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GroQSM: integrating quantitative structure models in plant and growth modeling

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Software

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Summary

The presented work aims at integrating quantitative structure models (QSM), commonly reconstructed from terrestrial laser scans, in the plant modeling platform GroIMP (Kniemeyer, 2008).
The project includes import and export of QSM files, a set of additional cylinder specific descriptors for GroIMP, a library for post-processing measured trees, and additions to the GroIMP user interface for easier usage.

Statement of need

Modern improvements in 3D capturing raise interest in using these datasets as input for functional structural plant modeling (FSPM). Either for extracting characteristic features of a group of plants to simulate similar ones (Bekkers et al., 2025) or for simulating and predicting the future behavior of a specific individual (O'Sullivan et al., 2021).

Even though some FSPM platforms already enable the direct integration of scanning results (Bailey, 2019; Heidsieck et al., 2025), a link with an established format for reconstructed trees, such as QSM (Delagrange et al., 2014; Raumonen et al., 2013), could ease the process by using already existing reconstruction approaches (Fan et al., 2020; Jan et al., 2021; Raumonen et al., 2013). Additionally, the same link could also be used for model validation (Beyer et al., 2017) by comparing a scanned tree (reconstructed as a QSM) and a simulated tree (interpreted as a QSM).

In addition to **bidirectional data conversion**, such a link should acknowledge that these fields typically focus on different scales. FSP modeling aims to consider segments as organs and is therefore more affected by issues in individual reconstructions, potentially requiring **additional post-processing**. Conversely, QSM focuses more on higher-level relationships and requires **analytical functions** that are not typically used in FSPM projects.

GroIMP

GroIMP is a graph-based 3D simulation platform, mostly used for FSP modeling. It uses its own Java-based programming language XL to create, rewrite, and query graphs that can be interpreted as 3D structures. The platform is an integrated environment including UI tools for modeling, simulating, and analyzing.

QSM

A QSM describes a tree as a network of cylinders, each holding the knowledge about its parent cylinder. Additional information, such as global coordinates, length, diameter, or branching order, allows the 3D recreation of the tree. The term QSM does not refer to a single data format but a set of algorithms and conceptual structures. In this project, we use the standardized QSM defined by the rTwig library (Morales & MacFarlane, 2025b). RTwig supports the translation of the most common QSM formats into this standard.

Functionalities

We address the above described needs with the GroQSM plugin, which enables the handling of QSM files and improves the analysis on higher scales and post-processing of QSM-like structures within GroIMP.

The plugin can be installed using the GroIMP plugin manager. The presented work describes the functionalities of the plugin version 2.2.5, which requires GroIMP 2.2.1 or higher.

File handling

QSM files are imported by converting each cylinder into a GroIMP shoot object in the project graph. Each shoot is connected to its parent (known from the QSM) by either a branch edge for lateral shoots (children with higher order) or a successor edge for apical shoots (children with the same order). The root cylinder, defined by not having a parent, is also the root of the imported subgraph. This results in a graph following the basic structure of most GroIMP models.

To export from a GroIMP graph into a QSM file, each shoot object is converted into a cylinder. Each cylinder is then mapped to its parent by resolving the preceding shoot object in the project graph. Additional information, such as global coordinates and branching order, is computed from the graph and added to the QSM.

Analyzing

GroIMP contains native analysis tools suitable for QSM: mainly its graph query language and the visual attribute editor. Additionally, the GroQSM plugin provide a set of descriptors more adapted to the specific structure of QSMs.

Most of these additional descriptors are based on or inspired by literature descriptions (Hackenberg & Bontemps, 2023; McMahon & Kronauer, 1976), such as the reverse branching order or the tip distances.

The additional descriptors can be accessed either via a dedicated panel, the QSMInspector, or directly in XL queries.

Post processing

The imported QSMs can be manipulated by the XL graph rules. The rules enable removing cylinders, updating their attributes and appearance, adding new objects, or changing the connections and relationships between different parts of the graph. This can be enhanced by the newly introduced descriptors to apply filters similar to (Hackenberg & Bontemps, 2023; Morales & MacFarlane, 2025a).

Additionally, a set of UI tools was created to manually improve the tree structure. These tools include merging, smoothing, or splitting, as well as rearranging the taxonomical relationship between cylinders and shifting branches towards the surface of their parents.

