FinEst Centre
for Smart Cities

SMART CITY CHALLENGE 2024

Solution idea for the city challenges

Max 3 pages

send to smartcity@taltech.ee by Sept 16, 2024

Solution Idea Title Tree root urban digital twins

Planned pilot project duration –24 months

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1. Which urban challenge or problem are you planning to provide a solution to?

Urban underground infrastructure and tree roots

2. The solution you are proposing

Urban trees improve the living quality and health of citizens, while also providing many Ecosystem Services. However, the value of trees gets easily undermined or lost against other competing factors in urban planning, largely because of a lack of visibility of tree information in urban information systems. This is particularly the case with tree roots, which often take up the same space that city planners and constructors are targeting when building or maintaining critical urban infrastructure. As tree roots are invisible to citizens and urban stakeholders, it is generally poorly understood how e.g. damage to tree roots during excavations will affect tree health and can cause tree death. As a solution to these problems, we propose to produce algorithmic 3D models of local tree roots for urban digital twins, together with data collection and model updating procedures, root growth prediction models and solutions for city data formats and interoperability. The models will complement aboveground algorithmic 3D tree models, help to model the life and well-being of trees, and allow city stakeholders to view, use and study tree root systems and their needs via 3D city models, digital twins and VR/AR applications.

Stakeholder interviews and integration to city processes in pilot cities: A preliminary expert survey demonstrated several aspects in which 3D tree root system models can benefit cities: (a) Knowledge of the extent of the tree's root system helps to choose the appropriate spacing for the existing tree when planning and designing buildings, roads or utility networks so that the roots do not damage the network in the future, (b) The use of models of root systems helps to choose the right working techniques for the installation and repair of pipes, such as locations where directional drilling or AirSpade could be used instead of open excavations to avoid unnecessary tree root damage; sites where geotextiles or bundle walls can be used to direct tree root growth away from collision areas, and sites where tree root protection would best be ensured by repairing pipes with sockets, or by installing completely new pipes in new locations, and (c) tree root models can help urban planners to plan the needed tree root protection zones when creating urban project plans.

In this project, we will further detail our stakeholder knowledge by documentation of the stakeholders, information systems, standards, code systems and processes where the trees and roots are involved in each pilot city, related legislation, and the exact questions that the tree root models must answer for each stakeholder group. Besides carrying out thematic interviews with key stakeholder groups, we will conduct information sharing & feedback sessions with cities throughout the project.

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Empirical tree root data collection: For the development of 3D tree root models and for prototyping them in 3D city models, we will choose target areas in the participating cities based on the existence of suitable tree species in the area for model development and adequate 3D data availability of the main entities and underground infrastructure of the city at different levels of detail (LoD0 >LoD3), which enable prototype integration of the 3D root system models into a 3D city model.

The employed fieldwork methods will be selected on a site basis from three methods: (a) scanning of the root system area using Ground Penetrating Radar, (b) clearing the soil around surface roots with AirSpade and using mobile georeferencing tools for root system documentation (e.g. F3D; f3d.geosystems.fr), and (c) 3D scanning of visible tree roots from open excavations as widely in the city as possible. The excavation documentation data will be used to setup of a cost-effective tree root data collection and documentation process for cities that accumulates data for tree root modelling without the need of expensive equipment and surveys (e.g. during excavations, pipe installations, underground infrastructure imagery and tree felling). Tree survey methods will be accompanied by soil and moisture data measurements (e.g. the Brussels CBS+ indicator).

AI-based tree root system growth models: We will develop spatially explicit tree root growth models based on the collected empirical data and available background knowledge on tree root growth in the selected target species. AI-based model development (in collaboration with FARI Brussels; https://www.fari.brussels/) offers a flexible approach for combining complex (historical and real-time) data from multiple sources for model building. Therefore, it is possible to also extend the models later on to account for multiple environmental factors, such as varying environmental conditions, and to connect tree root models later on to AI-based aboveground tree models that can model detailed tree shapes as a result of tree pruning.

The resulting tree root growth models will (1) summarize the effect of root system functioning (e.g. water and nutrient uptake) based on tree species and root system volume and structure, which estimates can then be linked to the growth and health of aboveground digital tree models, (2) demonstrate the effect of soil type, water availability, in-soil transitions and obstacles to root system growth, and (3) estimate the proportion of root system damage that a tree can tolerate depending on its age, health and species. Algorithmic growth models can then be simulated inside game-engine-based software for the development of 3D tree roots in various soil types and structures, water conditions and in the presence of physical obstacles.

