Presentation of CPlantBox: a whole functional-structural plant model (root and shoot) coupled with a mechanistic resolution of carbon and water flows

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I. INTRODUCTION

Carbon forms the structure of every life form, especially plants. Within the plant architecture, water and carbon flows are linked through tight interactions between xylem and phloem vessels (Münch theory[1]). Root growth is locally constrained by the amount of carbon available for the meristem. Thus, to evaluate and manipulate root growth and development, we need to:

· Understand how carbon is allocated and prioritized between different roots (e.g. primary vs laterals, principal vs seminals vs nodals).

· Understand connection between local water availability and carbon allocation.

II. MODEL DESCRIPTION

CPlantBox is currently being developed based on the root model CRootBox [2]. We took advantage of the object-oriented structure of CRootBox and added new modules to represent the different shoot organs (see Fig. **A**). Main additions in CPlantBox are:

· The input parameter files are now XML-based (instead of plain text-based in CRootBox). This has the following advantages: increased robustness, flexibility (more parameters for the shoot) and readability. For example, the *functiontype (lnf)* is added to create different architectures of plants in Fig. **B**.

· As we move from simulating only roots to a full plant, more complex relationships between the different organs have been included in the model. For instance, roots can now be formed by either the seed, other roots or shoot organs (Fig. **A**).

By following the flow chart (Fig. **A**), we can simulate a plant structure. Two manual steps needed are generating the input file and visualize the output file. Firstly, we could use any text editor to modify red colored text in Fig. **B**. Then we can use the CPlantBox to run simulation based on this input file, at the end of the simulation, we will have an output file. By using visualization software, we could get a 3D plant in Fig. **C**.

In order to simulate the carbon and water flow, we created an conversion function in CPlantBox, such as the model's output could serve as an input for the model PiafMunch [3], [4]. The conversion is shown in Fig. **D**.

III. RESULTS

1) Carbon flow between nodes

As shown in Fig. **E**, the carbon flows are increasing in the first 25 hours, then stay at stable levels. The sum of carbon flow in each leaf is equal to the carbon flow in main stem or the sum of carbon flow in each root.

2) Water flow between nodes

The water flow is calculated at the same time as the carbon flow in PiafMunch. In Fig. **F**. A simple function is used to mimic the transpiration difference between days and nights.

IV. CONCLUSIONS AND PERSPECTIVES

At this stage of development, CPlantBox can simulate realistic 3D root and shoot structures, which can be coupled with mechanistic models of carbon and water flows. We believe CPlantBox will be a useful tool to understand how plant grow and develop in response to heterogeneous environmental conditions better. Future lines of work include:

· Benchmarking the carbon and water flow resolution with experimental data;

· Releasing parameters files for multiple plant species;

· Developing a WebApp for the model, similarly to what was done with CRootBox (http://bit.ly/crootbox);

· Exploring how heterogeneous soil conditions influence the carbon and water flow within the plant.

WebApp Demo

[1] E. Münch and b., 1930.
[2] A. Schnepf et al., Ann. Bot., vol. 121, no. 5, pp. 1033–1053, Apr. 2018.
[3] A. Lacointe and P. E. H. Minchin, Funct. Plant Biol., vol. 35, no. 10, pp. 772–780, Nov. 2008.
[4] P. E. H. Minchin and A. Lacointe, Funct. Plant Biol., vol. 44, no. 5, pp. 507–514, May 2017.

