BeingAliveLanguage: An Integrated Digital Framework for Understanding and Designing with Living Systems in Landscape Architecture

Zhao Ma[1], Zhi Wang[2], Teresa Galí-Izard[2]
[1]ETH Zurich, Zurich/Switzerland · zhma@ethz.ch
[2]ETH Zurich, Zurich/Switzerland

Abstract: Contemporary landscape architecture faces increasingly complex environmental challenges that require sophisticated approaches integrating multiple ecological processes. While digital tools have advanced many aspects of landscape design, significant limitations remain in analyzing and communicating dynamic interactions between soil, vegetation, and climate processes. This paper presents the development of BeingAliveLanguage, a computational framework that explores these challenges through visualization and analysis tools. Operating within the Rhino-Grasshopper environment, the framework integrates four key components: soil analysis, root dynamics, tree growth modeling, and climate integration. The research combines scientific principles with visual representation methods to facilitate communication between stakeholders while maintaining technical accuracy. Applications ranging from urban forestry to landscape restoration projects demonstrate the framework's potential for supporting design decisions and interdisciplinary collaboration. This work suggests future directions for computational approaches in landscape architecture, particularly regarding complex environmental challenges and cross-disciplinary communication.

Keywords: Visualization, simulation, drawing language, interdisciplinary communication

1 Introduction

Contemporary landscape architecture increasingly confronts environmental challenges that necessitate solutions spanning multiple ecological processes. While digital tools have transformed many aspects of landscape design, from site analysis to construction documentation, significant gaps remain in effectively analyzing and communicating dynamic interactions among soil, vegetation, and climate processes for design purposes. These limitations are particularly evident in three areas: the visualization and analysis of subsurface conditions and their temporal changes; the prediction of long-term vegetation development; and the integration of climate data into design decision-making.

Modern landscape projects require collaboration among diverse professionals, including landscape architects, soil scientists, arboriculturists, urban planners, and government decision-makers. This interdisciplinary nature necessitates methods that can bridge communication gaps while maintaining scientific accuracy. Traditional documentation approaches often inadequately represent the dynamic and interconnected nature of living processes, potentially leading to misunderstandings among stakeholders and suboptimal design outcomes.

This paper examines the ongoing development of BeingAliveLanguage, a computational framework exploring innovative visualization and analysis approaches for understanding living processes in landscape architecture. Building upon previous work (MA & GALI-IZARD 2023) that established methods for visualizing soil separates, this research focuses on developments over the past two years, particularly applications derived from real-world projects.

Journal of Digital Landscape Architecture, 10-2025, pp. 471-482. © Wichmann Verlag, VDE VERLAG GMBH · Berlin · Offenbach. ISBN 978-3-87907-754-0, ISSN 2367-4253, e-ISSN 2511-624X, doi:10.14627/537754045.

The framework investigates ways to integrate multiple aspects of landscape processes to support evidence-based design decisions and enhance interdisciplinary collaboration.

