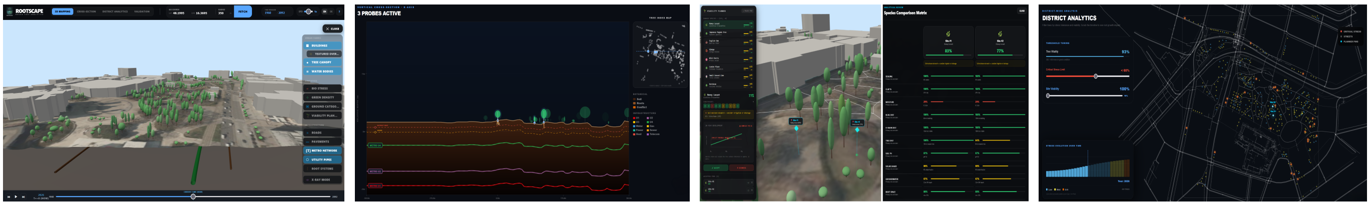
RootScape: Visual Analytics for Subsurface-Aware Urban Tree Planning

Angeliki Grammatikaki[1,2], Milena Vuckovic[2], Manuela Waldner[1]

[1]TU Wien, Institute of Visual Computing and Human-Centered Technology, Vienna, Austria
[2]VRVis GmbH, Vienna, Austria



(a) (b) (c) (d)

Figure 1: *RootScape: (a) 3D Mapping with genus-coloured trees and metro lines; (b) Cross-Section from crown to underground metro at true depth; (c) Viability Planner with per-constraint breakdown and conflict-year prediction; (d) District Analytics with Stress Evolution chart.*

Abstract

*We present **RootScape**, a browser-based visual analytics system fusing eight open geospatial datasets for Vienna into a depth-coherent 3D scene from tree crown to tunnel. Four coordinated views support the full planning workflow: a 3D Mapping environment with user-controlled temporal simulation of root-halo and crown growth, a Cross-Section view revealing subsurface geometry at true depth, a Viability Planner scoring eight species against ten substrate constraints with per-factor breakdown and conflict-year prediction, and a District Analytics view for strategic stress assessment. Retrospective validation against the Vienna Baumkataster surfaces 81 unexplained high-stress trees in our study area as inspection candidates and produces zero false high-risk alarms. RootScape is the first system to expose the invisible subsurface conflict between urban greenery and gray infrastructure in an interactive, open-data, planning-oriented context. The codebase and demo are publicly available at* `https://github.com/AngelikiGram/rootscape`.

CCS Concepts

• ***Human-centered computing*** → ***Visual analytics;*** *Geographic visualization;* • ***Computing methodologies*** → *Rendering;*

1. Introduction

Street trees are critical urban infrastructure: Vienna's Baumkataster records over 200,000 trees spanning 130 species [Cit24]. They reduce heat island temperatures by up to 2 °C [GHEP07], sequestering carbon, yet die at dramatically higher rates than rural counterparts [NCS06]. A chronically underappreciated cause is the *Invisible Forest Problem*: roots expand into the same subsurface envelope as gray infrastructure—sewer pipes, building foundations, and metro tunnels. Confined roots become stressed and die [RMC01]; large roots crack pavements and invade pipes [WB83]. Species-specific root-spread models exist [TSCFS06, DWDH10] but have never been operationalised into an interactive planning tool.

Visualization and GIS communities offer no solution. Miranda et al. [MOM*24] survey 150+ urban visual analytics systems (2008–2023) and identify traffic, wind, energy, and flooding as dominant themes, but not subsurface root conflict. Commercial GIS platforms (ArcGIS Urban, QGIS) and existing tree visualization systems [BML09] address above-ground morphology but offer no coupling between tree biology and subsurface infrastructure geometry. Tree cadastres carry no subsurface context, while arboricultural research documents root–infrastructure conflicts [RMC01, WB83, DWDH10] without interactive planning support.

We present RootScape (Figure 1), bridging this gap. Our contributions are: **(1)** the first depth-coherent 3D environment integrating the vertical urban substrate, from tree crown to metro depth; **(2)** a location-first species viability model operationalising root-spread

BMG8 /.,01/0-ctnb,0.04/.03

and substrate-tolerance norms [TSCFS06, DWDH10, RMC01] into a real-time ten-constraint scoring function with explainable per-factor rankings; **(3)** a spatio-temporal simulation coupling species-specific root-halo and crown growth over a controlled time range, predicting the year of first conflict for existing and candidate trees; and **(4)** an open-data validation methodology correlating predicted scores with observed cadastre stress, controlled for species identity.

2. Data and System

RootScape is a browser-based SPA (React, Three.js, D3.js) with a Python FastAPI backend fusing eight open datasets (Table 1), all geometry projected into EPSG:3857.

