RootScape

Visual Analytics for Subsurface-Aware Urban Tree Planning

A browser-based visual analytics system for subsurface-aware urban tree planning, integrating depth-coherent 3D visualization, species-specific viability scoring, and root-growth simulation using open Vienna datasets.

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Live Demo

Urban Tree Planning · 3D Geospatial Visualization · Subsurface Infrastructure · Temporal Simulation

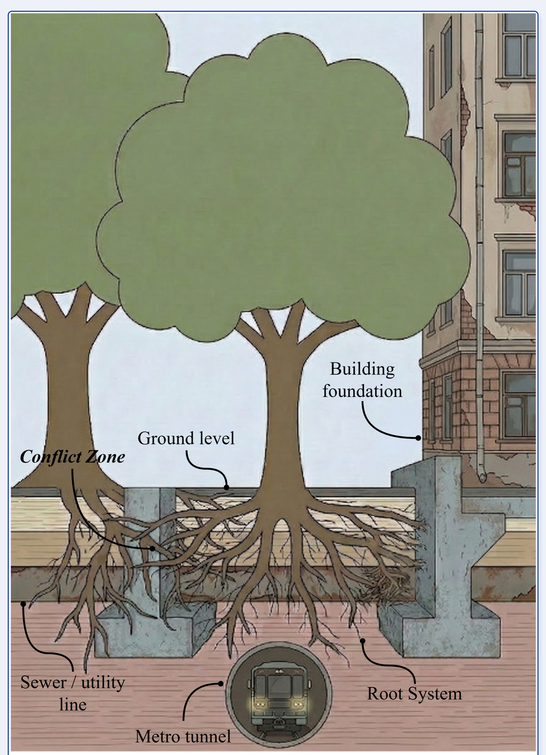
Introduction & Problem

Urban trees reduce heat, sequester carbon, and sustain biodiversity—yet they die prematurely because **subsurface constraints are never considered** at planting time. Root systems expand into the same vertical envelope as gray infrastructure: sewer pipes, building foundations, and metro tunnels.

Confined roots become stressed; large roots crack pavements and invade pipes. No interactive visualization system has yet exposed this *Invisible Forest Problem* to planners[1].

Research Question: *Can a 3D visual analytics system built on open data help planners select viable planting sites and explain why a location succeeds or fails—before a single tree is planted?*

Research Gap Miranda et al.[1] survey 150+ urban visual analytics systems (2008–2023): traffic, wind, energy, and flooding dominate. **Subsurface root conflict is absent.** Urban GIS uses 2D footprints; underground infrastructure is non-interactive; tree cadastres lack subsurface context. RootScape bridges arboricultural science and urban planning.



The Invisible Forest Problem: *Tree roots share underground space with building foundations, sewer infrastructure, and metro tunnels.*

Contributions

- **First depth-coherent 3D environment** across eight open Vienna datasets.
- **Location-first viability model**[3][4] with explainable rankings and intervention suggestions.
- **Spatio-temporal conflict prediction** using root and crown growth simulation.
- **Explainable multi-site comparison** via Species Comparison Matrix.
- **Open-data validation** against Vienna Baumkataster stress (n=205).

Open Data Sources

Dataset	Provider	Role
DTM 1 m	OGD Austria / TU Wien	Terrain mesh
Baumkataster Wien	City of Vienna WFS	Trees, species, stress
Baukörper LOD1/2	MA41 Wien	Buildings, shade
U-Bahn lines	Vienna GIS	Subway geometry
Abwasser / Kanal	Vienna GIS	Sewer geometry
OSM roads	OpenStreetMap	Pavement type
SoilGrids v2.0	ISRIC	Clay, pH, field capacity, CFVO
Versiegelungsgrad	City of Vienna WFS	Surface sealing %

