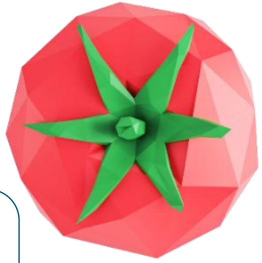
Digital Twin
Virtual Tomato Crops

Rick van de Zedde, Katarina Streit – Bringing Digital Twins to Life @WUR Wageningen, 13-14 December 2022

WAGENINGEN
UNIVERSITY & RESEARCH

Digital Twin – Virtual Tomato Crops (VTC)

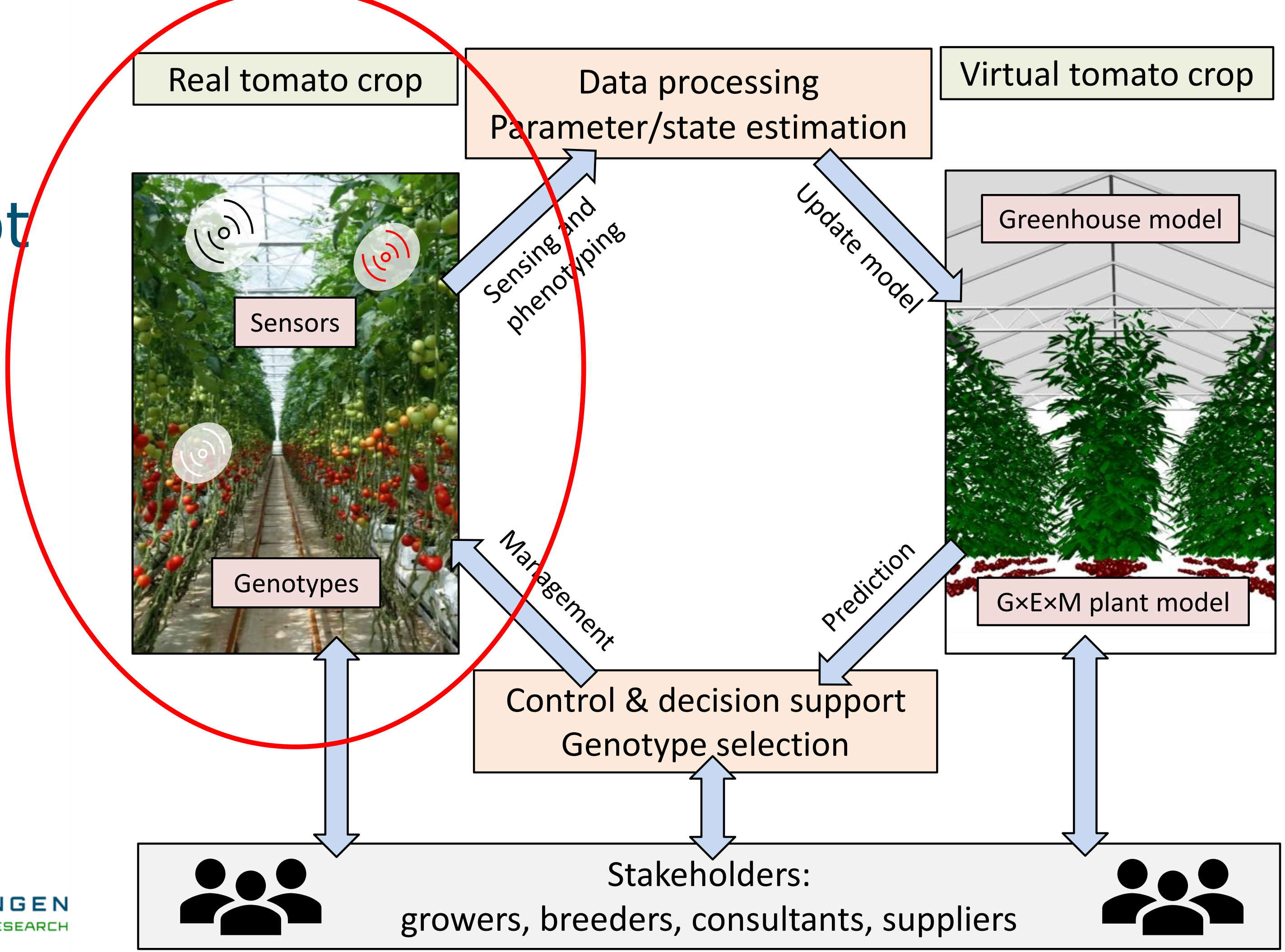


Digital twin – a digital equivalent to a real-life object of which it mirrors its behaviour and states over its lifetime in a virtual space

(Ariesen-Verschuur et al., 2022)

- 3 important parts of our digital twin:
  - A virtual plant model & a greenhouse model,
  - Measurements on actual tomato plants growing in a greenhouse,
  - Dynamically updating the model based on the measured data.
- Why: To develop a digital twin that helps increase resource use efficiency (energy, space, water, inputs) of greenhouse tomatoes

Digital Twin concept



Bringing scientists together

data visualisation
Wander - Bart Knuiman

plant physiology
Elias Kaiser, Nastassia Vilfan

socio-economics
Marc-Jeroen Bogaardt

phenotyping technologies
Rick van de Zedde, Harm Bartholomeus

greenhouse & climate modelling
Gert-Jan Swinkels

digital twin

3d plant measurements
Gert Kootstra, Bolai Xin

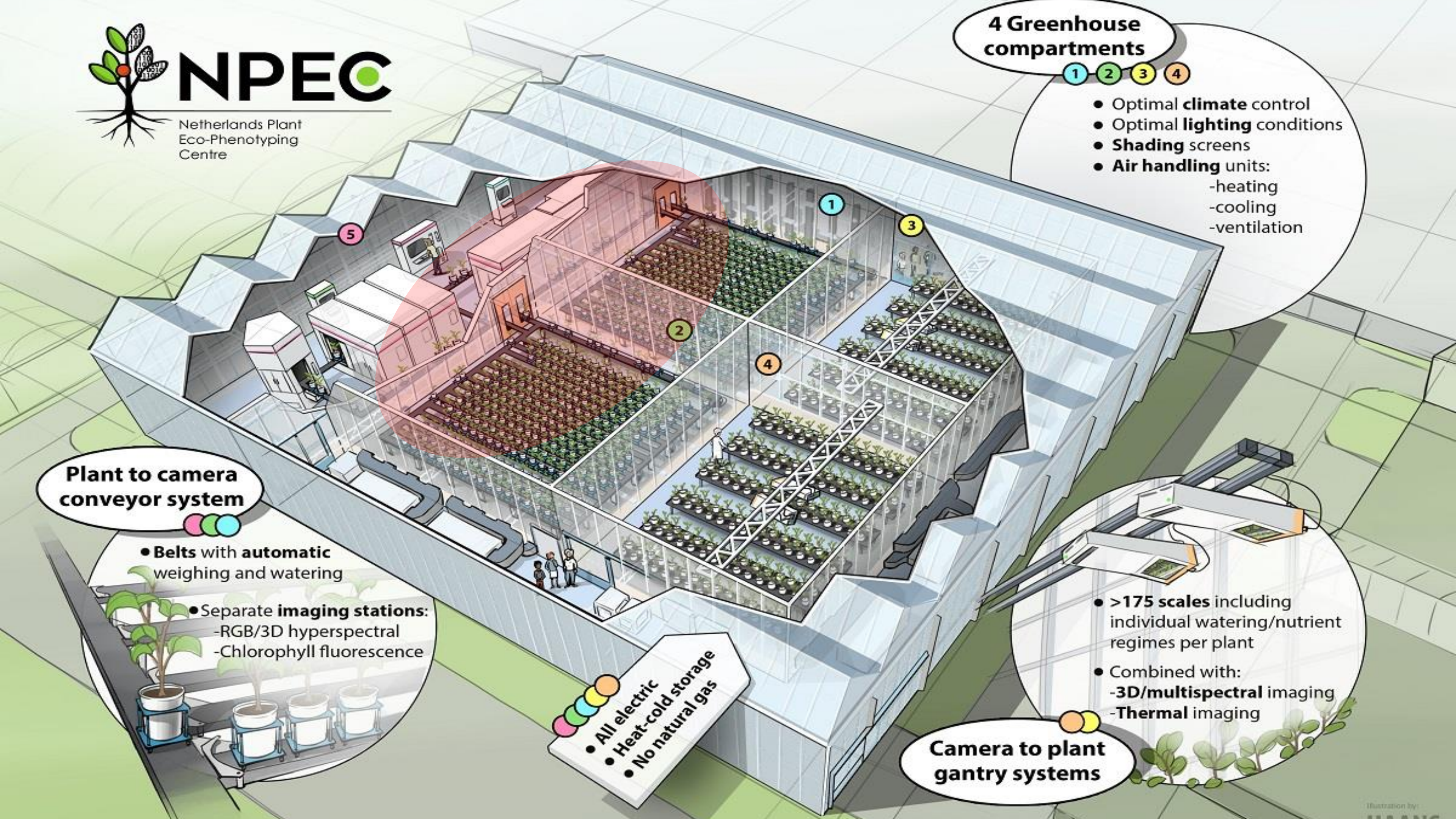
data management
Peter Roos

experimental design & statistics
Daniela Bustos Korts

3d plant modelling
Jochem Evers, Pieter de Visser, Katarina Streit

software & data processing
Tim van Daalen

adaptive control / feedback loop
Simon van Mourik, Sjoerd Boersma


NPEC
Netherlands Plant Eco-Phenotyping Centre
4 Greenhouse compartments
1 2 3 4
• Optimal climate control
• Optimal lighting conditions
• Shading screens
• Air handling units:
-heating
-cooling
-ventilation
5
Plant to camera conveyor system
• Belts with automatic weighing and watering
• Separate imaging stations:
-RGB/3D hyperspectral
-Chlorophyll fluorescence
• All electric
• Heat-cold storage
• No natural gas
• >175 scales including individual watering/nutrient regimes per plant
• Combined with:
-3D/multispectral imaging
-Thermal imaging
Camera to plant gantry systems