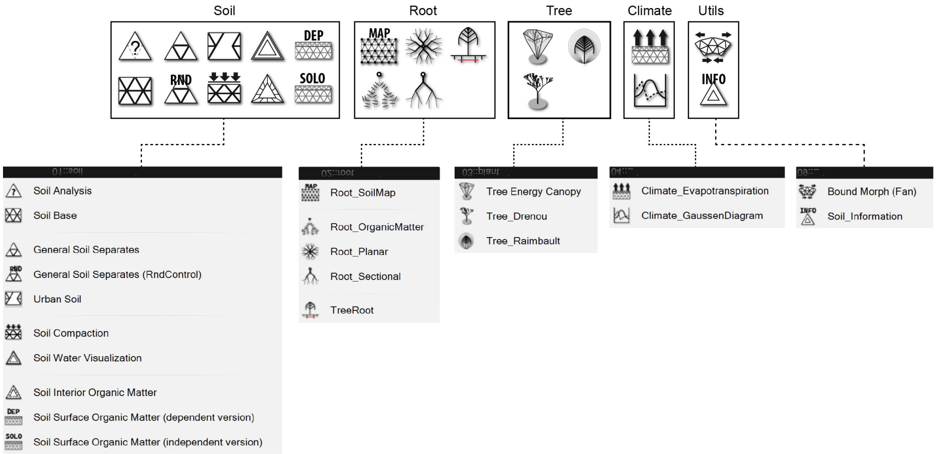

Fig. 1: Status of the BeingAliveLanguage software

BeingAliveLanguage is developed using the .NET framework and .NET Core within the Rhino/Grasshopper platform, an industry-standard CAD environment that enables algorithmic design through visual programming. Figure 1 presents an overview of the computational components provided by BeingAliveLanguage. Section 2 introduces four independent systems – soil, tree, root, and climate – and their application in creating dynamic diagrams. Section 3 demonstrates the integration of these systems and their compatibility with external software tools, such as Ladybug and Honeybee for climate analysis. Sections 4 and 5 discuss current limitations and future development plans, respectively.

2 Four Facets of BeingAliveLanguage

The research explores four interrelated components that contribute to understanding landscape processes (Figure 1). These include:

1) **Soil composition analysis**: Methods for representing and analyzing soil types based on horizon-specific data.
2) **Root development modeling**: Approaches to simulating root growth in two and three dimensions, incorporating environmental interaction factors.
3) **Tree development analysis**: Investigation of tree growth patterns using established architectural models (RAIMBAULT & TANGUY 1993, RAIMBAULT et al. 1995; DRÉNOU et al. 2015, LARRIEU et al. 2022).
4) **Climate analysis integration**: Methods for analyzing and representing climate data relationships with other landscape processes.

Each component represents an area of ongoing research, enabling investigation of complex landscape relationships through computational methods.

2.1 Soil Composition Analysis

This research component focuses on developing methods for visualizing soil composition while maintaining scientific accuracy in interdisciplinary communication. Unlike traditional GIS-based approaches emphasizing geographic distribution, this work explores vertical relationships and temporal changes in soil properties. The investigation primarily addresses the representation of soil separates, water content, and organic matter, with potential extensions to include additional elements such as geological materials and biological components.

Building on previous work (MA & GALI-IZARD 2023), the research employs triangular geometries as fundamental units representing soil separates (Figure 2a, 2c). This approach is consistent with the geometric structure underlying the USDA soil texture classification system (GARCÍA-GAINES & FRANKENSTEIN 2015). The investigation explores various visualization parameters, including scale relationships and mixing patterns among separates.

Water content visualization emerged as a crucial research focus, examining methods to represent interstitial spaces between soil separates (Figure 2a). The system represents current water content as a ratio [0 - 1] through the spatial relationship between soil separate triangles and water stage triangles. The approach incorporates established research data (DATTA et al. 2017) to visualize critical water properties – wilting point, field capacity, and saturation (Figure 2b) – enabling comparative analysis of soil water conditions.

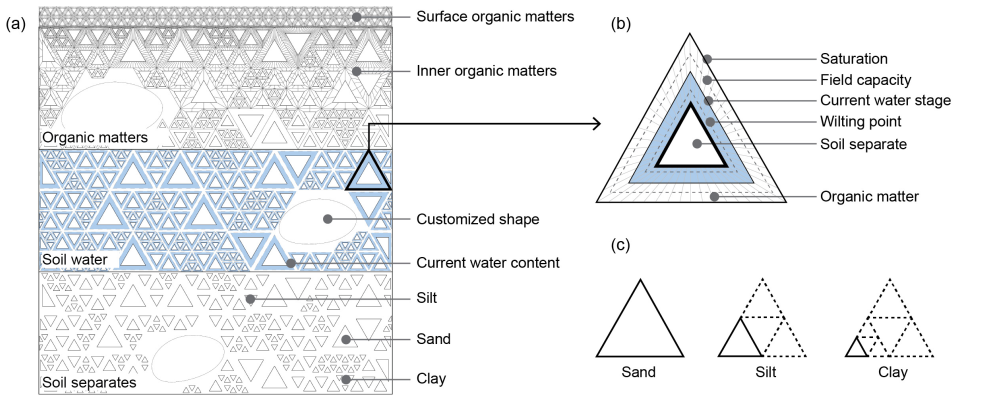

Fig. 2: (a) Soil system visualization of soil separates, water content, and organic matter. (b) Available soil water information for visualization. (c) Size differences of the soil separates.

The investigation includes methods for representing both internal and surface organic matter relative to soil separates (Figure 2a). Internal organic matter visualization employs radial line hatching between soil separates, with density gradients reflecting natural organic matter distribution patterns. Surface organic matter representation accommodates multiple layers of varying thickness, reflecting real-world conditions. Custom shapes representing rocks, insects, or other materials can be integrated by removing corresponding soil separate triangles.

