBI et al. 2024). Alternatively, one can parametrize each species separately, which yields more insights on the species level but is more localized and requires signifi-

[1] FATE-HD stands for Functional Attributes and Traits for Ecosystem functioning in High-Dimensional environmental space (BOULANGEAT et al. 2014).

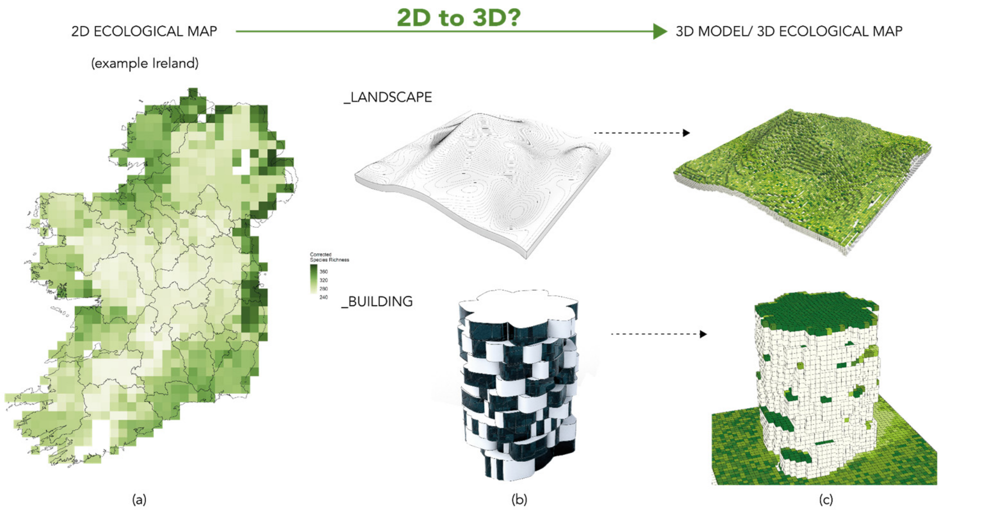

Fig. 2: (a) Two-dimensional spatial and temporal maps of plant species richness on the island of Ireland using *Frescalo*[2] (WHITE et al. 2019). *How to apply this method to a 3D model of a landscape or to buildings?* (b) and (c) our approach (© MCNEEL EUROPE 2025).

cantly more expert data. For the purpose of demonstrating the technical capabilities of the models, we chose the former, using ecologically informed but not strictly parametrized PFGs.

To enable ecological analysis in the CAD system Rhino, the model requires site-specific and 3D geometry-related inputs for soil and light conditions (Fig. 3) because the calculation of species distribution depends on the available soil volume, the depth of the soil (which determines root depth), the soil type (including its capacity to retain water), and the amount of light a plant can receive at a given site and location (JOSCHINSKI et al. 2024). To address this need, we developed custom computational programs that generate site- and project-specific soil distribution, soil type, and light intensity maps from 3D parametric Rhino and Grasshopper models. Our program subsequently outputs indexed numerical data compatible with the model (Fig. 3) (VOGLER et al. 2024). In the final step, we integrated the *Joschinski Model* into Rhino via a custom API that allows users to visualize the computed dynamic species distribution maps directly within the 3D CAD system. 3D environments are often represented with volumetric features, such as voxels, which capture complexity more accurately than 2D maps by considering and integrating the spatial dimensions of objects and obstacles (e. g., buildings and vegetation) (LIAN & GONG 2017, CHMIELEWSKI & TOMPALSKI 2017). Voxels (short for *"volume pixels"*) are the 3D equivalent of pixels in 2D images. Instead of representing data, such as color or intensity on a flat plane, voxels represent spatial data within a 3D volume, each holding information such as coordinates, density, or other attributes relevant to the simulated or modeled environment. Thus, the use of a voxel-based approach was key