Data acquisition
AB

Data acquisition

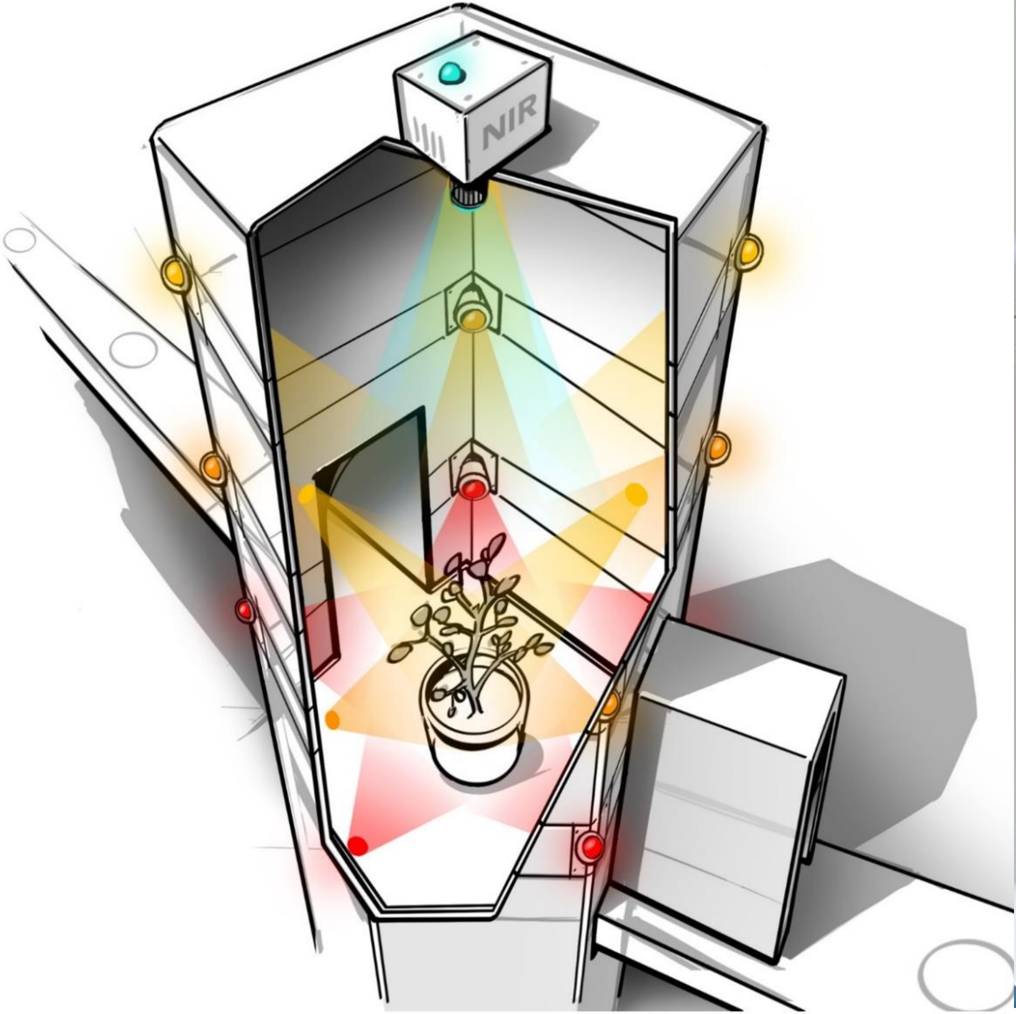
- 2 experiments in NPEC
  Spring/summer 2021
  Autumn 2021
- Climate measurements
- Plant measurements
  - Destructive (weekly)
  - Imaging (3x per week)
  - Photosynthesis
    Optical properties

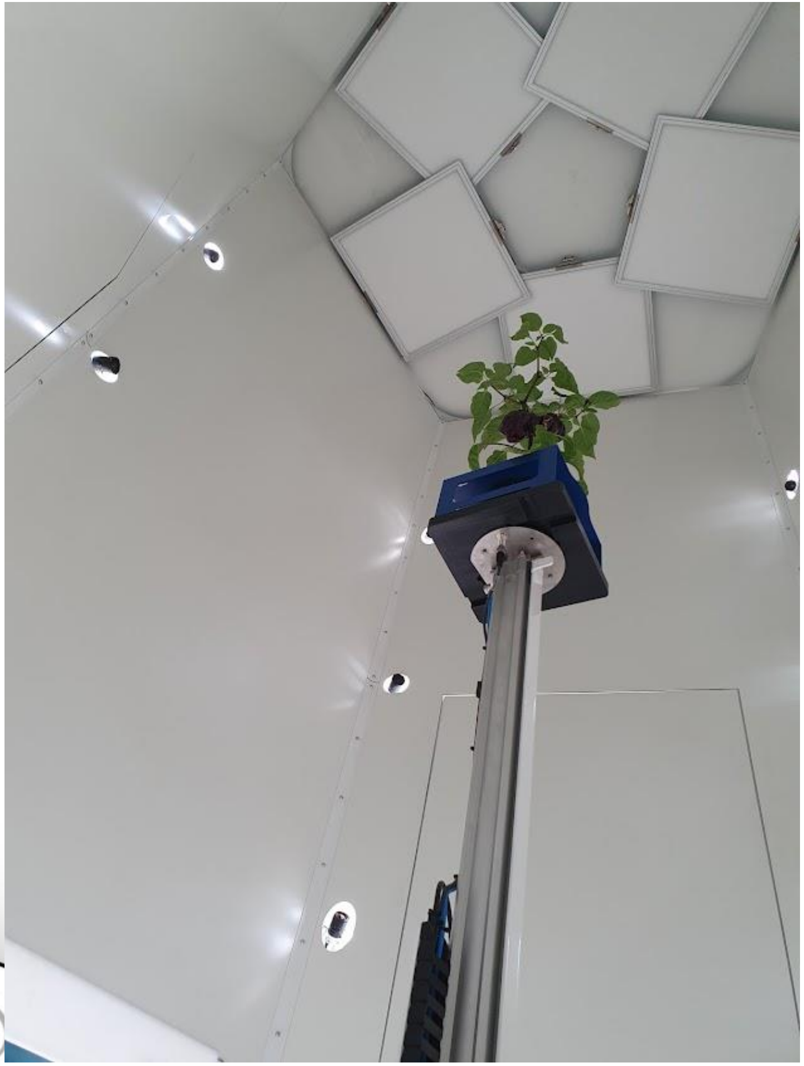
Merlice | Brioso | Gardener's Delight | Moneymaker