Dataset	Provider	Role
DTM 1 m [dat26]	OGD Austria / TU Wien	Terrain mesh
Baumkataster Wien [Cit24]	City of Vienna WFS	Trees, species, stress
Baukörper LOD1/2 [MA 24]	MA41 Wien	Buildings, shade
U-Bahn lines [Sd26]	Vienna GIS	Subway geometry
Abwasser / Kanal [Sta26b]	Vienna GIS	Sewer geometry
OSM roads [Ope26]	OpenStreetMap	Pavement type
SoilGrids v2.0 [PBH*21]	ISRIC	Clay, pH, field capacity, CFVO
Versiegelungsgrad [Sta26a]	City of Vienna WFS	Surface sealing %

Table 1: *Integrated open datasets. All freely available under CC-BY 4.0 or equivalent open licences.*

3D Mapping View (Figure 1a). A 256×256 terrain mesh is draped with the Vienna orthophoto; buildings are extruded from OSM footprints. Trees are rendered via the Rhizomorph engine [LKM*23]: branch skeletons grow using the Space Colonization Algorithm [RLP07] within species-specific crowns; leaves and twigs are billboards; root systems are visualised as depth-aware line skeletons within species-specific reach envelopes [DWDH10]. A *Chronos Window* scrubber drives real-time scene updates across a user-defined temporal range; root and crown growth are approximated by $r_{\text{root}}(T) = r_0 + g_{\text{sp}} \cdot T$, with stress reducing subsequent expansion. Trees are coloured by genus; cadastre biological stress is visualised as a ground heatmap when the Bio Stress toggle is active. Candidate pins from the Viability Planner are simulated alongside cadastre trees for direct comparison over time.

Cross-Section View (Figure 1b). A vertical slice at a user-chosen azimuth reveals terrain, tree crowns, SoilGrids depth bands, root halos, sewer pipes, and Vienna metro lines at true depth. A Tree Index minimap supports individual tree selection. This vertical substrate view is not available in any comparable planning tool.

Viability Planner (Figure 1c). A candidate pin ranks species by: $V(\mathbf{x}, \text{sp}) = \sum_{i=1}^{10} w_i^{(\text{sp})} \cdot s_i(\mathbf{x}) \in [0, 100]$ where $w_i^{(\text{sp})}$ are literature-derived species weights [DWDH10, RMC01] and s_i are normalised scores for: tree spacing (15 %), surface sealing (12 %), groundwater (11 %), building distance, moisture, solar shade, soil pH (10 % each), U-Bahn distance (8 %), clay and root space (7 % each). The *limiting factor*—the lowest $w_i s_i$ term—is highlighted with a context-sensitive intervention suggestion. A 20-year growth chart annotates the predicted *conflict year*; accepted pins feed a Species Comparison Matrix for side-by-side evaluation.

District Analytics View (Figure 1d). All 205 trees are plotted as stress-coloured dots with three tunable threshold sliders and a *Stress Evolution* bar chart; the *Chronos Window* scrubber drives real-time updates across the full simulation range, showing above-ground crown development and below-ground root halo expansion for existing cadastre trees and newly placed Viability Planner pins.

(a) (b)

Figure 2: *Retrospective validation (n=205, r=−0.04, R^2=0.002): **(a)** Observed stress distribution by species; **(b)** predicted constraint score vs. observed biological stress, with quadrants separating low-risk trees from inspection candidates.*

3. Validation and Conclusion

We retrospectively score all n=205 Baumkataster trees, comparing predicted spatial constraint score $C = 100 - V$ against observed cadastre biological stress (Figure 2). The stress distribution (Figure 2a) shows trees clustering in the 40–60 % stress range; species stratification confirms consistent patterns across Platanus, Acer, and Tilia, ruling out species identity as the primary stress driver.

The scatter plot (Figure 2b) reveals a weak negative correlation (r=−0.04, R^2=0.002), reflecting a *range restriction* effect: cadastre trees were planted by arborists who already avoided high-constraint sites, compressing variance in C. The model's primary utility is therefore *prospective*. In the study area, quadrant analysis is more informative: 122 trees are correctly low-risk; 81 exhibit unexplained high stress (*Fagus*×2, *Magnolia*, *Populus*, *Alnus*) and are surfaced as *inspection candidates* with low predicted constraint yet high observed biological stress, suggesting non-spatial causes warranting field inspection. Zero healthy trees are falsely flagged.

RootScape is the first interactive system to expose the full vertical urban substrate—tree crown to metro tunnel—for planning-oriented tree viability analysis, bridging a gap the visualization community has overlooked [MOM*24]. It enables planners to answer: *can this location support a healthy tree for twenty years, which species should I plant, and what is the single biggest obstacle?* Future work includes Sentinel-2 NDVI validation, eHYD groundwater integration, and a task-based evaluation with Vienna urban planners (MA 42 Wiener Stadtgärten).

Acknowledgements

The VRVis GmbH is funded by BMIMI, BMWET, Tyrol, Vorarlberg and Vienna Business Agency in the scope of COMET - Competence Centers for Excellent Technologies (904918, 911654) which is managed by FFG.