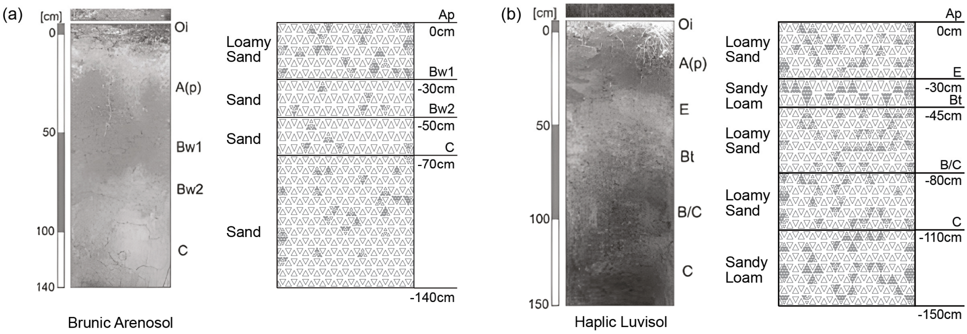

Fig. 3: Visualization and comparison of two different soil textures (PRZEWOŹNA 2014) using the BeingAliveLanguage

Figure 3 demonstrates a practical application. For comprehensive details, readers should refer to the previous publication. This section focuses on recent developments in the soil system.

2.1.1 Urban Soil Considerations

Investigation of urban applications revealed the need for adapted visualization approaches to address engineered soils containing specific ratios of additional components. This led to developing modified representation methods based on the established triangular framework while maintaining visual consistency. Figure 4 demonstrates examples of such adaptations, examining approaches to representing Stockholm soil and CU Structural soil compositions. Deriving from the fractal relationship of the soil system, we developed the urban soil language by combining the small triangles into bigger chanks with different shapes as gravels and adding additional visualization components such as bio-chars.

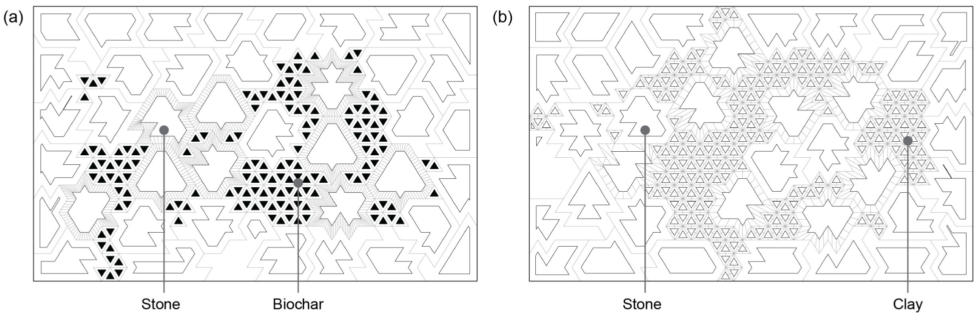

Fig. 4: Examples of two different typical urban soil (engineered soil): (a) Stockholm soil and (b) CU-Structural soil

2.1.2 Flexibility in Soil Diagram Representation

Project feedback over recent years has revealed varying requirements for soil-related information visualization and different levels of precision needed for soil-system interactions. These variations arise from three primary considerations:

1) **Project Context**: Research showed that in certain applications, soil information serves as a contextual background rather than primary focus, necessitating selective representation approaches.
2) **Growth Pattern Representation**: Investigation revealed that strict adherence to soil separate paths (defined by fractal triangle edges) may unnecessarily constrain the representation of root growth and microorganism activity.
3) **Dimensional Translation**: Analysis demonstrated that mathematical relationships governing triangular tessellation present challenges in three-dimensional translation.

These findings led to extending the methodology defined in (MA & GALI-IZARD 2023) to investigate varying precision levels when representing soil interactions with other processes across different dimensions, as illustrated in Figure 7. Applications of these adaptations are examined in subsequent sections.

2.2 Root Development Analysis

Root systems represent fundamental living processes within soil environments and offer critical insights into organism-environment interactions. This research component investigates methods for simulating and visualizing root growth under various conditions, drawing from established research in root architecture (ATGER 2011, FITTER 1987) and root-soil interactions (JIN et al. 2017).