A UML Flow Chart of CPlantBox
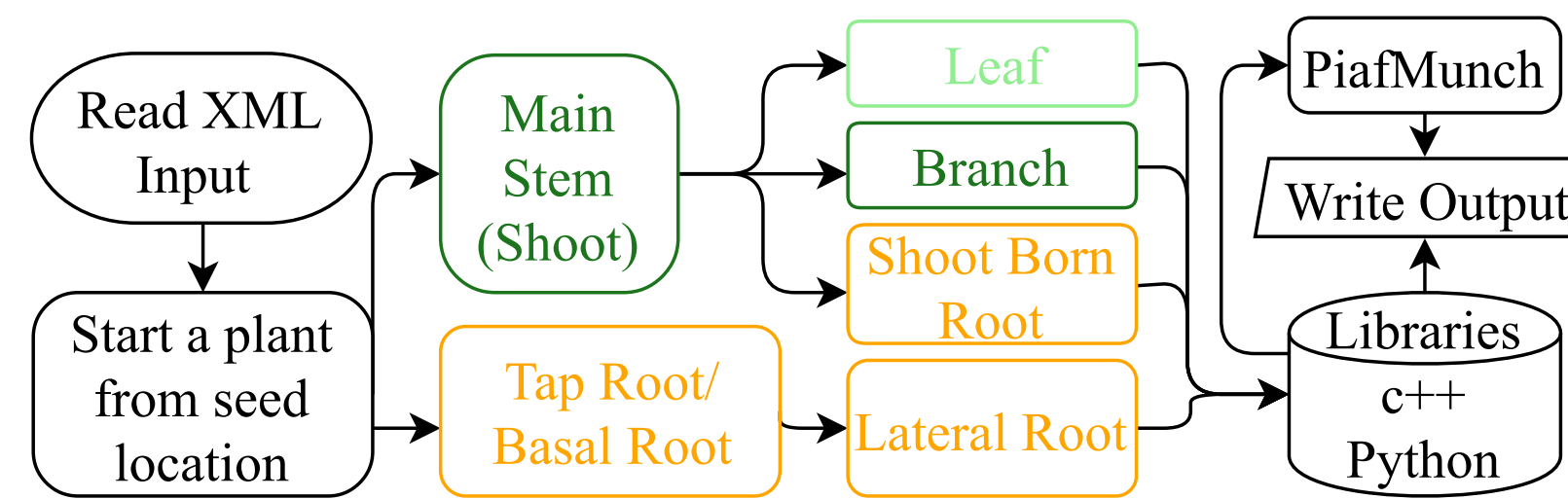
B Input: Parameter File

```
1  <?xml version="1.0" encoding="UTF-8"?>
2 -<Plant name="tree" filetype="parameters">
3 +   <organ type="seed" subType="0">
4 +   <organ type="root" name="taproot" subType="1">
5 -   <organ type="stem" name="mainstem" subType="1">
6        <parameter name="lb" value="100" dev="0"/>