Example usage

An example of importing and exporting a QSM, and the user interface shown in figure 1 is provided in the tutorial Post processing a QSM with GUI tools in the GroIMP wiki.

Additionally, two simplified filters are presented in Post processing a QSM with XL.

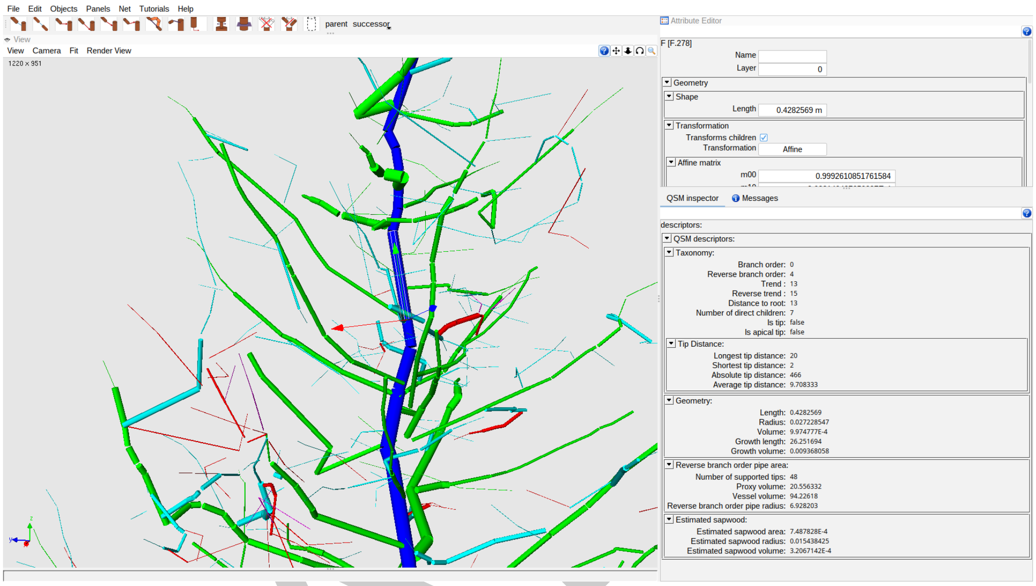

Figure 1: GroIMP showing an imported tree with a cylinder on the stem selected. Above the 3d view the possible tools can be seen and on the right the attributes and descriptors of this cylinder are listed.

QSM based modeling

Through the structured import, transforming the captured data into a growth model is a simple matter of organ-wise replacement. In a simple example (Figure 2), each imported cylinder is replaced by either a shoot organ or a shoot with leaves and additional buds. The used QSM, the code, and explanation can be found in the tutorial: Turning a QSM into a growable model.

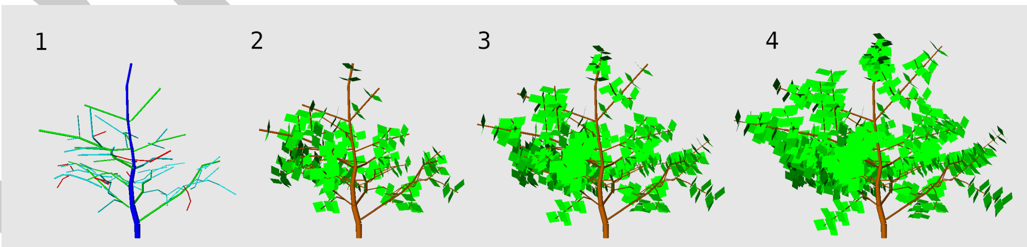

Figure 2: A small QSM imported in GroIMP color-coded based on the order (1), updated to a growth model(2), and grown for one and two steps(3,4)

Discussion

The bidirectional conversion of the shape and the structure of tree models between QSM and GroIMP shows potential for reconstruction-driven plant modeling. Indeed, the QSM data fits directly into the GroIMP data structure, which eases the usage of advanced GroIMP analysis features on the imported data. Features such as the analysis of structures, the abstraction of relationships, and rule-based processing open up additional possibilities. Moreover, the additional UI tools help users to visualize their data and improve their reconstructions.

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