The investigation developed an abstract simulation approach capable of representing both annual and perennial root growth patterns across various visualization formats. The methodology incorporates adjustable parameters including growth phase, division number, and scale, while exploring flexibility in soil base representation through points, grids, or defined soil conditions.

To examine root responses to environmental conditions, the research implements “attractors” and “epellers” (Fig. 5a) that model root growth patterns in response to both beneficial conditions (water availability, nutrient concentrations) and limiting factors (soil compaction, poor drainage). This approach enables investigation of potential root development patterns before physical manifestation. The methodology also explores temporal root system development (Fig. 5b), facilitating analysis of interactions between root networks and underground infrastructure.

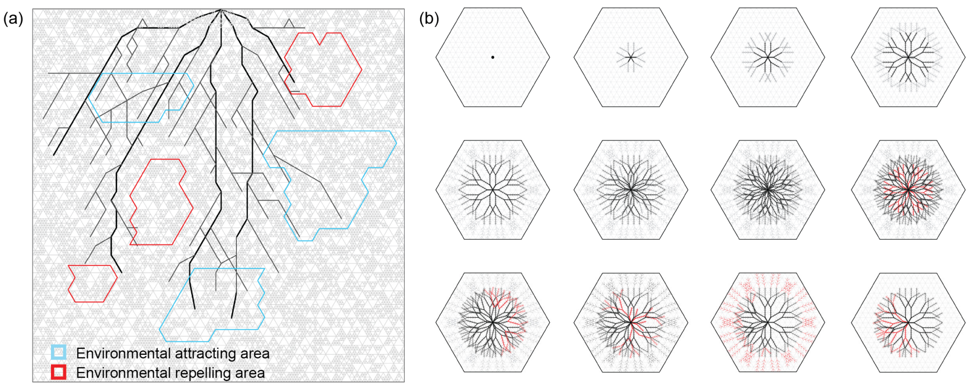

Fig. 5: (a) Sectional root simulation with environmental factors. (b) Planar roots in various phases in ideal conditions with no environmental factors.

2.3 Tree Development Analysis

BeingAliveLanguage's tree system builds upon seminal research regarding tree developmental stages, incorporating both Raimbault's foundational research (RAIMBAULT & TANGUY 1993, RAIMBAULT et al. 1995) and contemporary investigations by Drénou (DRÉNOU et al. 2015). While Raimbault established conceptual frameworks for developmental stages, Drénou's research provides deeper understanding of growth processes and form development.

The investigation developed two complementary visualization approaches:

1) A two-dimensional diagrammatic methodology based on Raimbault's tree model
2) A three-dimensional simulation approach drawing from Drénou's research

Both methods examine tree representation across 13 developmental phases, with examples shown in Figure 6a. These phases can be further consolidated into 4 stages, ranging from juvenile to senescent stages, addressing various analytical needs in landscape architecture and urban planning. This dual approach enables investigation of existing vegetation patterns while supporting analysis of future development scenarios.

The research examines both solitary and community growth patterns, with particular attention to forest-scale dynamics where tree forms adapt based on proximity to neighboring specimens (Figure 6b). This investigation acknowledges that trees typically develop as part of larger ecological communities rather than in isolation, leading to complex morphological adaptations.

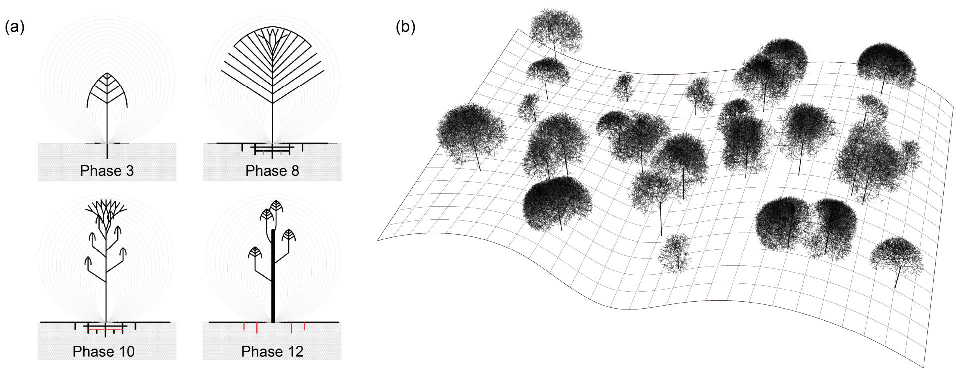

Fig. 6: (a) Example of abstracted tree growth diagram in different phases in 2D; (b) Realistic tree growth simulation in various phases with neighbor adaptation in 3D