WAGENINGEN
UNIVERSITY & RESEARCH

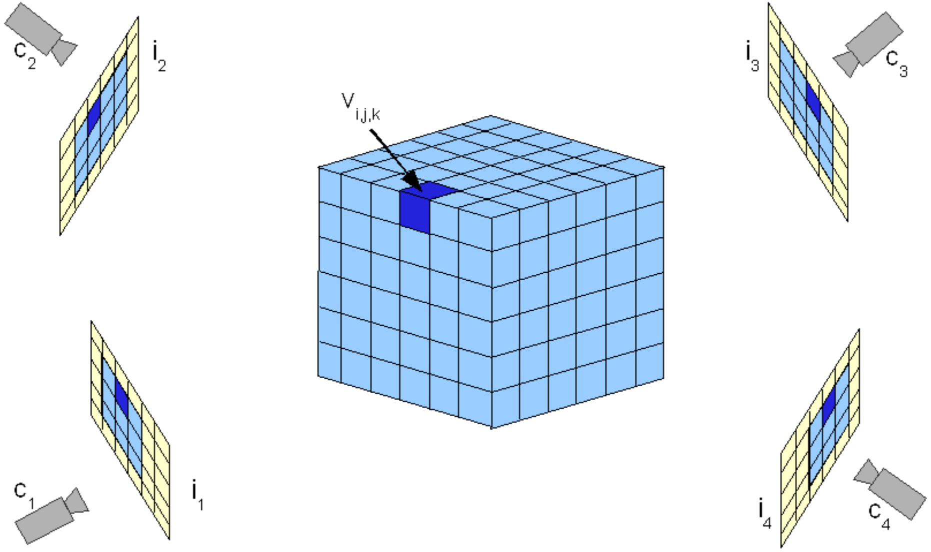

Grodan Max
Grodan Max

Maxi Marvin


NIR

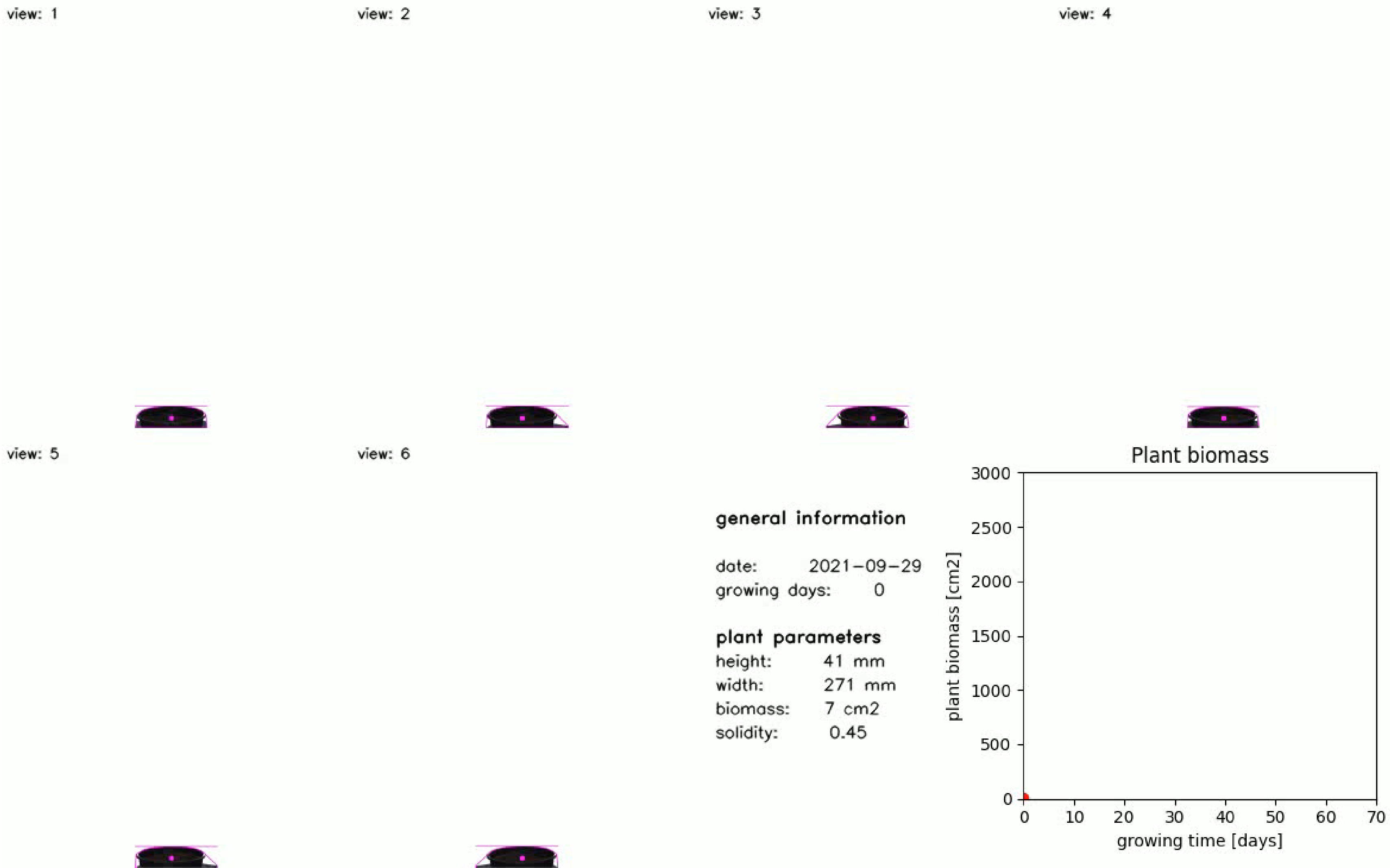


Volumetric intersection – 3D point cloud



WAGENINGEN
UNIVERSITY & RESEARCH

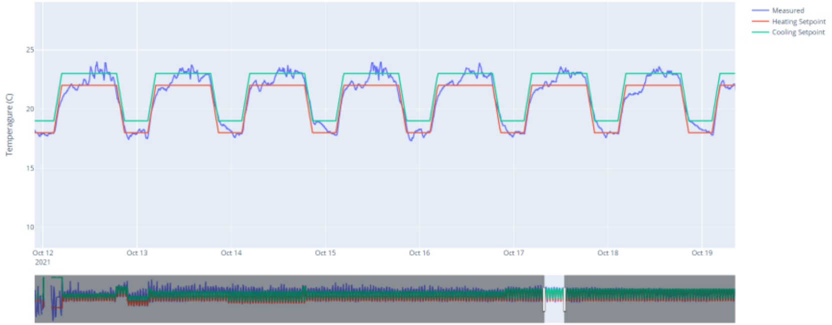
RGB side view & chlorophyll fluorescence imaging


view: 1
view: 2
view: 3
view: 4
view: 5
view: 6
general information
date: 2021-09-29
growing days: 0
plant parameters
height: 41 mm
width: 271 mm
biomass: 7 cm2
solidity: 0.45
Plant biomass
plant biomass [cm2]
0
500
1000
1500
2000
2500
3000
growing time [days]
0
10
20
30
40
50
60
70

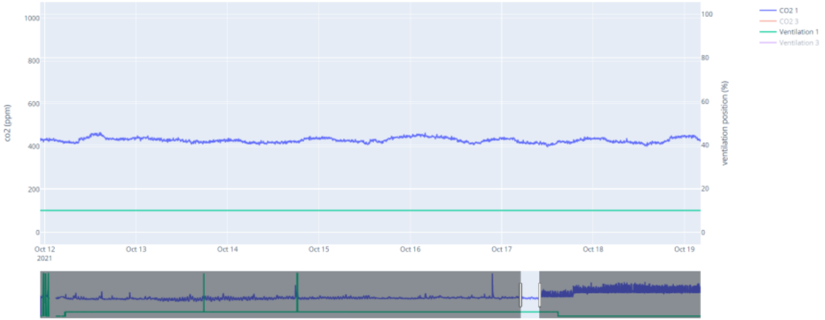
Manual measurements – Ground truth

Climate data

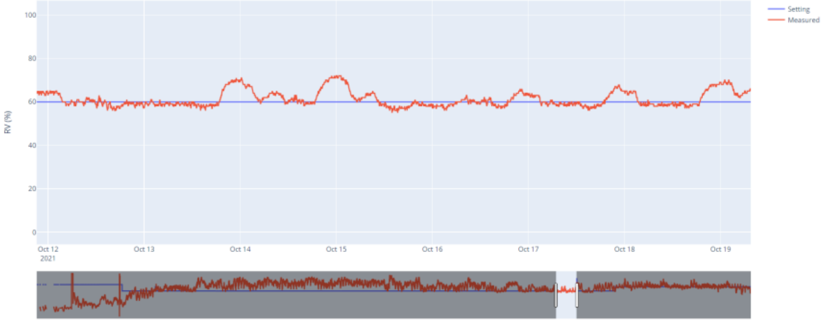
Temperature



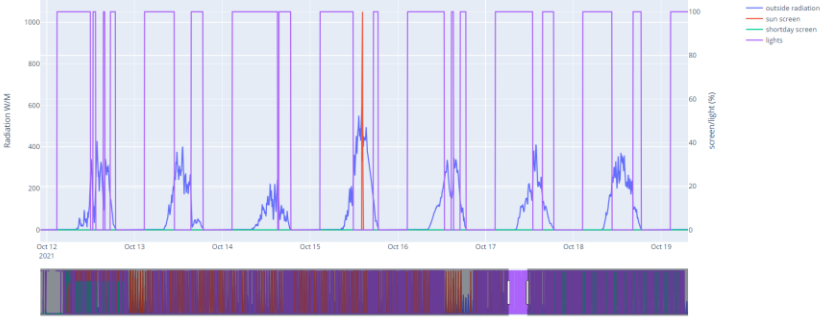
CO_2



Relative humidity



Outside radiation

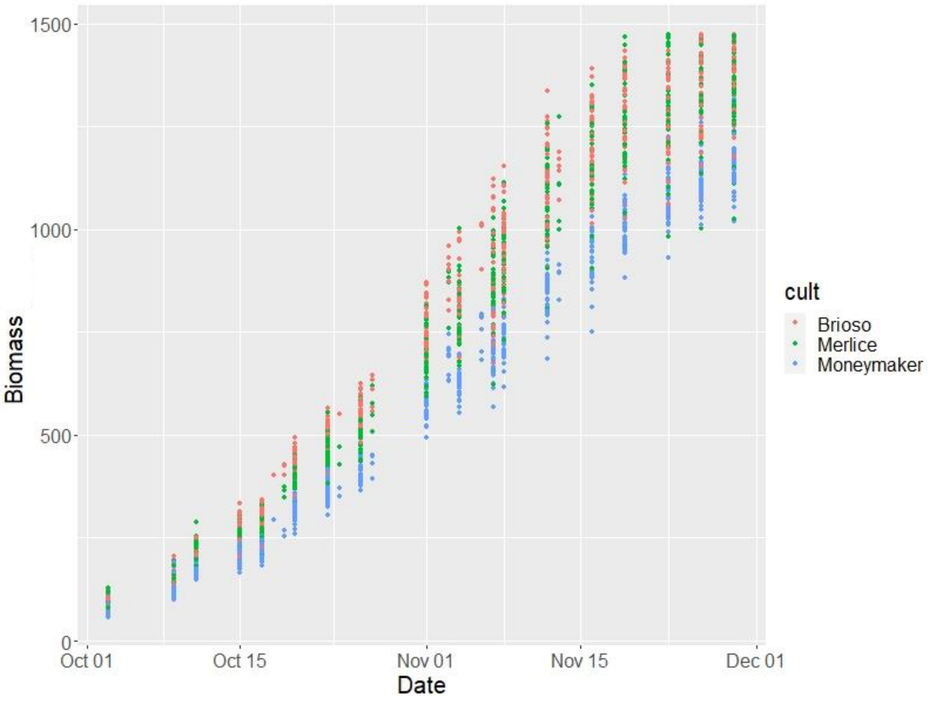


WAGENINGEN UNIVERSITY & RESEARCH

Graphs visualise one week of climate data

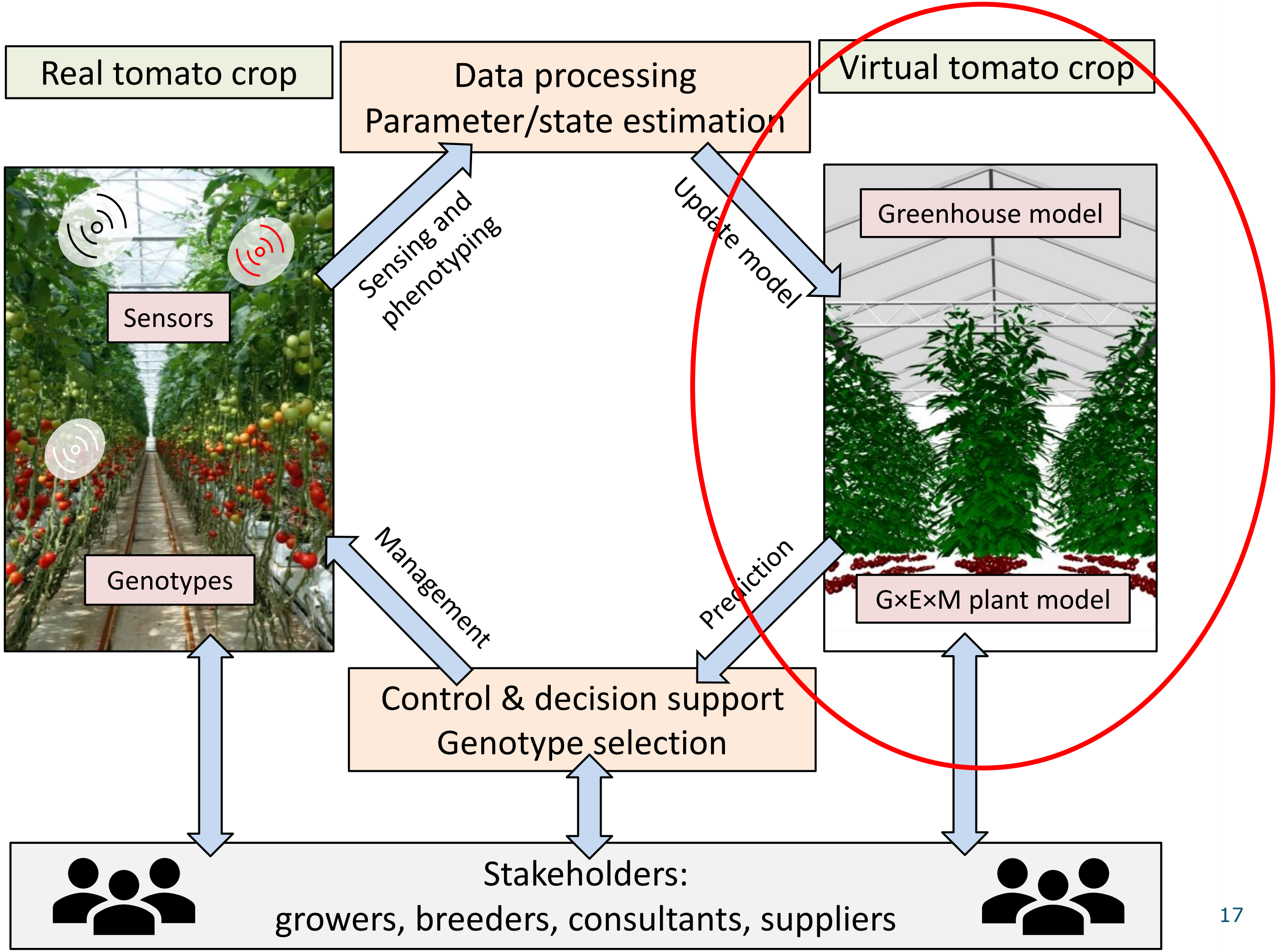
Phenotypic data: challenges

- Because of the conveyor belt, not all plants were measured simultaneously (4 hours).
- Spatial & cultivar effects in comp.
- More replicates at the beginning than at the end because of the harvesting.