[2] Frescalo (short for Frequency Scaling with Optional local smoothing) is a statistical method designed to quantify changes in species frequency or occupancy over time, while accounting for variations in sampling effort. Frescalo analyzes how often species are recorded in different areas or time periods and adjusts those frequencies to make them comparable; thereby helping ecologists and conservationists detect genuine trends in species distributions (HILL et al. 2012).

to facilitating SDM analysis of 3D models in Rhino in order to represent volumetric spatial information of a specific site at a high-resolution, enabling detailed and accurate simulations of complex environmental and ecological interactions (VOGLER et al. 2023). In this context, Figure 3 illustrates how custom 3D models are divided into voxels, each assigned soil, light, and geometry-related attributes to enable ecological analysis. In the final step, the ecological analysis results such as species distribution over time, biomass and biodiversity values are mapped as additional attributes to each voxel cell.

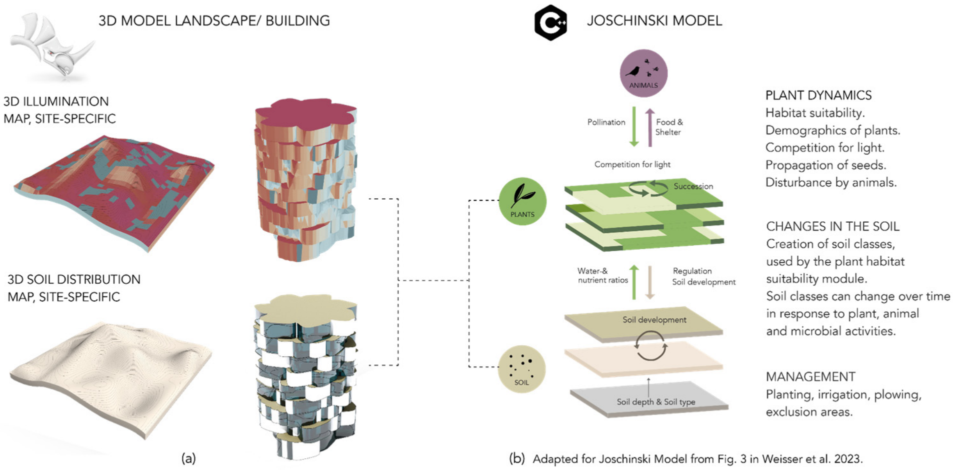

Fig. 3: In our new Rhino/Grasshopper plugin, RHINO.ECOLOGIC®, we integrated the *Joschinski Model* and followed a voxel-based approach to represent complex environmental and ecological analysis results at high resolution for 3D models of landscapes and buildings. Future extensions could include soil and animal communities, allowing a holistic 3D ecological analysis (© MCNEEL EUROPE 2025).

In summary, to facilitate a seamless integration of an ecological SDM model within Rhino, we introduced several computational techniques. First, we developed custom algorithms to analyze soil depth, soil type, and light/shading based on the global 3D geometry of building envelopes. Second, we employed a voxel model to index and store data as attributes, which then serve as inputs for the ecological model. Finally, we integrated the *Joschinski Model* into Grasshopper, enabling the visualization of plant succession directly within Rhino. A detailed discussion of the analysis results is presented in the following section.

3 Results

Our preliminary findings demonstrate that, through close collaboration with professional architects and ecologists, ecological analysis of 3D geometry models can be successfully achieved (VOGLER et al. 2023). Output are voxel-based plant distribution maps that show the dynamics of different plant species over a defined period of time (Fig. 4), the accumulated biomass as well as a biodiversity index (Fig. 5).