2.4 Climate Analysis Integration

Climate change impacts increasingly influence environmental design decisions, necessitating robust analytical approaches. BeingAliveLanguage explores a dual methodology: developing preliminary analysis tools for initial decision support while investigating integration with detailed environmental modeling capabilities. This approach aims to balance rapid assessment needs with requirements for comprehensive environmental analysis.

The investigation encompasses two analytical levels:

1) Preliminary Analysis Methods:
    a. Investigation of evapotranspiration calculations for global locations, incorporating precipitation, temperature, latitude, and soil parameters.
    b. Development of automated Bagnouls-Gaussen diagram generation from precipitation and temperature data.
2) Advanced Analysis Integration:
    a. Compatibility with established environmental analysis tools such as Honeybee (ROUDSARI & SUBRAMANIAM 2016) within the Ladybug tools ecosystem (ROUDSARI et al. 2013).
    b. Support for advanced metrics including annual radiation and human comfort analysis

The evapotranspiration research calculates both potential and actual evapotranspiration (THORNTHWAITE 1948), examining corresponding water surplus, deficit, and reserve quantities for specified soil conditions. While contemporary research indicates that evaporation responds to multiple factors including temperature, humidity, and solar radiation (ALLEN et al. 1998), with various calculation methodologies available (MELO & FERNANDES 2012). This work implements the Thornthwaite method (THORNTHWAITE 1948) for its balance of accuracy and data efficiency.

The Bagnouls-Gaussen diagram investigation explores methods for visualizing aridity conditions based on the Gaussen (or Bagnouls-Gaussen) Index (GAUSSEN & BAGNOULS 1952, 1957). This approach provides insights into precipitation-temperature relationships for specific locations, utilizing monthly precipitation and temperature data, compatible with Global Summary of the Month (GSOM) dataset formats from sources such as NOAA[1].

Figure 9 demonstrates an integration study combining Gaussen diagram with evapotranspiration calculation to examine soil water content variations across annual cycles. Integration capabilities with additional analytical tools are examined in Section 3.4.

3 Integration Studies and Cross-software Analysis

The full potential of BeingAliveLanguage emerges through the integration of its component systems and connection with external software. The following studies demonstrate advanced applications and use cases from recent and ongoing projects.

3.1 Soil-Based Living Systems

BeingAliveLanguage enables the visualization of organism life cycles through circular calendars that represent organism milieus as sections through soil, water, and air at specific sites. The investigation mapped soil profile information onto circular segments using fan mapping techniques, while water and air quality data visualization emerged through iterative development of parameter-based rendering approaches (Figure 7). These studies incorporate temperature and rainfall patterns, along with cyclical site interventions such as maintenance schedules.[1]

[1] https://www.ncdc.noaa.gov/cdo-web/search?datasetid=GSOM

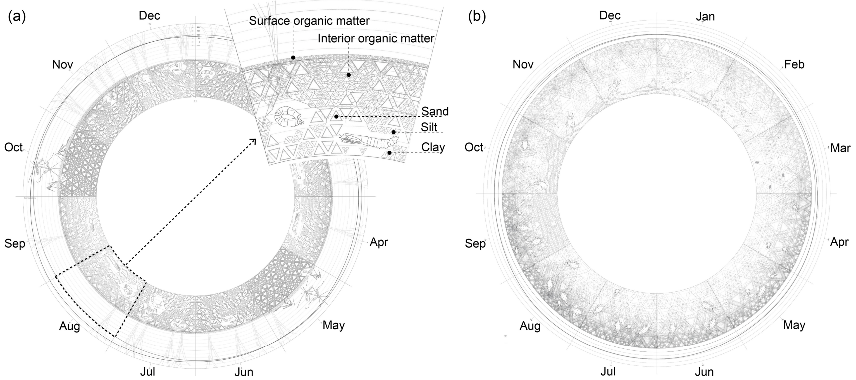

Fig. 7: Vital Milieus drawings of (a) Tipula oleracea and (b) Oppiella nova. The work was conducted using BeingAliveLanguage during a workshop by Dr. Johanna Just. (Credit: Nichin Tsai & Yuxuan Shi)

This methodological approach, developed within the doctoral research "An Earthly Writing of Space" (JUST 2025), investigates ways to represent non-human rhythms and inhabitation patterns within spatial design processes. Figure 7 presents findings from this investigation through a Tipula oleracea Vital Milieus study conducted during a research workshop led by Dr. Johanna Just.