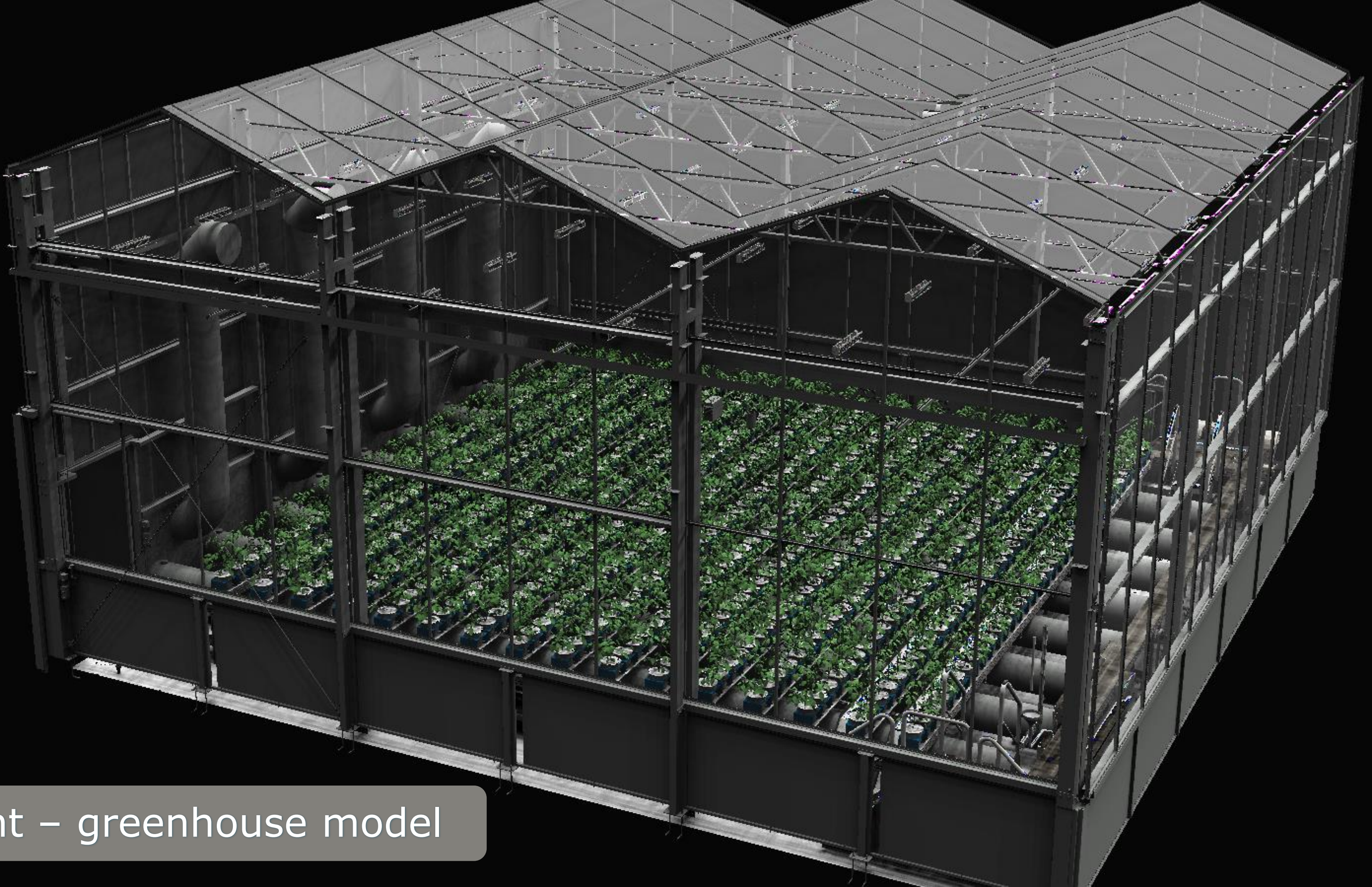


WAGENINGEN
UNIVERSITY & RESEARCH

Digital Twin concept



WAGENINGEN UNIVERSITY & RESEARCH



Plant – greenhouse model

Climate model – Kaspro

Greenhouse properties

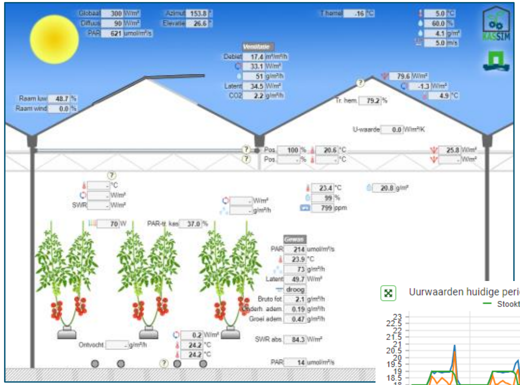
- Cover type/material
- Air treatment units
- Screens and illumination

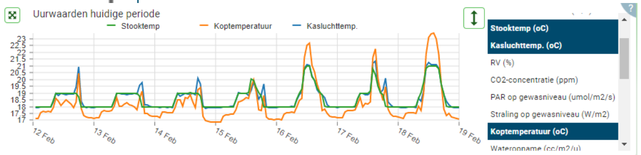
Meteo data

- Historical
- Forecast

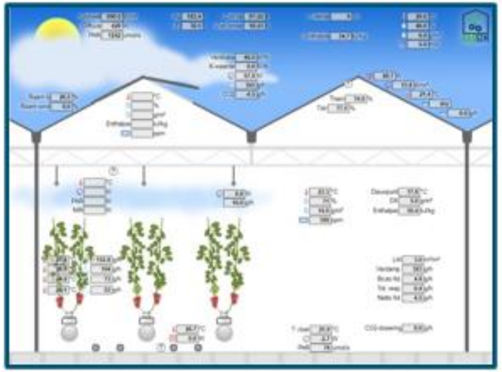
Sensor data

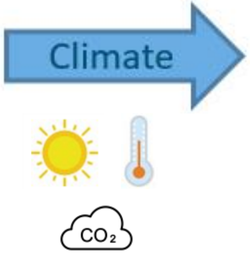
- Historical & real-time
- Realised climate
  Realised control data





Plant-greenhouse model





Climate model
Kaspro

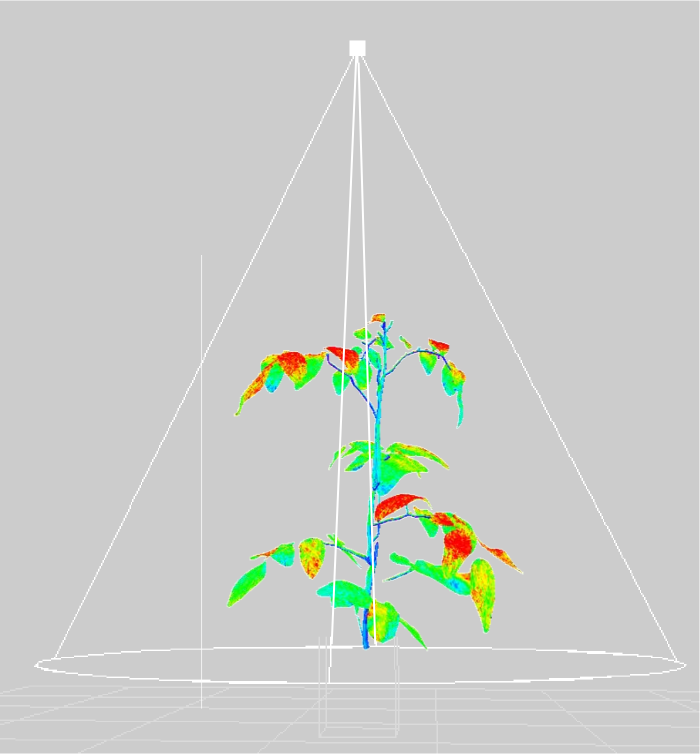
Plant model
Functional-structural plant (FSP) model

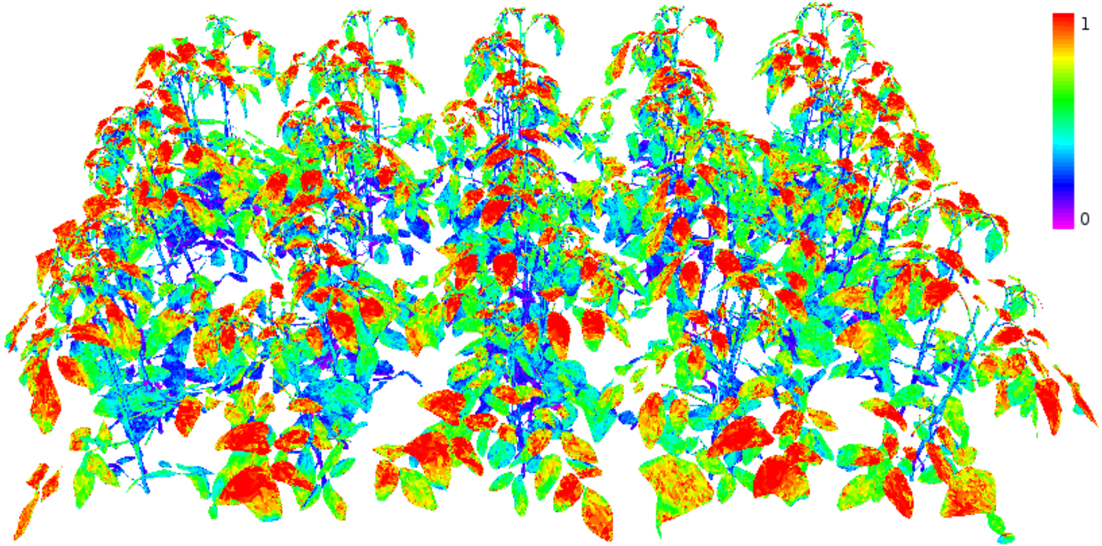
"... explicitly describes the development over time of the 3D architecture or structure of plants as governed by physiological processes which, in turn, depend on environmental factors"