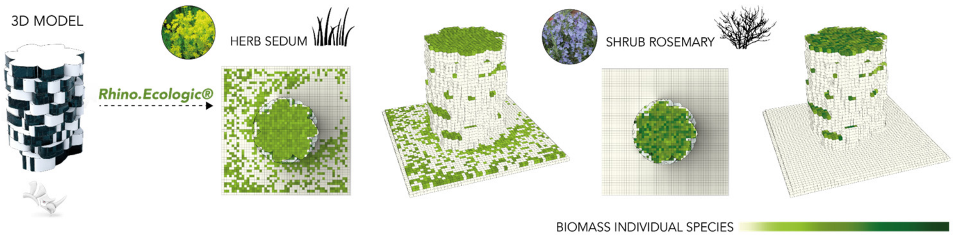

Fig. 4: RHINO.ECOLOGIC® is capable of analyzing parametric 3D models and returning in real-time site specific spatio-temporal environmental and ecological maps (© MCNEEL EUROPE 2025)

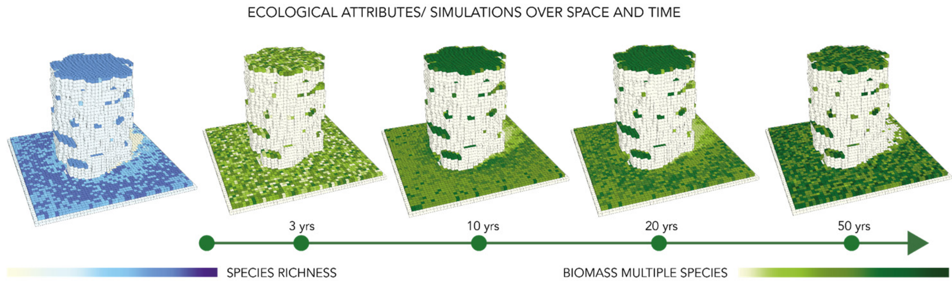

Fig. 5: Ecological simulation (biodiversity and biomass of multiple species) over a time period of 50 years

Furthermore, soil and light maps were generated and can be visualized in our new Rhino/ Grasshopper plugin RHINO.ECOLOGIC® (Fig. 5). RHINO.ECOLOGIC® is an advanced ecological simulation framework for Rhino and Grasshopper, designed to integrate ecological and environmental intelligence into the design process. It generates location- and time-specific 3D species distribution maps, as well as biomass and biodiversity analyses, enabling ecology-driven design solutions. To address site- and time-specific dynamic shading and soil interactions during simulations, we developed a soil model that simulates changes in the soil, while the amount of light is calculated based on the daylight received by each voxel cell over a defined period.

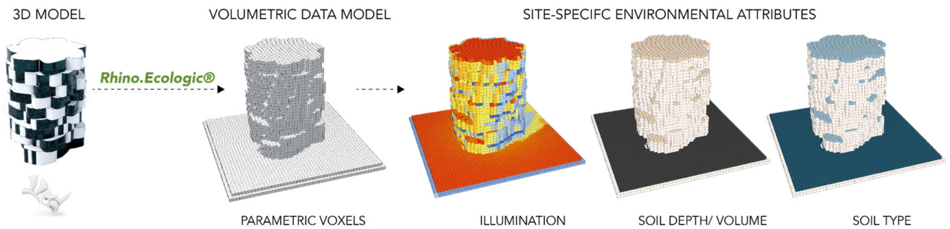

Fig. 6: Geometry and site-specific analysis of soil and illumination conditions for a specific space (© MCNEEL EUROPE 2025)

Behind each color-coded voxel cell lies a set of associated attributes that encode valuable environmental or spatial information. These attributes can subsequently be analyzed, exploited in data-driven design and optimization efforts, or even employed as training datasets for machine learning models (VOGLER et al. 2025) (Fig. 7).