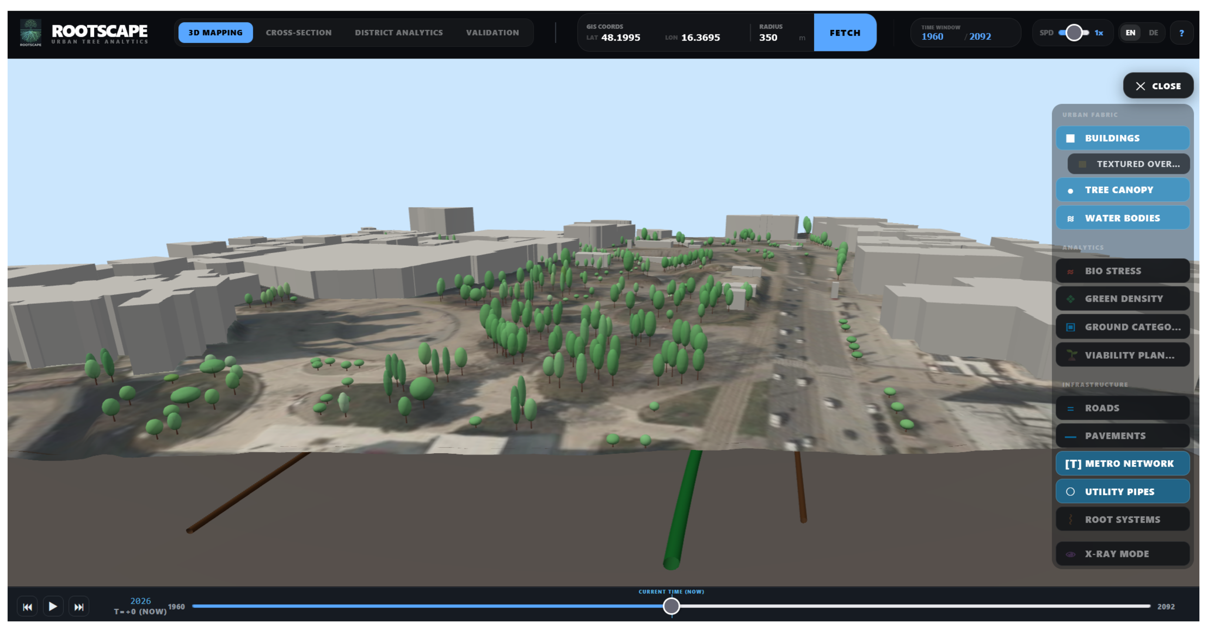
System

3D Mapping View

RootScape renders a depth-coherent 3D scene from terrain to metro depth. Trees use **Rhizomorph**[5] branch skeletons with depth-aware root line skeletons. The *Chronos Window* approximates growth as $r(T)=r_0+g_{sp}\cdot T$, with stress reducing expansion.