3.2 Tree-Root Integration in Urban Infrastructure

The research examines interactions between ecological and built systems in urban environments (Figure 8). These studies map tree development patterns and root growth in relation to surrounding infrastructure, investigating potential long-term impacts on both biological development and urban functionality.

The findings suggest ways to bridge understanding between natural and built environment, contributing to dialogue between designers and policymakers. This investigation demonstrates approaches for considering urban landscapes through integrated ecological and infrastructural perspectives.

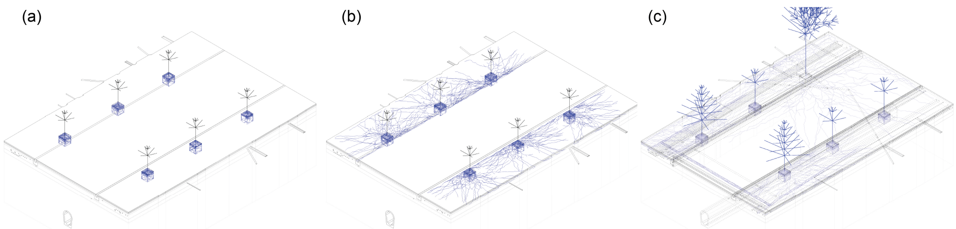

Fig. 8: Integration of 3D trees and roots, illustrating their growth and development within the urban environment (Credit: Uxia Varela)

3.3 Climate-Soil Interaction Analysis

Integration studies of soil processes with Gaussen diagrams explore interactive visualization methods for examining relationships between climate conditions and soil water content through annual cycles. These investigations have informed several landscape design projects in Barcelona, providing insights into seasonal variations in soil-water dynamics. The research developed methods for generating interactive temporal representations that enable examination of monthly variations in climate conditions and soil moisture status (Figure 9).

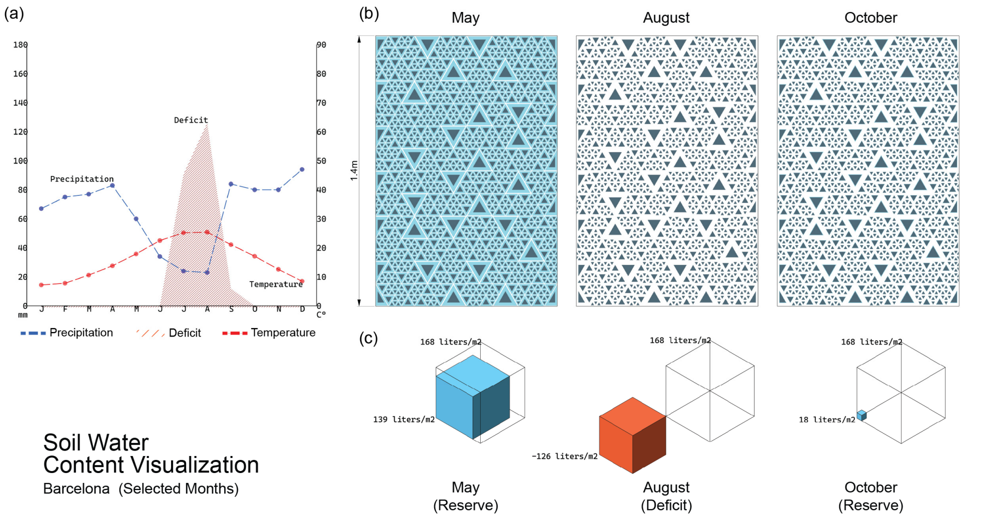

Fig. 9: Integration of (a) Gaussen diagram, (b) soil system, and (c) customized visualization system for soil water content visualization

3.4 Advanced Environmental Analysis Integration

While this research explores preliminary climate analysis methods, it also investigates integration with specialized environmental modeling tools through standardized data exchange protocols (Figure 10). A case study examining annual radiation analysis for courtyard designs with various tree configurations demonstrates this integration, utilizing established environmental analysis tools such as Ladybug tools.