Vos *et al.*, 2010, J Exp Bot

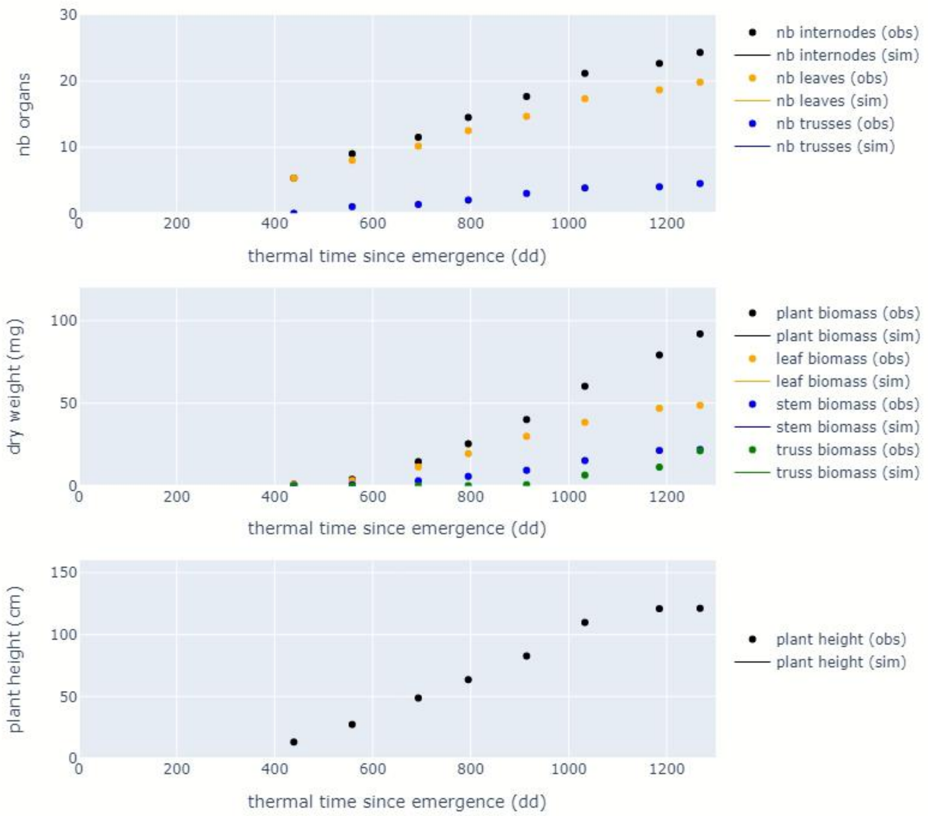
WAGENINGEN
UNIVERSITY & RESEARCH

Modelling light interception in the FSP model



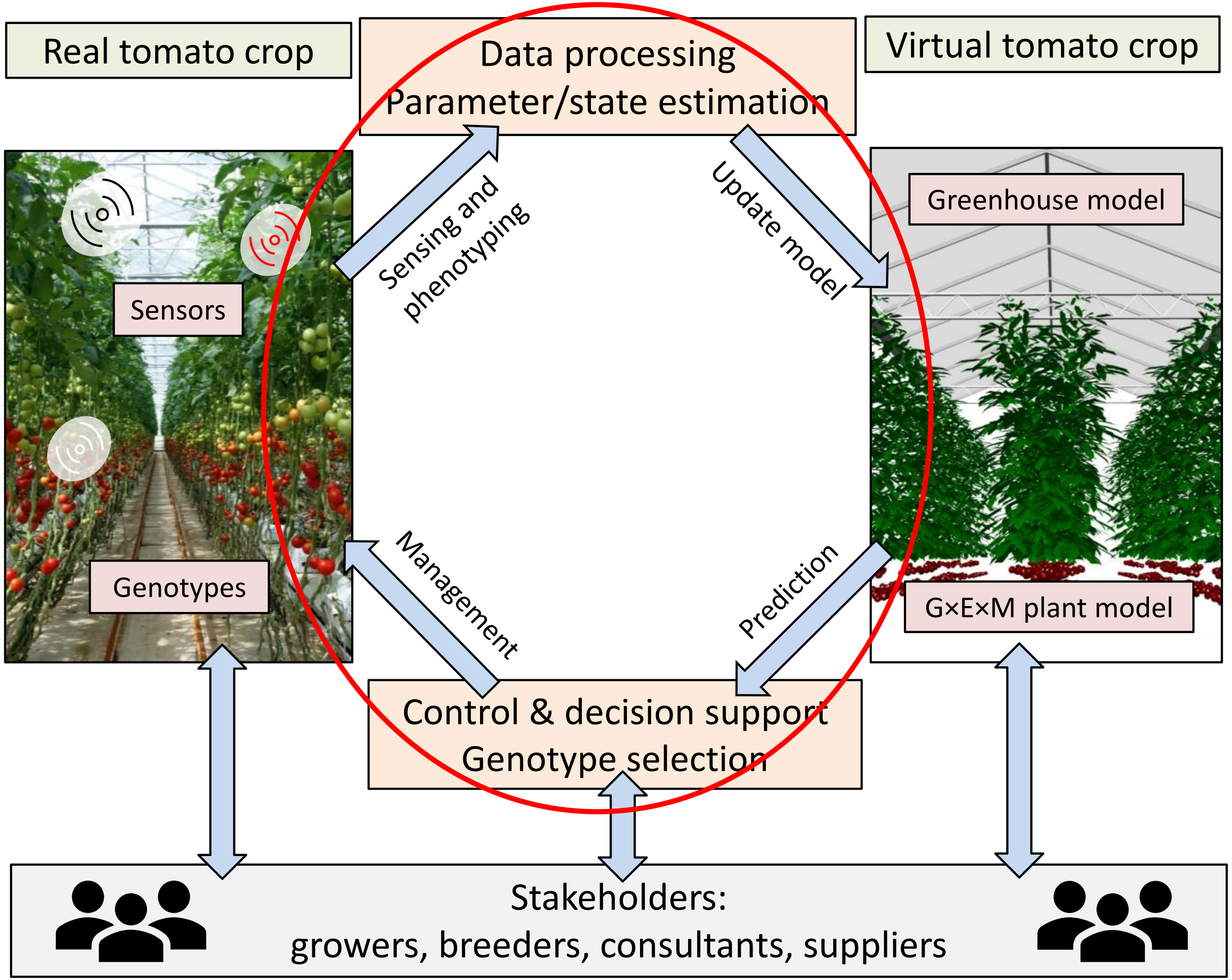


Dynamic plant model



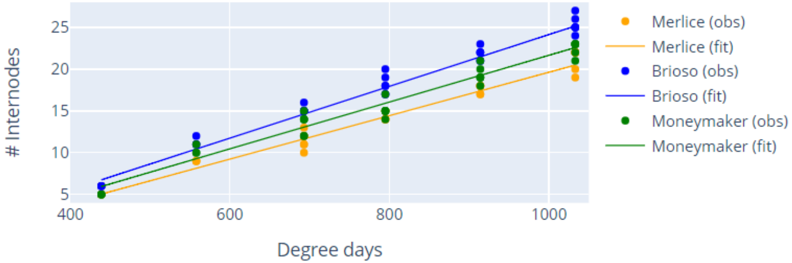
Cultivar: Merlice

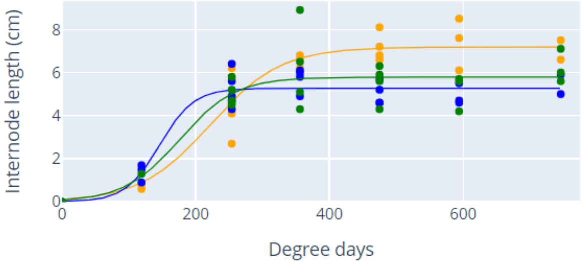
Digital Twin concept



WAGENINGEN UNIVERSITY & RESEARCH

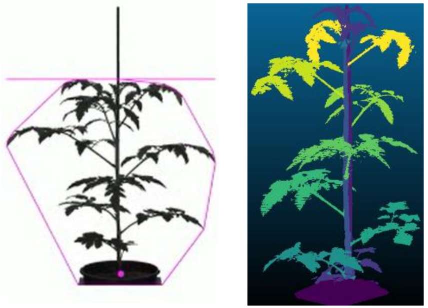
Plant model updating





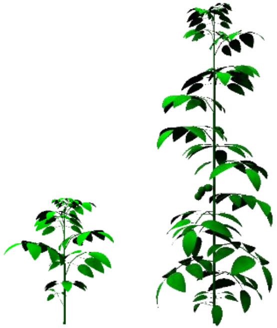
Fitting from manual measurements

Model parameterization



Traits estimation from RGB side view images and 3D point clouds

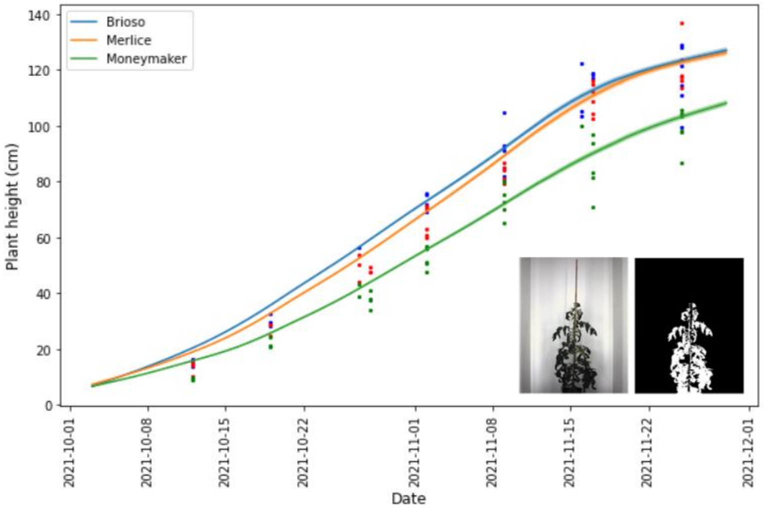
Model updating



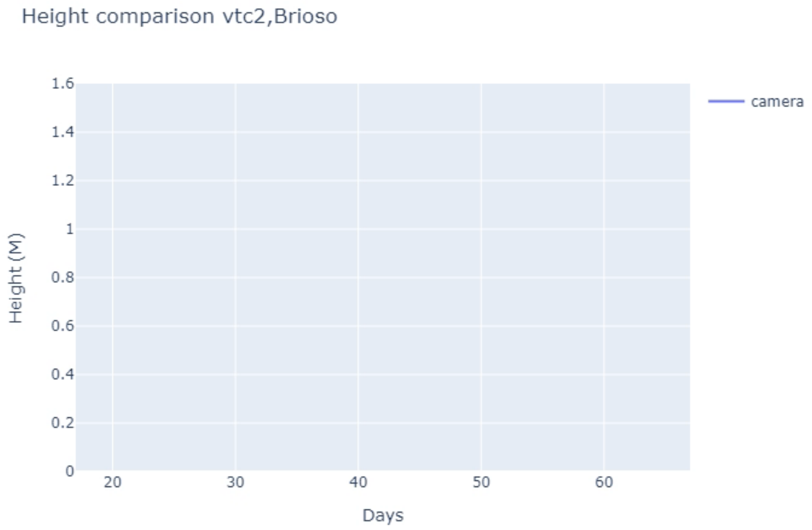
Dynamic FSP model

WAGENINGEN UNIVERSITY & RESEARCH

Model updating using 2D images



Predicted height from images (p-splines) vs manual measurements

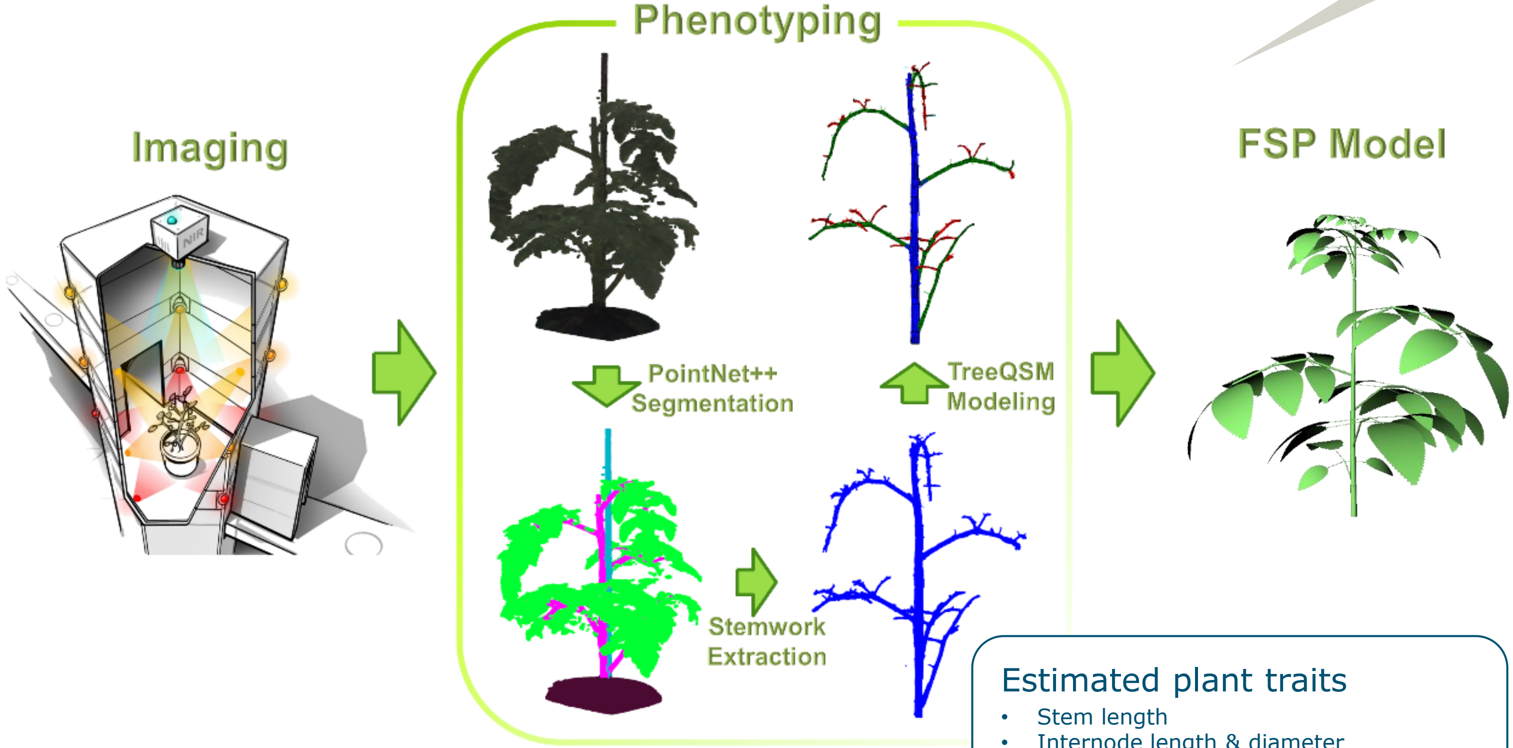


Plant model update from images using Bayesian optimisation

WAGENINGEN UNIVERSITY & RESEARCH

3D phenotyping pipeline

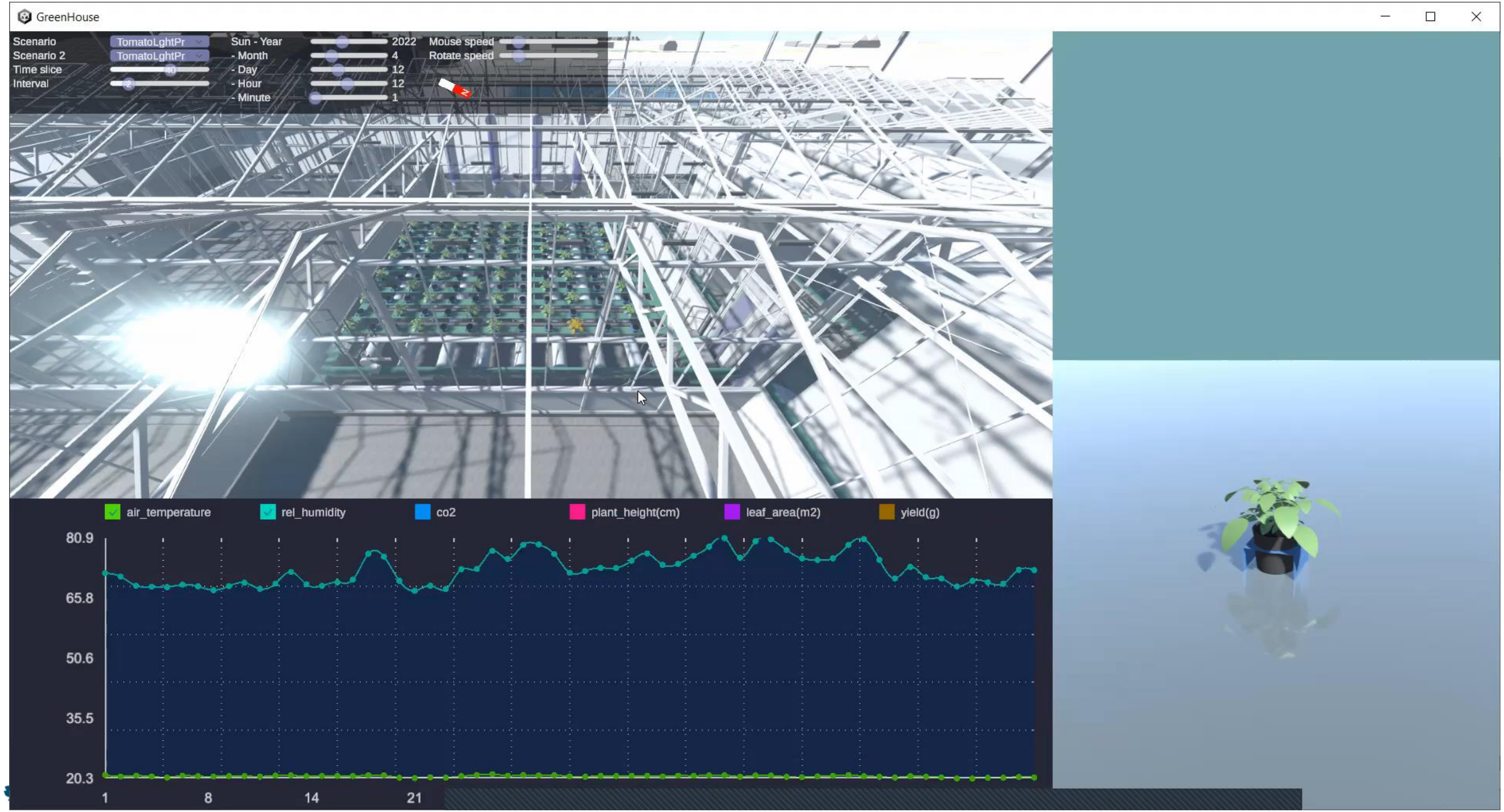
3D workshop on day 2

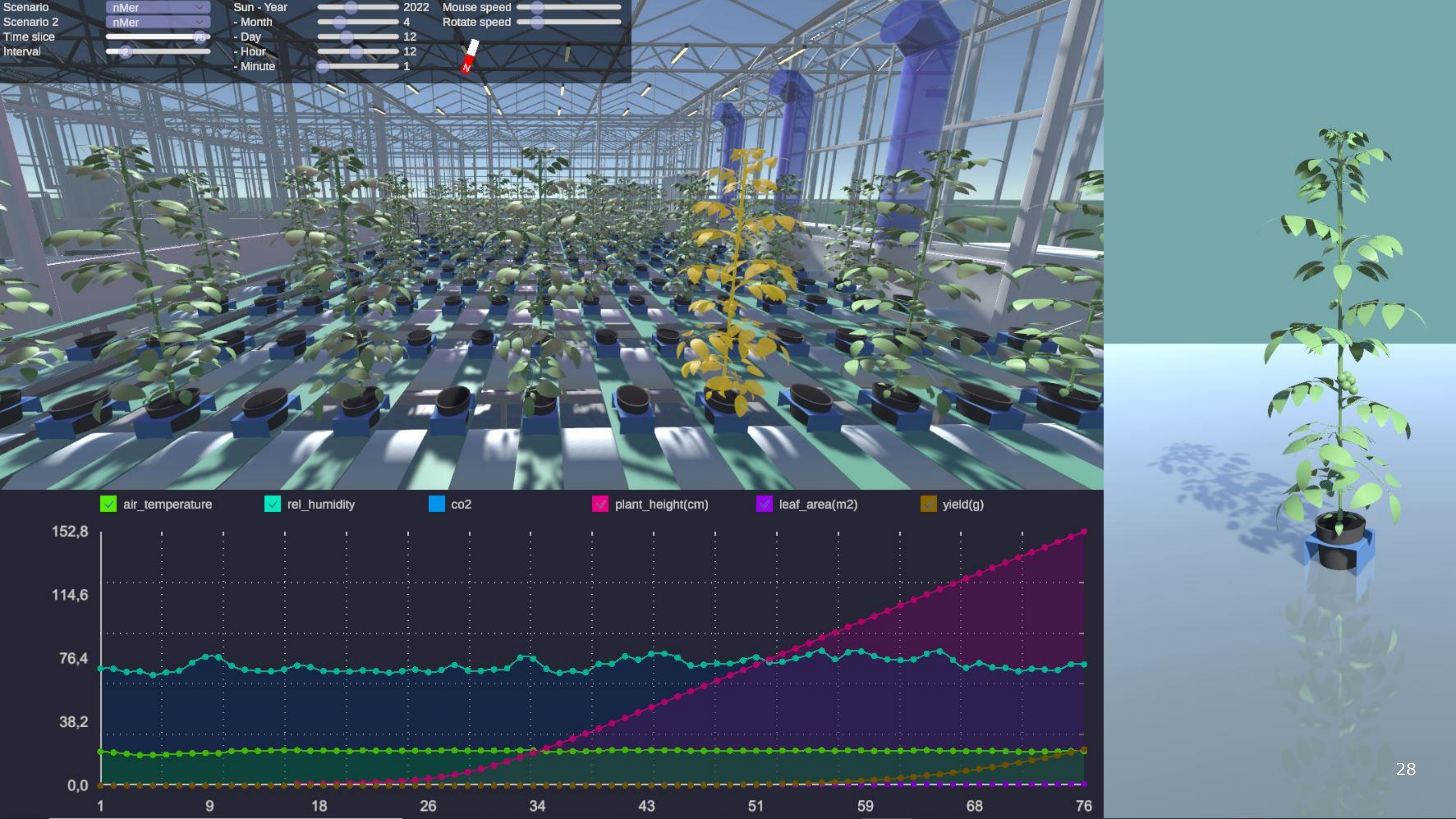


Estimated plant traits

- Stem length
- Internode length & diameter
- Leaf angle
- Phyllotactic angle

VTC Unity 3D implementation




Scenario
nMer
Scenario 2
nMer
Time slice
Interval