References

[BML09] BRASCH S., MCPHERSON E., LINSEN L.: Interactive data visualisation for animating urban tree growth. *International Journal of Modelling and Simulation 29*, 3 (2009), 306–314. URL: https://doi.org/10.1080/02286203.2009.11442538, arXiv:https://doi.org/10.1080/02286203.2009.11442538, doi:10.1080/02286203.2009.11442538. 1

[Cit24] CITY OF VIENNA (MA 42): Baumkataster Wien — öffentliche Bäume im stadtgebiet. Open Government Data Wien, 2024. URL: https://data.wien.gv.at. 1, 2

[dat26] DATA.GV.AT: Digitales geländemodell (dgm) Österreich – wien. https://www.data.gv.at/datasets/d88a1246-9684-480b-a480-ff63286b35b7?locale=de, 2026. Open Government Data record for Vienna terrain model, accessed 2026-04-05. 2

[DWDH10] DAY S. D., WISEMAN P. E., DICKINSON S. B., HARRIS J. R.: Contemporary concepts of root system architecture of urban trees. *Arboriculture and Urban Forestry 36* (07 2010). doi:10.48044/jauf.2010.020. 1, 2

[GHEP07] GILL S., HANDLEY J., ENNOS R., PAULEIT S.: Adapting cities for climate change: The role of the green infrastructure. *Built Environment 33* (03 2007), 115–133. doi:10.2148/benv.33.1.115. 1

[LKM*23] LI B., KLEIN J., MICHELS D. L., BENES B., PIRK S., PAŁUBICKI W.: Rhizomorph: The coordinated function of shoots and roots. *ACM Trans. Graph. 42*, 4 (July 2023). URL: https://doi.org/10.1145/3592145, doi:10.1145/3592145. 2

[MA 24] MA 41 STADTVERMESSUNG WIEN: Generalisiertes Dachmodell LOD2. City of Vienna Open Data, 2024. URL: https://www.wien.gv.at/stadtentwicklung/stadtvermessung/. 2

[MOM*24] MIRANDA F., ORTNER T., MOREIRA G., HOSSEINI M., VUCKOVIC M., BILJECKI F., SILVA C. T., LAGE M., FERREIRA N.: The state of the art in visual analytics for 3d urban data. *Computer Graphics Forum 43*, 3 (June 2024). URL: http://dx.doi.org/10.1111/cgf.15112, doi:10.1111/cgf.15112. 1, 2

[NCS06] NOWAK D. J., CRANE D. E., STEVENS J. C.: Air pollution removal by urban trees and shrubs in the united states. *Urban Forestry & Urban Greening 4*, 3 (2006), 115–123. URL: https://www.sciencedirect.com/science/article/pii/S1618866706000173, doi:https://doi.org/10.1016/j.ufug.2006.01.007. 1

[Ope26] OPENSTREETMAP CONTRIBUTORS: Openstreetmap. https://www.openstreetmap.org, 2026. Road network data, accessed 2026-04-05. 2

[PBH*21] POGGIO L., BATJES N., HEUVELINK G., KEMPEN B., RIBEIRO E., ROSSITER D.: Soilgrids 2.0: producing soil information for the globe with quantified spatial uncertainty. *SOIL 7* (06 2021), 217–240. doi:10.5194/soil-7-217-2021. 2

[RLP07] RUNIONS A., LANE B., PRUSINKIEWICZ P.: Modeling trees with a space colonization algorithm. pp. 63–70. doi:10.2312/NPH/NPH07/063-070. 2

[RMC01] RANDRUP T., MCPHERSON E., COSTELLO L.: A review of tree root conflicts with sidewalks, curbs, and roads. *Urban Ecosystems 5* (09 2001), 209–225. doi:10.1023/A:1024046004731. 1, 2

[Sd26] STADT WIEN, DATA.GV.AT: Öffentliches verkehrsnetz linien wien. https://www.data.gv.at/katalog/datasets/36a8b9e9-909e-4605-a7ba-686ee3e1b8bf, 2026. Used for Vienna public transport / U-Bahn lines, accessed 2026-04-05. 2

[Sta26a] STADT WIEN: Versiegelungsgrad wien, 2026. Replace with the exact City of Vienna WFS/OGD dataset title you used. 2

[Sta26b] STADT WIEN / VIENNAGIS: Abwasser / kanal dataset for vienna, 2026. URL: https://www.data.gv.at/katalog/dataset/35472189-71d4-435b-81ef-061d9b2587fa. 2

[TSCFS06] THOMAS SMILEY E., CALFEE L., FRAEDRICH B. R., SMILEY E. J.: Comparison of structural and noncompacted soils for trees surrounded by pavement. *Arboriculture & Urban Forestry (AUF) 32*, 4 (2006), 164–169. URL: http://auf.isa-arbor.com/content/32/4/164, arXiv:http://auf.isa-arbor.com/content/32/4/164.full.pdf, doi:10.48044/jauf.2006.022. 1, 2

[WB83] WAGAR J. A., BARKER P. A.: Tree root damage to sidewalks and curbs. *Arboriculture & Urban Forestry (AUF) 9*, 7 (1983), 177–181. URL: http://auf.isa-arbor.com/content/9/7/177, arXiv:http://auf.isa-arbor.com/content/9/7/177.full.pdf, doi:10.48044/jauf.1983.044. 1