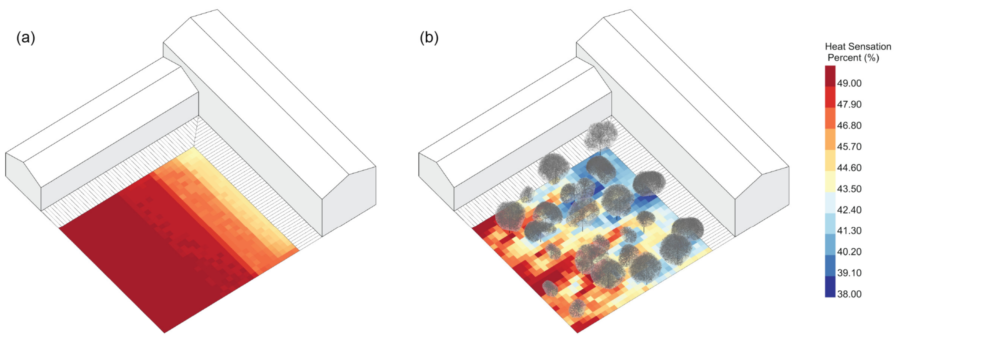

Fig. 10: Integration of the tree system with Ladybug Tools to analyze the impact of trees on heat sensation in a square in Athens

The investigation developed energy analysis approaches that enable evaluation of tree placement impacts on thermal comfort and energy performance. These studies demonstrate potential pathways for enhancing detailed environmental analysis while maintaining accessibility for design applications.

4 Discussion

While BeingAliveLanguage demonstrates promising capabilities for visualizing and analyzing living systems in landscape architecture, several limitations have been identified through development and initial implementation.

The tree growth visualization methodology, while drawing from established architectural models, currently addresses a limited morphological range. This limitation particularly affects representation of species with unique growth patterns, such as palms or multi-stemmed specimens. Future research should examine ways to incorporate more diverse growth patterns and species-specific characteristics.

Three-dimensional root modeling presents challenges regarding environmental interactions. While two-dimensional representations effectively demonstrate basic growth patterns and soil interactions, more sophisticated approaches are needed to accurately represent root responses to soil conditions, underground infrastructure, and root competition in multi-tree scenarios. This limitation suggests opportunities for integrating advanced soil physics models and root growth algorithms.

The current scope of validation studies, while informative, remains limited in breadth. Broader testing across diverse professional contexts and project scales would provide valuable insights into the methodology's effectiveness and limitations. Additionally, computational intensity in complex simulations, particularly for forest-scale modeling, presents ongoing challenges that require further investigation.

Integration capabilities with industry-standard software platforms reveal both opportunities and constraints that merit additional research. While current methods demonstrate potential for environmental analysis integration, opportunities exist for developing more robust data exchange protocols and analytical workflows.

5 Conclusions and Outlook

BeingAliveLanguage represents a significant step forward in integrating living systems visualization and analysis in landscape architecture. The framework successfully combines soil, vegetation, and climate analysis tools while maintaining scientific accuracy and user accessibility.

Future research and development will focus on several key areas:

1) Investigation of diverse tree growth patterns and species-specific characteristics
2) Advanced root system modeling to better represent environmental interactions
3) Implementation of improved feedback mechanisms to foster software iteration
4) Optimizing computational performance for complex simulations
5) Developing additional integration capabilities with industry-standard software

The complexity of environmental challenges in landscape architecture necessitates parallel advancement in both theoretical understanding and practical design tools. While this research contributes to methodological approaches for representing and analyzing living systems, it also demonstrates that future computational frameworks must balance scientific accuracy with design intuition, and technical sophistication with user accessibility. Continued development of such tools, guided by research findings and practical feedback, can help landscape architects better address contemporary environmental challenges while advancing the field's theoretical foundations.

References

ALLEN, R. G. et al. (1998), Rome: Food and Agriculture Organization of the United Nations. FAO irrigation and drainage, 56 (97), e156.

ATGER, C. (2011), La racine et le système racinaire des arbres: structure et développement. Plante & Cité, Pousse conseil.

BAGNOULS, F. & GAUSSEN, H. (1957), Les climats biologiques et leur classification. doi:10.3406/geo.1957.18273.