Sun - Year
2022
- Month
4
- Day
12
- Hour
12
- Minute
1
Mouse speed
Rotate speed
air_temperature
rel_humidity
co2
plant_height(cm)
leaf_area(m2)
yield(g)
152,8
114,6
76,4
38,2
0,0
1
9
18
26
34
43
51
59
68
76

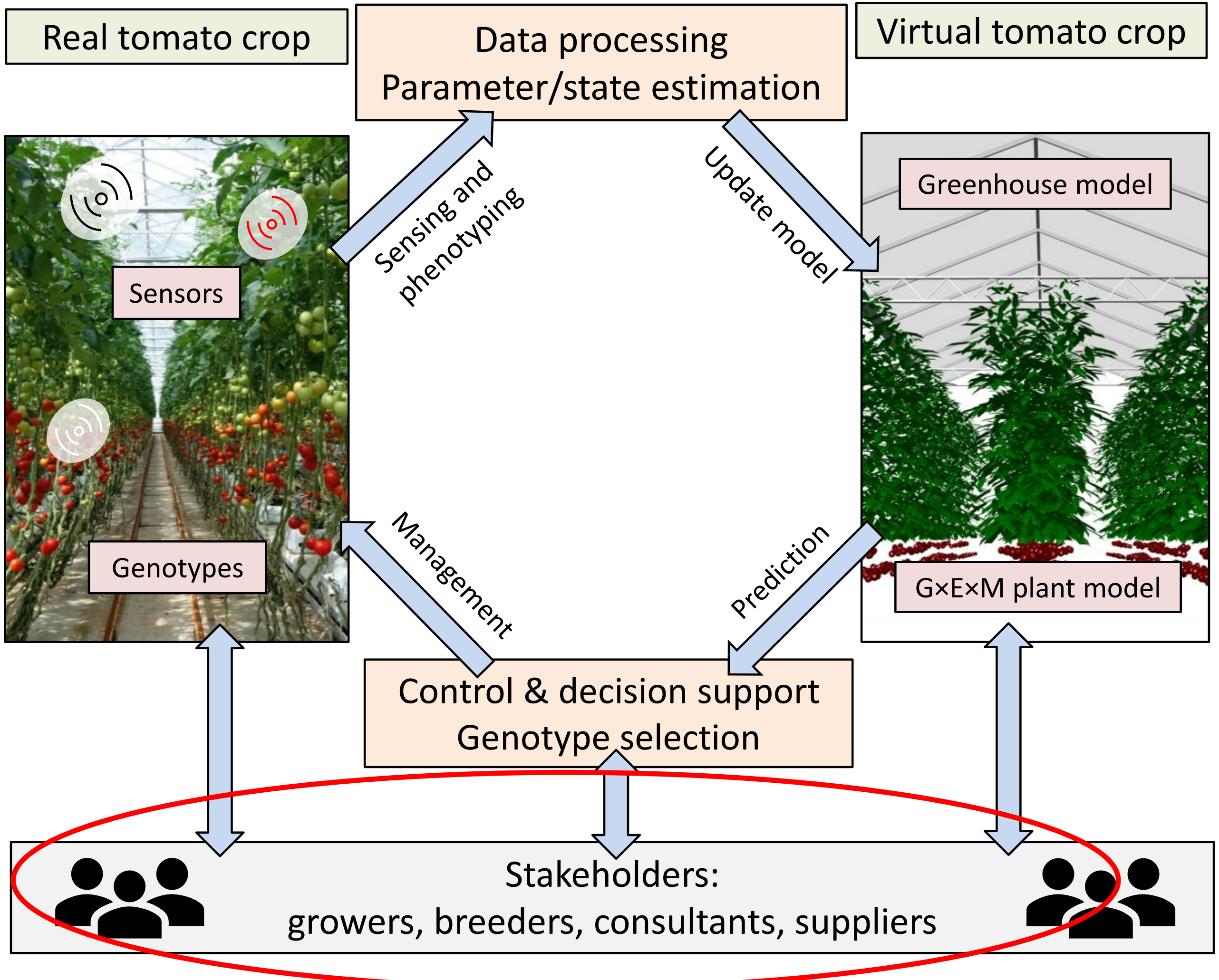
Virtual reality exploration

Live demo during the drink sessions

Will Hurst - Quest2

WAGENINGEN UNIVERSITY & RESEARCH

Digital Twin concept



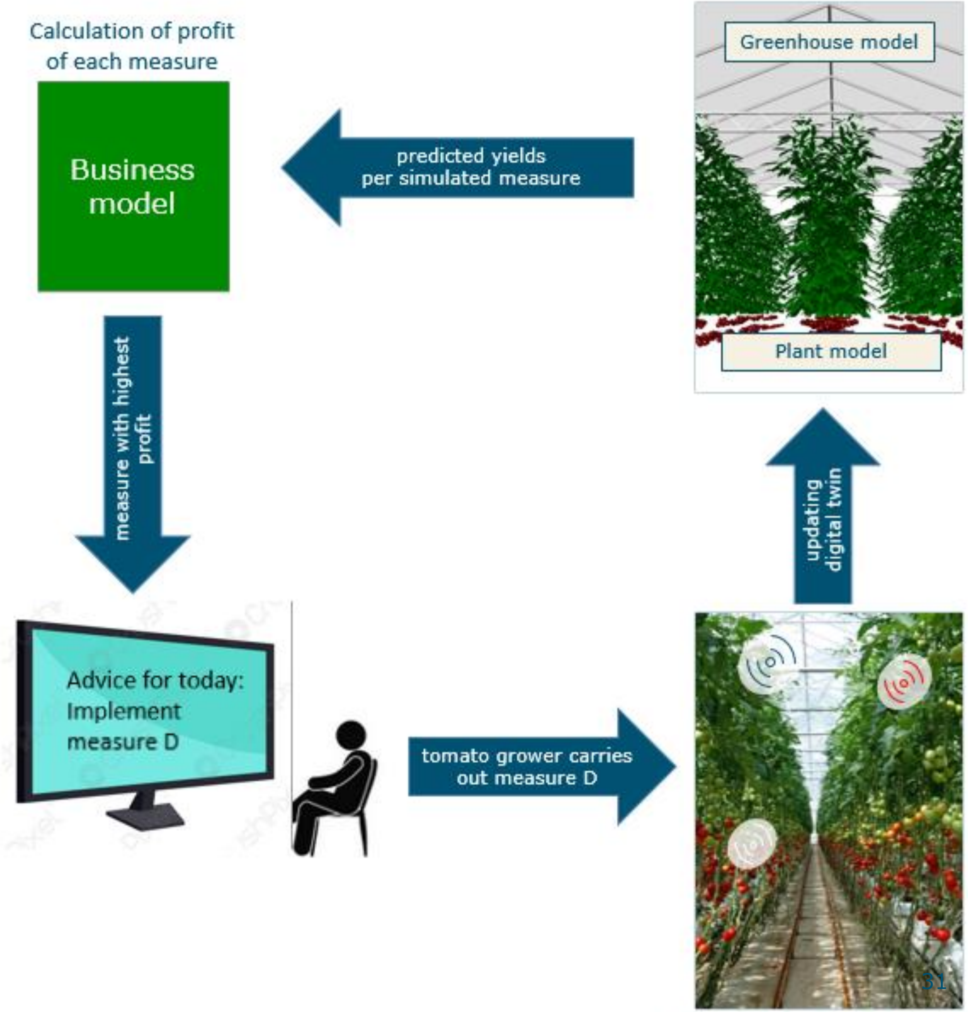
WAGENINGEN UNIVERSITY & RESEARCH

Bringing VTC into practice

- Stakeholder involvement:

  Growers, breeders, ICT companies, and tech suppliers of lighting, sensors, cameras, climate control, etc.

- Workshop 1: 29 sept 2021 (19 visitors)
  - Introduction to Digital Twin
  - Stakeholder wish list
  - Input for the project
- Workshop 2: 19 dec 2022 (next week)
  - Discuss results/ lessons-learned
  - Follow-up ideas and projects



Tomato grower carries out measure D

Use of VTC expertise / follow-up projects:

- Coupling of Digital twins (CODIT) for the tomato production pipeline
  - Goal: coupling Digital Twins on greenhouse (TNO), climate (Delphy) and tomato crop (WUR), to assist breeders, growers and retail
  - Approach: realtime calibration of Digital Twin in Delphy trials, and model use in scenario studies
  - Period: 2022-2025
  - PPS TKI (Topsector Tuinbouw en Uitgangsmaterialen)