Standardisation and interoperability: The integration of tree root system models to the 3D city modelling infrastructure is supported by developing a CityGML 3.0 converter and a LoD adjustment algorithm that allow the algorithmically developed 3D tree root system models to be presented in multiple Levels of Detail (from LoD0 to LoD3) in 3D city models and digital twins. The new Dynamizer module of Citygml 3.0 can be a key element to transform static 3D models into dynamic digital twins, capable of reflecting in real time the evolution of objects in relation to other existing modules (Building, Transportation...). CityGML also allows implicit (probabilistic) presentation of a typical root system of a tree species at a certain age, thus allowing the presentation of tree root systems of trees that have not been inventoried in detail in 3D city models and digital twins. We will also initiate collaboration with University of Liège regarding designing a new CityGML ADE (Application Domain Extension) module for urban soil and tree furniture, which are currently lacking standardisation.

Additionally, many cities have their particular information models for transferring data about underground utility infrastructure like pipes and cables, such as the KLIP platforms for Flanders and KLIM-CICC for Brussels and Wallonia and the CCI coding system of Tallinn. We plan to provide an interface with such platforms that ensure the exchange of plans concerning underground network infrastructures which are the source of many attacks on the integrity of tree roots. The prototype interaction would be done via the IMKL model for exchanging data concerning underground utilities assets.

Deliverables: The deliverables of the project include (a) a game engine-based tree root 3D growth simulator, tree root models of the studied trees and example models for species that represent all the typical root system growth types, prototype target area 3D city models (built using either GreenTwin.ai platform or a FARI CAVE integration) with integrated root system models, (b) tree root model converters to CityGML 3.0 and a prototype converter to IMKL pipes and cables format, and a (c) tool for cities for cost-effective tree root data collection during street excavations and other tree root related real-life activities. These solutions will enable future development of smart AR tools for viewing tree root information e.g. in mobile devices.

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Support of strategic goals: Enhancing the sustainability of urban trees, our project targets are well in line with Estonia 2035 goals (supporting biodiversity and a healthy living environment), with the new Bauhaus principles (providing tools and guidance and incorporating views of various stakeholders into the process of design and implementation) and EU Biodiversity Strategy for 2030 (which foresees more greenery in the cities).

3. Innovation and piloting of your pilot solution.

State-of-the art research of tree root system growth models include prototype 3D simulators of root system growth in varying soil types, but these models have not been developed into practical tools available for cities. To our knowledge, there are also no 3D models for tree root systems in the market that can present both the explicit root systems of studied tree individuals and typical root systems of a particular tree species, and that can be present as 3D objects in multiple Levels of Detail, as well as in a CityGML format. Tree root systems have been integrated in the City of Rotterdam's 3D City model, but these include only cylinder forms without any individual-specific tree root information. Our solution is based on a 3D CityGML semantic modelling that combines both geometric and semantic information, allowing a rich and coherent representation of urban objects. This semantic framework ensures increased interoperability between public services, facilitates the management of land rights, improves urban planning and strengthens territorial governance.

Cities interested in the piloting of the solution can collaborate with the project team by looking for a suitable target area and target species, followed by co-planning of field data collection that is suitable for the targeted trees. Prototyping of the developed tree root models in a 3D city model could be done either by the project team, or by the city GIS team integrating the tree root models to the city model. Additionally, cities can collaborate by providing experts for interviews and details of the city's pipes and cables information, which can serve as a prototype root system data integration and use case definition.

Besides FinEst Centre researchers and city collaborators from Brussels (via public institutions Brussels Mobility and Brussels Environment), Tallinn and Helsinki, the team is strengthened by collaborations with Paradigm Brussels (IT systems and interoperability), FARI Brussels (AI), GreenTwin.ai (game engine-based environments and integration), Eurosense (tree data in Belgium) and University of Liège (CityGML ADE). Team members have thematic knowledge of landscape architecture and tree ecology, tree root empirical data collection, realistic data collection and model update procedures, 3D algorithmic modelling of tree roots for urban digital twins, AI-based root growth prediction models, stakeholder interviews, and CityGML.

4. Expected impact of your pilot solution.

The implementation of a digital twin for tree root systems could significantly impact various fields and include key benefits: better understanding of tree root systems, which are challenging to study directly due to their underground nature; reduction in damage frequencies and longer lifetimes both for urban trees and for underground infrastructure; more informed green space and urban area management and planning regarding potential future damage; faster permit processes for urban excavations (as all stakeholders have better visibility to the excavation consequences to trees); community engagement by raising citizen awareness of the importance and functions of tree roots; and potential for many future developments.

Disclaimer: by submitting this form you will give the FinEst Centre for Smart Cities the right to share this idea with cities and other researchers, companies through FinEst Centre homepage. If this idea is selected, the FinEst Centre for Smart Cities has the right to implement this idea with offering you an active role in conducting the pilot. If this pilot is selected then the financing is an investment by the FinEst Centre for Smart Cities.