DATTA, S., TAGHVAEIAN, S. & STIVERS, J. (2017), Understanding Soil Water Content and Thresholds for Irrigation Management. doi: 10.13140/RG.2.2.35535.89765.

DRÉNOU, C., BOUVIER, M. & LEMAIRE, J. (2015), The diagnostic method ARCHI applied on declining pedunculate oaks. Arboricultural Journal, 37 (3), 166-179. doi:10.1080/03071375.2015.1075336.

FITTER, A. H. (1987), An Architectural Approach to the Comparative Ecology of Plant Root Systems. New Phytologist, 106 (s1), 61-77. doi:10.1111/j.1469-8137.1987.tb04683.x.

GARCÍA-GAINES, R. A. & FRANKENSTEIN, S. (2015), USCS and the USDA Soil Classification System: Development of a mapping scheme, This Digital Resource was created in Microsoft Word and Adobe Acrobat. REPORT. Cold Regions Research and Engineering Laboratory (U.S.). http://hdl.handle.net/11681/5485 (26.01.2025).

GAUSSEN, H. & BAGNOULS, F. (1952), L'indice xérothermique. doi:10.3406/bagf.1952.7361.

JIN, K., WHITE, P. J., WHALLEY, W. R., SHEN, J. & SHI, L. (2017), Shaping an optimal soil by root-soil interaction. Trends in Plant Science, 22 (10), 823-829. doi:10.1016/j.tplants.2017.07.008.

JUST, J. (2025), Drawing a Vital Milieu – An Attempt to Unflatten the Upper Rhine Plain, in Under the Landscape: Disciplinary Convergences and Emerging Alliances of Worlding. 1st Edition. Hatje Cantz Verlag.

LARRIEU, L., COURBAUD, B., DRÉNOU, C., GOULARD, M., BÜTLER, R., KOZÁK, D., KRAUS, D., KRUMM, F., LACHAT, T., MÜLLER, J., PAILLET, Y., SCHUCK, A., STILLHARD, J., SVOBODA, M. & VANDEKERKHOVE, K. (2022), Perspectives: Key factors determining the presence of Tree-related Microhabitats: A synthesis of potential factors at site, stand and tree scales, with perspectives for further research. Forest Ecology and Management, 515, 120235. doi:10.1016/j.foreco.2022.120235.

MA, Z. & GALI-IZARD, T. (2023), BeingAliveLanguage: Visualizing soil information from a design perspective to enhance multidisciplinary communication. Ecological Informatics, 76, 102151. doi:10.1016/j.ecoinf.2023.102151.

DE MELO, G. L. & FERNANDES, A. L. T. (2012), Evaluation of empirical methods to estimate reference evapotranspiration in Uberaba, State of Minas Gerais, Brazil. Engenharia Agrícola, 32, 875-888. doi:10.1590/S0100-69162012000500007.

PRZEWOŹNA, B. (2014), Changes of bulk density, air-water properties and morphology of soils in basins without outlets as an effect of erosion and anthropogenic denudation (a study from northwestern Poland). Soil Science and Plant Nutrition, 60 (1), 30-37. doi:10.1080/00380768.2013.842456.

RAIMBAULT, P., DE JONGHE, F., TRUAN, R. & TANGUY, M. (1995), La gestion des arbres d'ornement. 2e partie :gestion de la partie aérienne :les principes de la taille longue moderne des arbres d'ornement, Revue forestière française, 47 (1), 7-38. doi:10.4267/2042/26626.

RAIMBAULT, P. & TANGUY, M. (1993), La gestion des arbres d'ornement. 1re partie : une méthode d'analyse et de diagnostic de la partie aérienne'. Revue forestière française, 45 (2), 97-117. doi:10.4267/2042/26414.

ROUDSARI, M. & SUBRAMANIAM, S. (2016), Automating radiance workflows using Python, in 15th international radiance workshop. Padova, Italy.

SADEGHIPOUR ROUDSARI, M., PAK, M. & VIOLA, A. (2013), Ladybug: A Parametric Environmental Plugin for Grasshopper to Help Designers Create An Environmentally-conscious Design. doi:10.26868/25222708.2013.2499.

THORNTHWAITE, C. W. (1948), An Approach toward a Rational Classification of Climate. Geographical Review, 38 (1), 55-94.