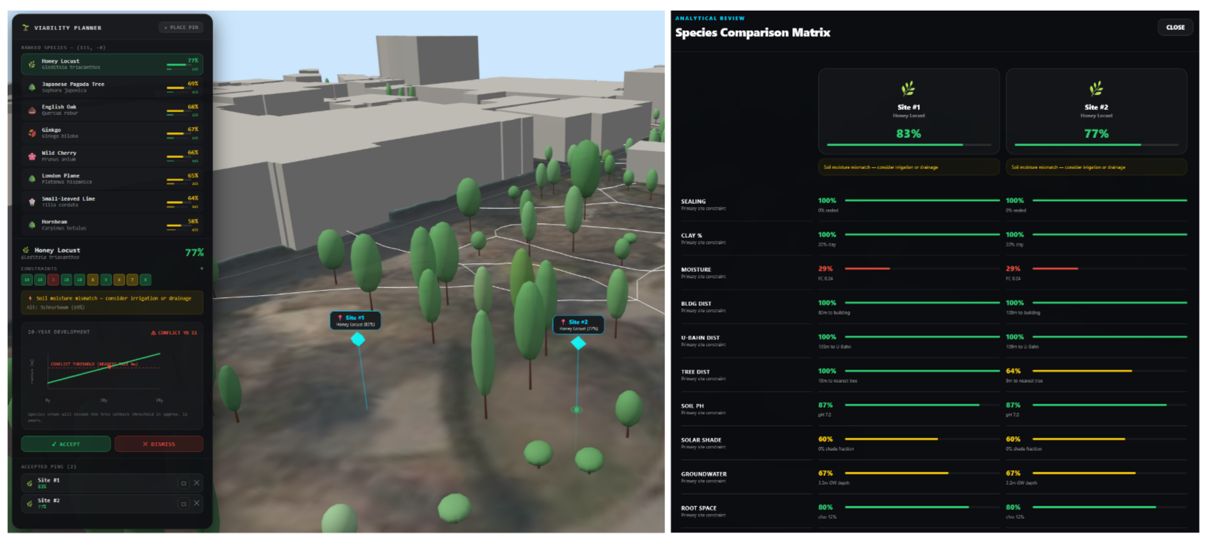
Main View

Terrain, orthophoto, OSM buildings, and Baumkataster trees fused into one georeferenced scene. Trees coloured by genus; cadastre biological stress visualised as a ground heatmap.



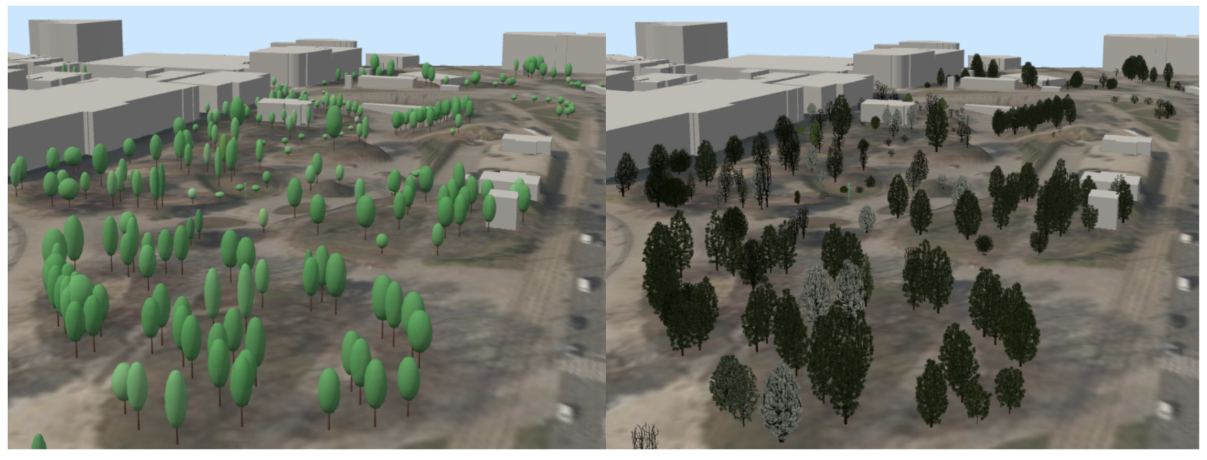
Viability Planner

A candidate pin ranks species by $V(\mathbf{x},\mathrm{sp})=\sum_{i=1}^{10} w_i^{(\mathrm{sp})} s_i(\mathbf{x})\in[0,100]$[3][4]. The **limiting factor** drives intervention; a 20-year chart predicts the **conflict year**.