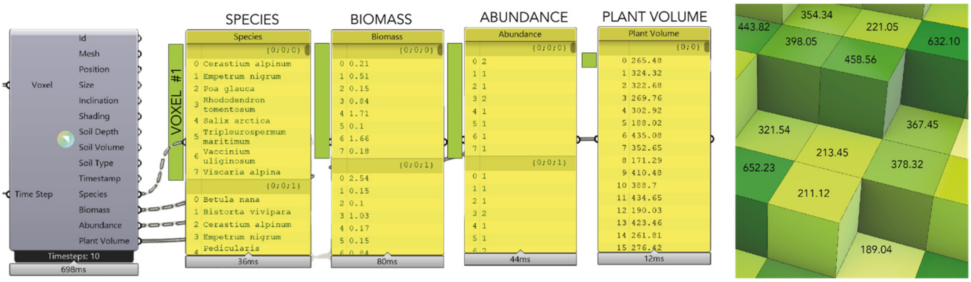

Fig. 7: Screenshot of structured and indexed dataset with RHINO.ECOLOGIC® in Grasshopper (©MCNEEL EUROPE 2025)

The developed technology including all analysis types and the corresponding datasets will be made available to the Rhino and Grasshopper user community. Once released, users can explore its unique functionalities with respect to ecological analysis of parametric 3D models (Fig. 8).

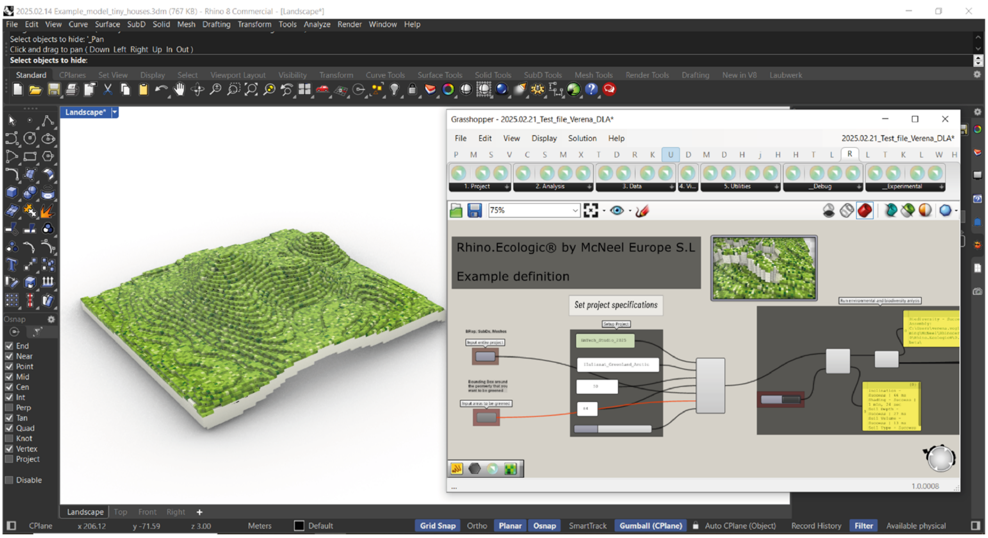

Fig. 8: RHINO.ECOLOGIC® for ecological analysis (species distribution, biomass and biodiversity) and calculations of spatio-temporal dynamics between species in Rhino (© MCNEEL EUROPE 2025)

To ensure that the ecological analysis outputs and the usability of Rhino.Ecologic® align with professional landscape design practices, we conducted pilot tests with renowned landscape architecture firms such as *Henning Larsen Architects*. By following a user-centered development approach that integrated direct feedback from these practitioners, we developed a technology poised for market readiness while maintaining practical relevance. Ensuring real-world applicability is paramount, as this solution that practitioners cannot readily implement would lose much of its value. To address this challenge accordingly, we analyzed different real-world 3D models, discussed the results with the corresponding landscape architects, and adapted the technologies based on their feedback (Fig. 9). The challenge was to analyze not just a single construction site but an entire neighborhood, placing considerable demands on computational resources. Consequently, the system architecture was enhanced through faster voxelization and analysis processes, the introduction of parallel computing, and a switch from JSON to direct API communication between Rhino and the *Joschinski Model*. Using this updated approach, we performed both (a) a green-space analysis and (b) a biodiversity assessment of part of the city with RHINO.ECOLOGIC®.