  - Partners: TNO (project lead), WUR, Delphy, Hortivation and many sensor companies

- Digital Twin for decision support in tomato cultivation
  - Goal: Digital Twin for commercial practice of highwire tomato cultivation
  - Approach: Kaspro-Intkam API with some 3D functionality, connected to sensors on plant and slab weight, and cameras on plant dimensions and assimilate status
  - Period: 2022-2024
  - PPS TKI (Topsector Tuinbouw en Uitgangsmaterialen)
  - Partners: WR (project lead), Ridder, Sobolt, Fluence, OnePlanet, Glastuinbouw Nederland, Stoffels

Use of VTC expertise / follow-up projects:

- NextGen Hightech: Agrifood project 11: Digital Twin
    - Goal: Fully versatile Digital Twin tomato, for national and international market
    - Approach: Full 3D crop model, realtime connection to 3D vision and climate/crop sensors
    - Period: 2023-2026
    - Partners: Sobolt (project lead), WR, Letsgrow, Hoogendoorn and many others

NXT GEN HIGHTECH

- Application in vertical farming (PhD project)
    - Goal: Improving light use efficiency in dwarf tomato plants growing indoors
    - Approach: 3D model for bush tomatoes, focus on light sensors
    - Period: 2022-2025
    - Partners: WU (project lead), WR, InFarm

infarm

And more projects to come (EU/ PPS/ NWO/ etc.), will you join us?