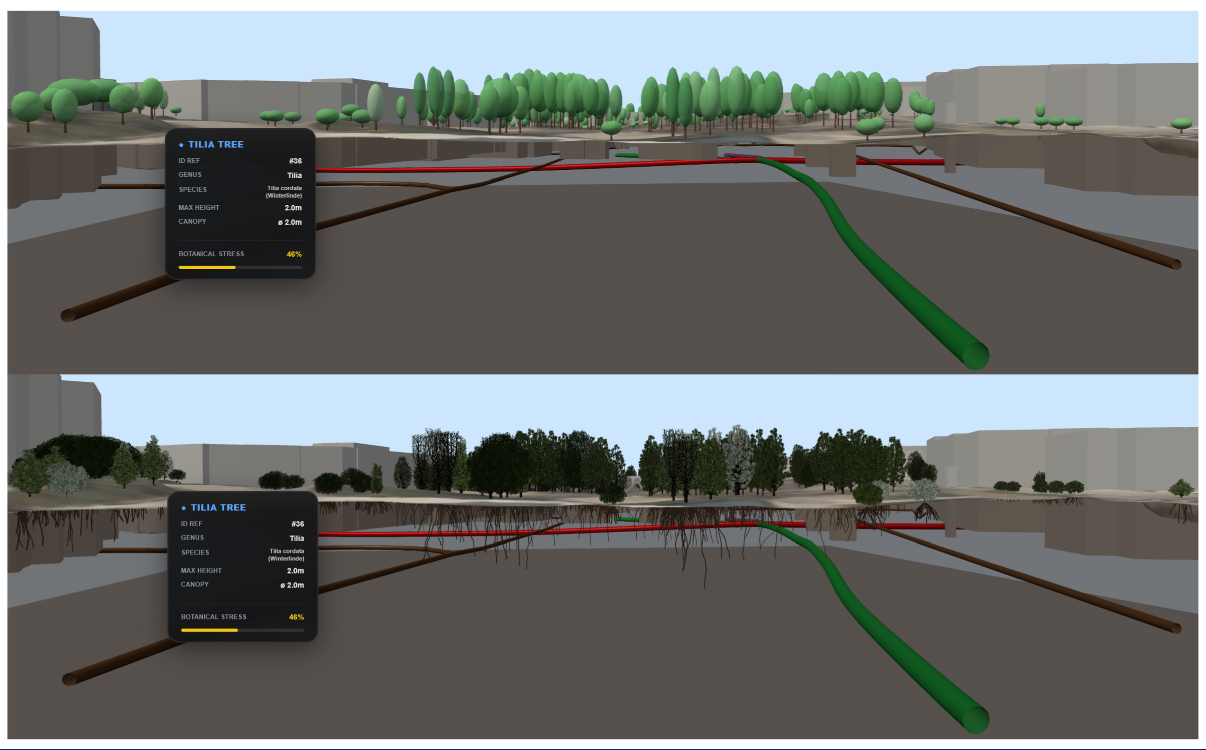
Tree Rendering Options

Low-poly proxy and Rhizomorph SCA model with species-specific branch skeletons and billboard foliage. Both preserve root geometry and stress colouring below ground.