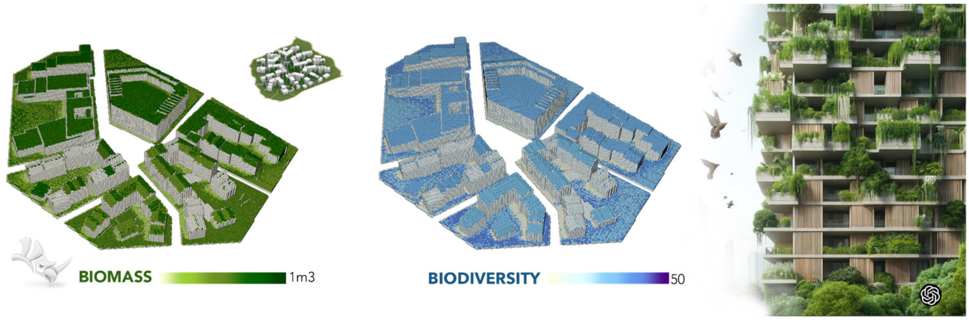

Fig. 9: Pilot test with international landscape architecture practice Henning Larsen Architects: *Fælledby*, Copenhagen's first all-timber neighborhood. Designed by Henning Larsen Architects (©MCNEEL EUROPE 2024).

During the development process of RHINO.ECOLOGIC®, we have conducted end-user tests. Overall, there was strong interest in the plug-in's capabilities and its ability to generate site-specific results, with most feature requests focusing on starting populations, management plans, hydrological dynamics, climate change effects, and customization for different localities or species pools. Additionally, we identified a need for easily interpretable yet scientifically robust indices to support decision-making.

In summary, a close collaboration with professional architects and ecology experts led to the successful integration of a voxel-based SDM approach and a new Rhino/Grasshopper plugin for advanced ecological analysis of parametric 3D models. This technology, tested on real-world sites ranging from building envelopes to entire neighborhoods and landscape models, offers high-resolution spatio-temporal maps for soil, light, greenery and biodiversity that practitioners can readily incorporate into their workflows. By iterating on user feedback, optimizing computational processes, and refining ecological parameters, our approach is ready for widespread adoption in landscape architecture and sustainable urban planning. In the following section, the paper will discuss the approach's limitations.

4 Discussion

The integration of ecological modeling within architectural design software, as exemplified by the development of RHINO.ECOLOGIC®, underscores the growing convergence of computational design and environmental analysis. This plugin represents a significant step towards reconciling the historical relationship between ecology and architecture by using modern digital tools to address contemporary environmental challenges. By embedding ecological considerations directly into the 3D CAD platform Rhinoceros and utilizing parametric modeling through Grasshopper, the tool enables practitioners to make informed, data-driven decisions at early design stages, promoting more sustainable and adaptive architectural outcomes. The use of SDMs within Rhino.Ecologic® offers a novel approach to real-time ecological analysis, generating high-resolution 3D spatio-temporal outputs for species, biodiversity and biomass. The integration of the mechanistic and stochastic *Joschinski Model* further enhances the plugin's ability to simulate complex ecological dynamics within landscapes, urban sites and building envelopes. This approach aligns with recent efforts in the field to incorporate ecological intelligence into architectural workflows, bridging the gap between computational design and ecological planning (WEISSER et al. 2022).

The integrated ecological model has undergone preliminary validation by ecologists, focusing on its ability to represent species distribution, biodiversity, and biomass dynamics across various spatial and temporal scales. However, the broader acceptance of the simulation results remains an open question, as predictive ecological modeling must balance scientific rigor with practical applicability in real-world design workflows. Preliminary evaluations indicate that the model aligns with expected ecological patterns, but further empirical validation is required to ensure robust parameterization. Key areas for refinement include the simulation of plant life cycle traits, stochastic ecological processes, and their interactions with built environments. While computational simulations provide valuable insights, the next critical step is to conduct a long-term real-world study through the implementation of an industry-scale prototype. Such a prototype would allow for direct testing and validation of the model's predictive capabilities in dynamic ecological conditions, providing essential feedback for improving the tool's accuracy, usability, and relevance in architectural and ecological design.