7        <!--Basal zone [cm]-->
8        <parameter name="la" value="2" dev="0"/>
9        <!--Apical zone [cm];-->
...      ....
28 -     </organ>
29 +   <organ type="leaf" name="taproot" subType="1">
30 -</Plant>
```
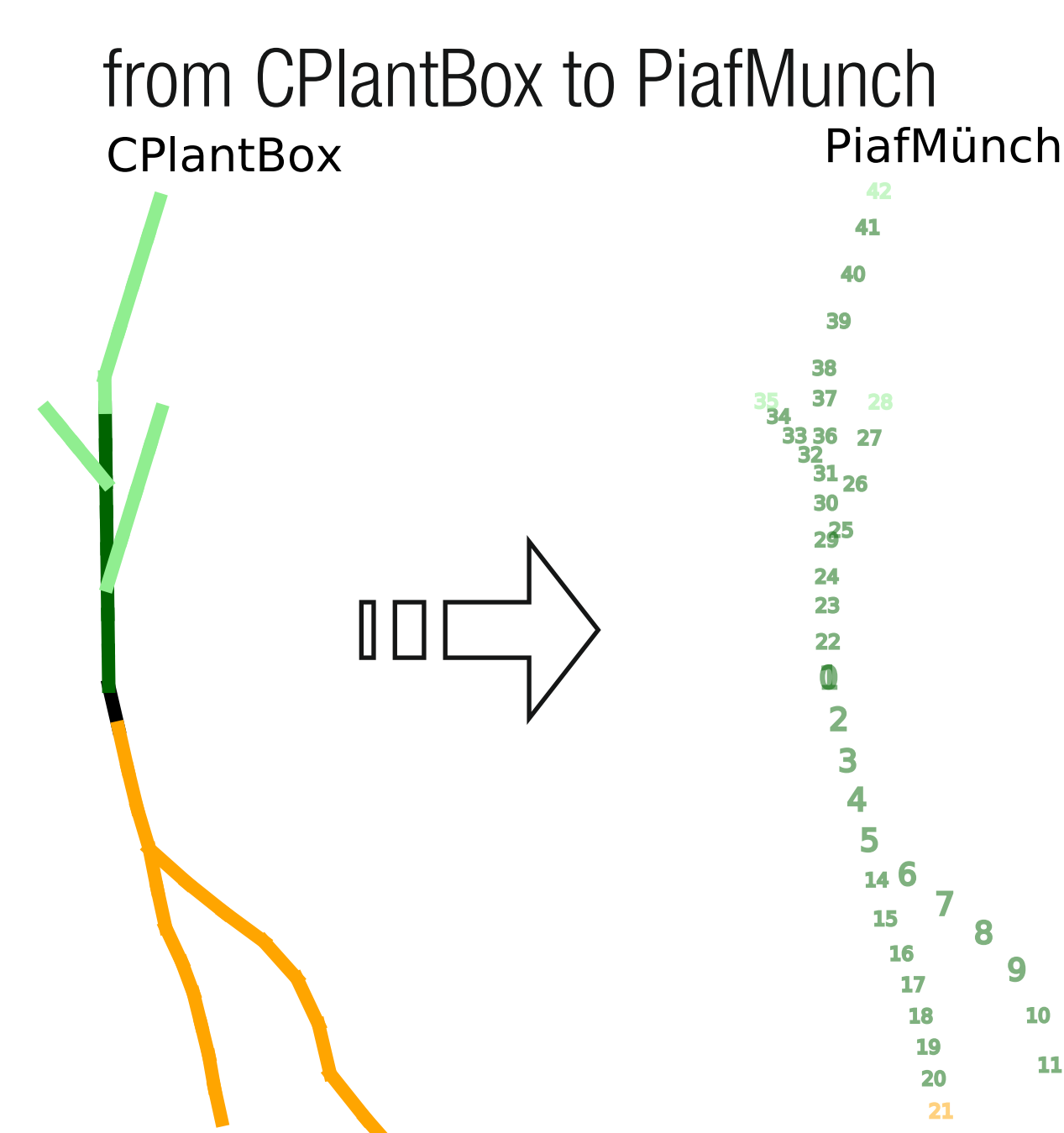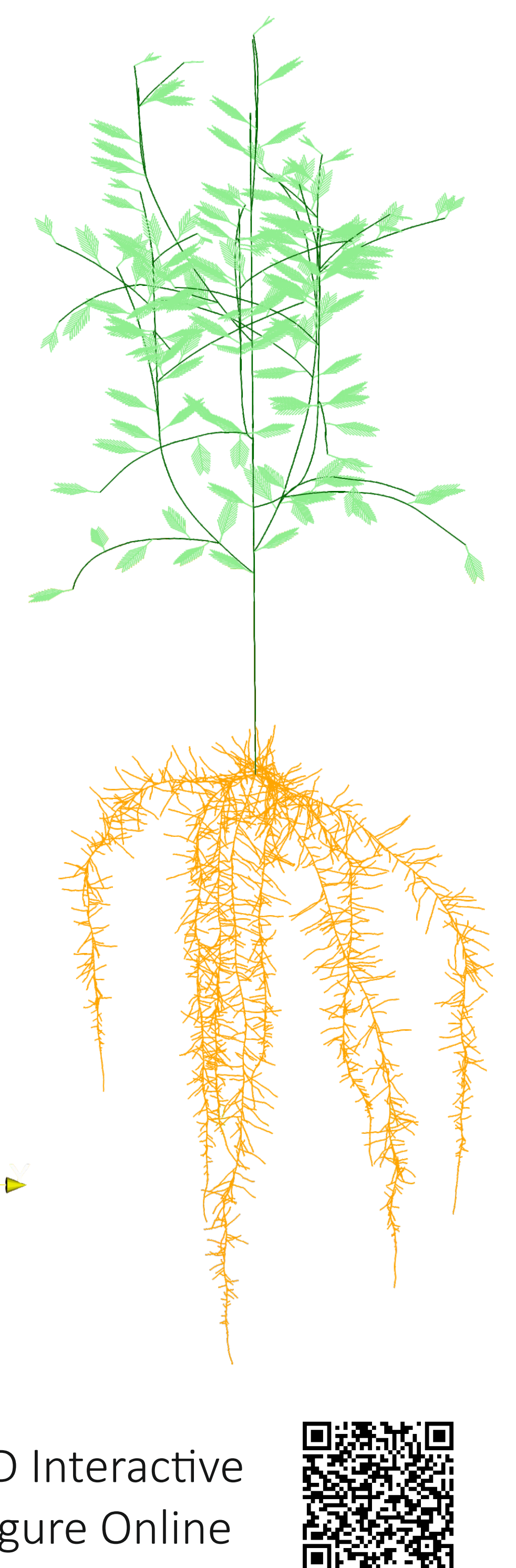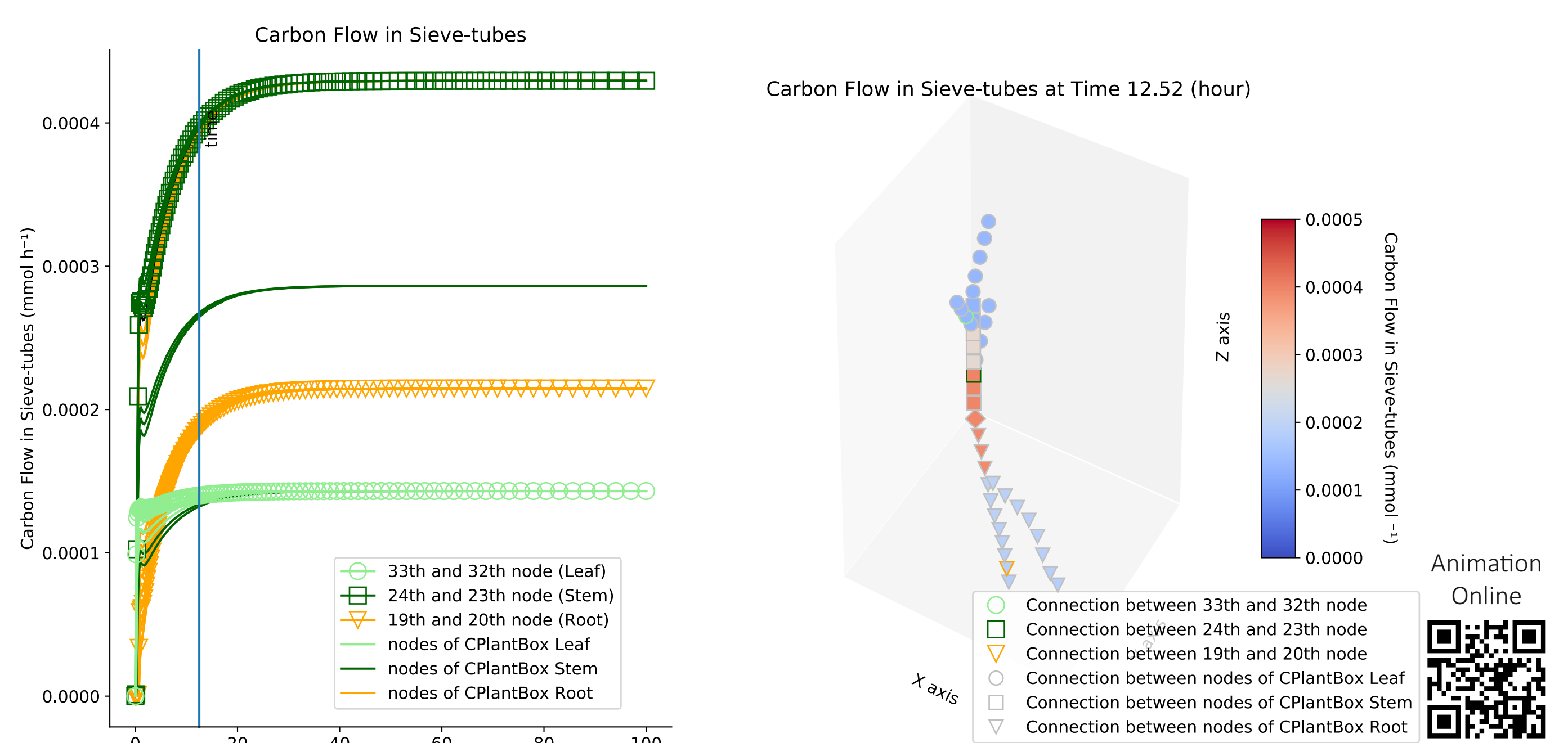
C Output: Plant Structure

D Coupling: Conversion from CPlantBox to PiafMunch

CPlantBox   PiafMünch

3D Interactive Figure Online

E Carbon Flow in Line Chart and 3D Structure

Carbon Flow in Sieve-tubes

Carbon Flow in Sieve-tubes at Time 12.52 (hour)

Animation Online

F Water Flow in Line Chart and 3D Structure

Water Flow in Xylem

Water Flow in Xylem at Time 12.52 (hour)

Animation Online