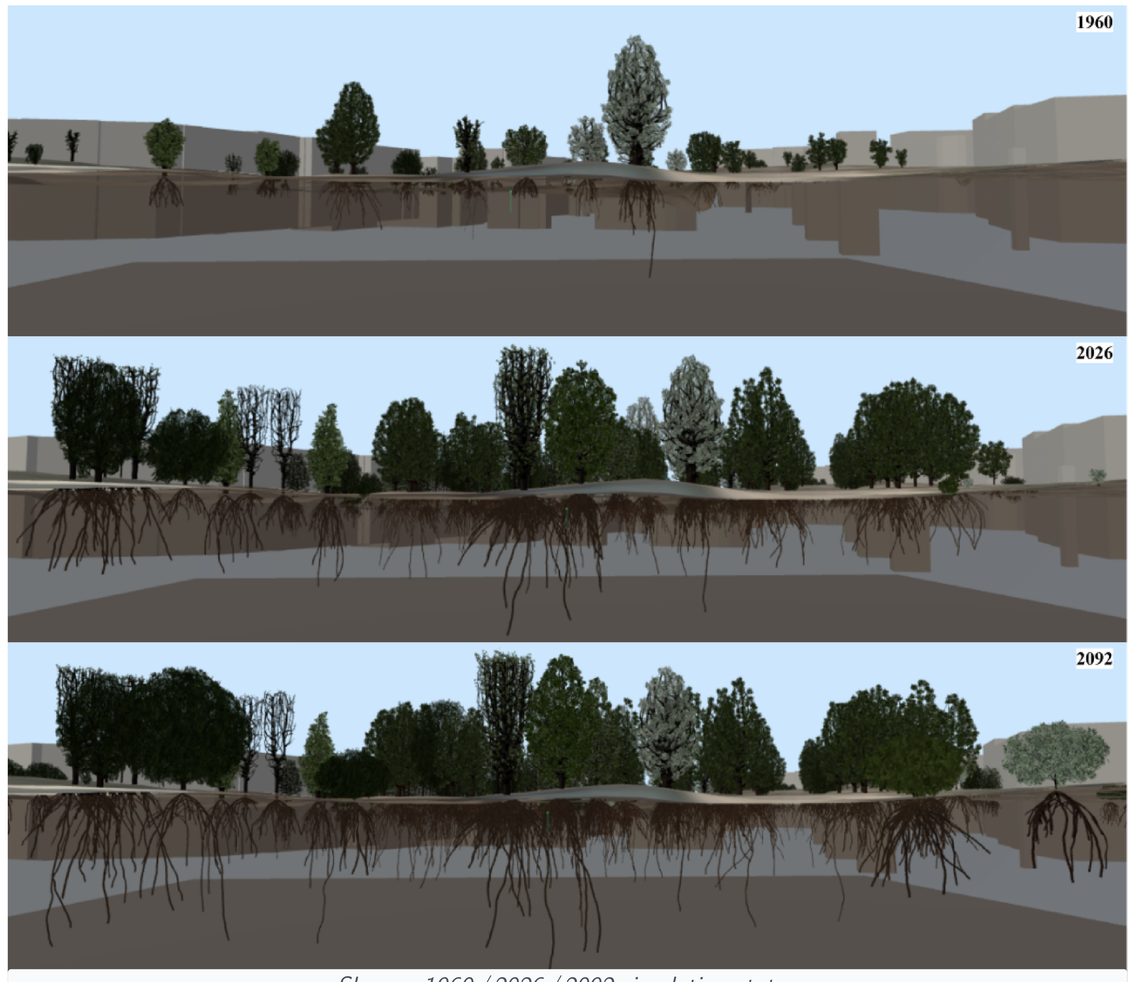
Underground X-Ray Mode

Transparent terrain reveals metro tubes, sewer lines, and foundations, making root–infrastructure proximity readable.



Temporal Simulation

The *Chronos Window* models expansion as $r(T) = r_0 + g_{sp}\cdot T$, where g_{sp} is species-specific and modulated by current stress. It advances root and crown growth for cadastre trees and new pins, revealing when today's planting decisions will collide with subsurface infrastructure in 5–50 years.



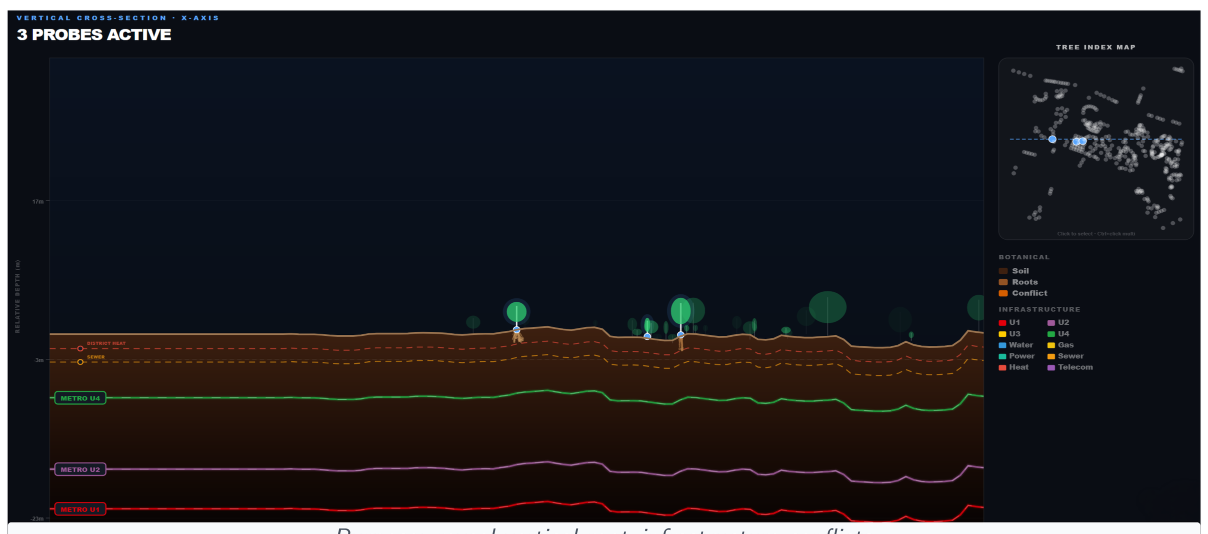
Shown: 1960 / 2026 / 2092 simulation states.