Furthermore, the current version of RHINO.ECOLOGIC® has notable limitations. One primary concern is the reliance on dimensionless units (e. g., "little," "much") and, in earlier iterations, the focus on Plant Functional Groups (PFGs) rather than individual species modeling. This abstraction simplifies ecological complexity but limits the precision of the analysis. Alternatively, the model may be parametrized with site-specific life cycle traits (e. g. lifespan, height) and local species pools, but this requires expert knowledge and high-resolution data, and the plugin's accuracy depends heavily on robust parameterization. As noted by ORESKES et al. (1994), ecological models often struggle with balancing complexity and usability, where oversimplification can reduce explanatory power, while excessive complexity may hinder practical application. While the current model simulates key processes such as germination and mortality, the simplifying assumptions, such as the use of a logit growth curve, necessitate further validation (JOSCHINSKI et al. 2025). This challenge is compounded by the stochastic elements embedded in the model, which lead to variability in numerical outputs across different simulation runs. Consequently, while the tool is well-suited for conceptual and design-oriented ecological insights, it is not appropriate for applications requiring high numerical precision, such as calculating structural loads on green roofs. The modular software development approach, grounded in Object-Oriented Programming (OOP) principles, offers a pathway to overcoming many of these limitations. This approach facilitates future enhancements, including the integration of more complex ecological models and refined parameterization, without necessitating major changes to existing workflows. As additional ecological data become available, we expect that these refinements will improve the tool's accuracy and applicability, enabling more reliable and detailed ecological analyses. Looking ahead, planned enhancements for RHINO.ECOLOGIC® include the incorporation of precipitation data, more sophisticated ecological modeling (e. g., realistic 3D plant growth simulations), and a user interface that allows practitioners to specify site-specific species. Additionally, prediction models capable of computing climate change projections could be integrated into the plugin to account for location-specific abiotic factors, enabling more accurate and dynamic ecological analyses. These improvements are aimed at increasing the plugin's versatility and accuracy, thereby empowering architects and planners to integrate validated ecological insights confidently into their design processes. In conclusion, RHINO.ECOLOGIC® represents an important step toward integrating ecological intelligence into architectural design. While the current version has limitations, its conceptual and design-oriented insights provide valuable guidance for promoting sustainable practices in architecture. Future developments, driven by enhanced data integration and modeling capabilities, hold the potential to transform this tool into a comprehensive solution for ecological analysis in the built environment.

5 Conclusion

In conclusion, the integration of advanced ecological modeling into computational design environments, such as the Rhino and its parametric extension Grasshopper, marks a significant paradigm shift in the fields of architecture, landscape architecture, and urban planning. By embedding ecological data directly into the early stages of design, this approach facilitates dynamic, data-driven decision-making that supports both biodiversity and sustainability. Through the exploitation of parametric modeling in Grasshopper, voxel-based data structures, and advanced ecological simulation models such as the *Joschinski Model*, designers and urban planners can now generate species distribution, biomass, and biodiversity maps at an early stage of project development. This capability allows for real-time feedback on the ecological impact of design decisions, promoting resilient, nature-inclusive, and aesthetically compelling outcomes. By systematically considering the habitat requirements of non-human species, these design methodologies not only enhance ecological resilience but also promote environmental justice by ensuring equitable access to green spaces and healthier living environments. Ultimately, these advancements offer a new horizon for sustainable urban development, where computational design and ecological science work hand in hand to shape more adaptive, livable, and environmentally responsible cities.

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