Procedural Growth Model

Trees are procedurally generated via a **Space Colonization Algorithm** (SCA)[2] within species-specific reach envelopes. This fidelity ensures that simulated conflicts represent biologically plausible root architectures, not just simplified distance buffers.

Cross-Section View

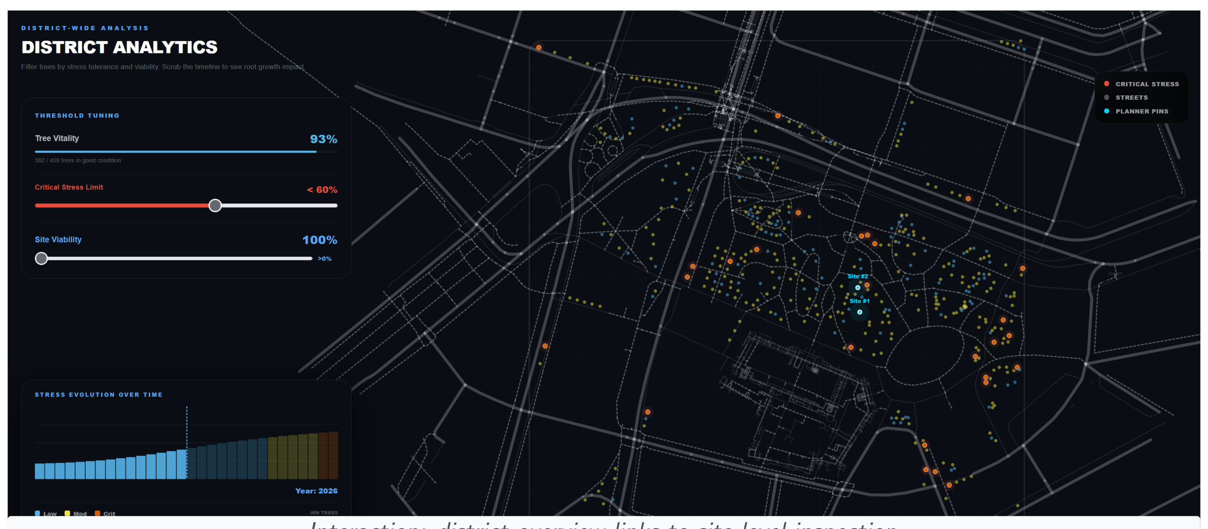
Full substrate at true depth: soil bands, root halos, sewer, foundations, and Vienna metro lines. Tree Index minimap links selection to the Viability Planner. **Not available in any comparable planning tool.**



Purpose: reveal vertical root–infrastructure conflicts.

District Analytics View

All 205 cadastre trees are shown as stress-coloured dots with threshold sliders and a Stress Evolution chart. Planner pins — cyan dots marking candidate sites — are overlaid, enabling comparison against future projections at T+18 (2044).



Interaction: district overview links to site-level inspection.

Explainable Planning

Limiting-Factor Analytics. While the Cross-Section reveals physical conflicts, RootScape quantifies planning risk using Liebig's Law of the Minimum: the weakest constraint, not the average condition, determines site viability. The system exposes this bottleneck as the **limiting factor**, explaining why a specific location fails and which intervention is most relevant.

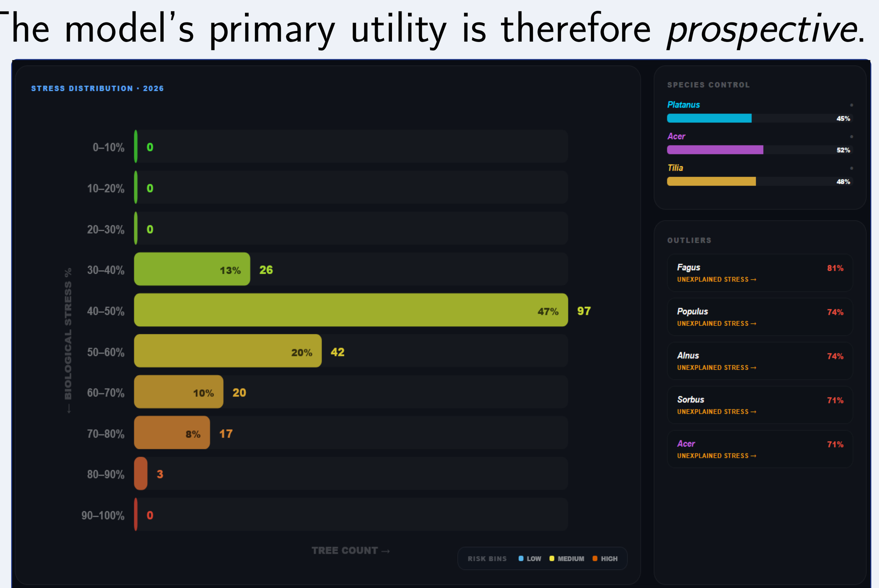
Contrastive reasoning is supported via the Species Comparison Matrix, which isolates the specific parameters that make one species or site outperform another.

Output: ranked species, limiting constraint, intervention suggestion, predicted conflict year, and Species Comparison Matrix for accepted candidate pins.

Validation, Findings & Outlook

Validation All n=205 cadastre trees scored retrospectively; $C = 100 - V$ shows near-zero correlation with biological stress (r=−0.04, R^2=0.002), reflecting *range restriction*: arborists historically avoided high-constraint sites, compressing variance in C. The model's primary utility is therefore *prospective*.

Scatter plot: Spatial Constraint vs. observed stress.



Histogram: Stress distribution per genus (Acer/Platanus/Tilia).

Key Findings

122 low-risk matches **81** inspection candidates **0** false alarms

RootScape is the **first interactive visual analytics system** to expose the vertical urban substrate for tree viability planning.

As a *prospective tool*, it avoids false alarms while highlighting 81 inspection candidates. It reveals root–infrastructure conflicts before planting, moving beyond 2D footprints.

"Can this location support a healthy tree for 20 years—which species, and what is the biggest obstacle?"

Limitations Approximate infrastructure depths and literature-based species weights.

Future work NDVI and groundwater integration; evaluation with MA 42; improved shade inference from street imagery.

Selected References

[1] Miranda et al. *The State of the Art in Visual Analytics for 3D Urban Data*. Computer Graphics Forum, 2024.

[2] Runions et al. *Modeling Trees with a Space Colonization Algorithm*. Natural Phenomena, 2007.

[3] Day et al. *Contemporary Concepts of Root System Architecture of Urban Trees*. Arboriculture & Urban Forestry, 2010.

[4] Randrup et al. *A Review of Tree Root Conflicts with Sidewalks, Curbs, and Roads*. Urban Ecosystems, 2001.

[5] Behnke et al. *Rhizomorph: The Coordinated Function of Shoots and Roots*. ACM Transactions on Graphics (TOG), 2023.