Digital twin of tomato crop

- Ultimate aim:
  To develop a digital twin that helps increase resource use efficiency (energy, space, water, inputs) of greenhouse tomatoes

- How?
  - Predict crop yield and energy use using (nearly) real-time crop and greenhouse data
  - Help determining leaf pruning strategies, planting layout
  - Explore options for plant varieties, identify better plant traits
  - Explore options in lighting, glass type, greenhouse construction
  - Help optimising greenhouse climate control

Thanks to the entire VTC team!

data visualisation
Wander - Bart Knuiman

plant physiology
Elias Kaiser, Nastassia Vilfan

socio-economics
Marc-Jeroen Bogaardt

phenotyping technologies
Rick van de Zedde, Harm Bartholomeus

greenhouse & climate modelling
Gert-Jan Swinkels

digital twin

3d plant measurements
Gert Kootstra, Bolai Xin

data management
Peter Roos

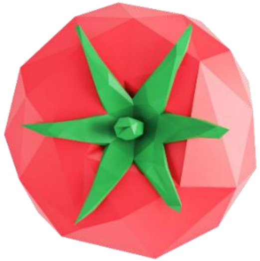
experimental design & statistics
Daniela Bustos Korts

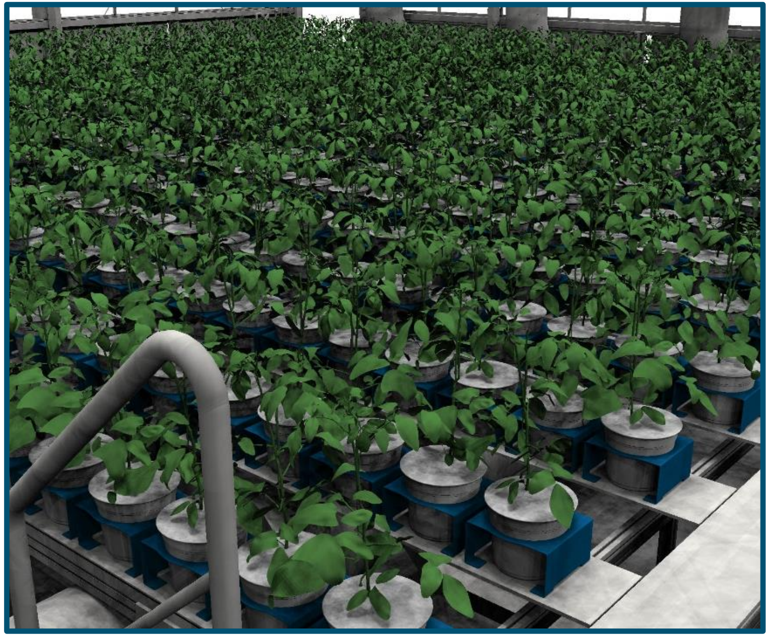
3d plant modelling
Jochem Evers, Pieter de Visser, Katarina Streit

software & data processing
Tim van Daalen

adaptive control / feedback loop
Simon van Mourik, Sjoerd Boersma

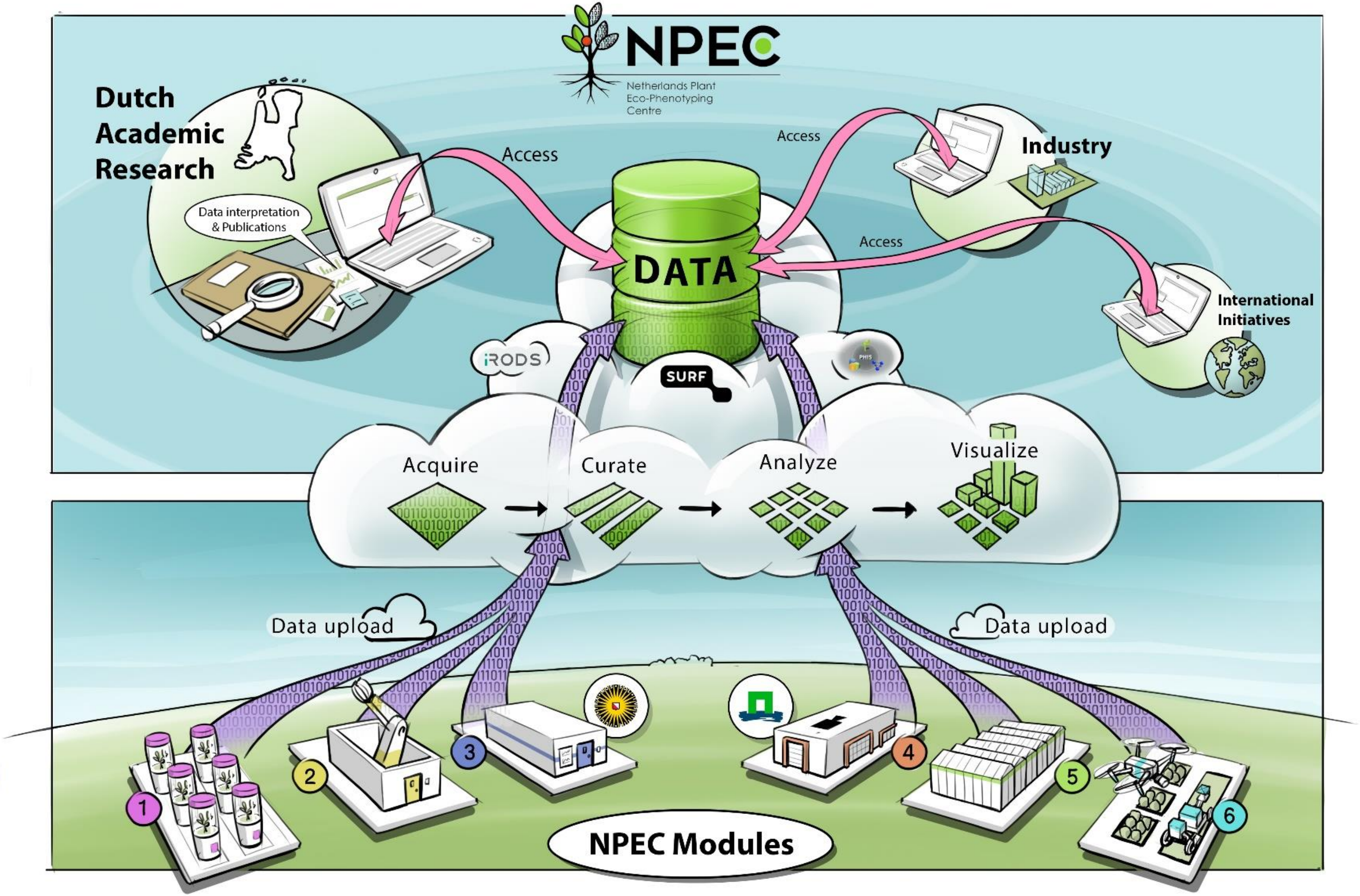
Thank you, questions?





WAGENINGEN UNIVERSITY & RESEARCH

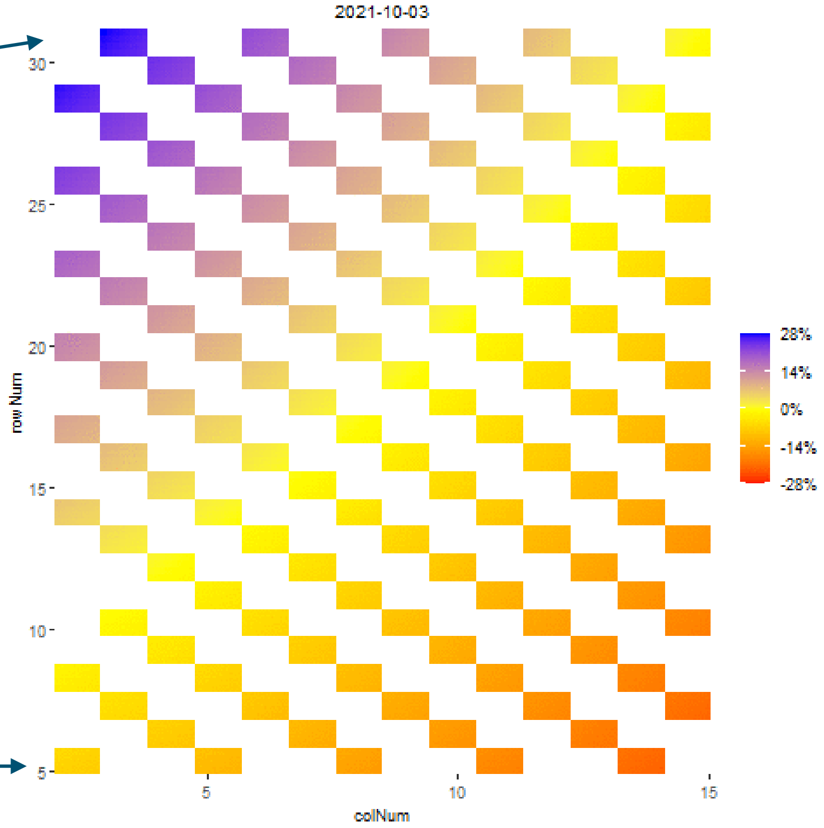
Contact: rick.vandezedde@wur.nl


NPEC
Netherlands Plant Eco-Phenotyping Centre
Dutch Academic Research
Data interpretation & Publications
Access
Access
Industry
Access
International Initiatives
DATA
iRODS
SURF
PHIS
Acquire
Curate
Analyze
Visualize
Data upload
Data upload
1
2
3
4
5
6
NPEC Modules

Time-lapse of the spatial effects

- Spatial effects change over time
- Largest at the beginning and end of the experiment (max 28% of variation)
- Gradients mostly driven by both doors

(watering station+ door)



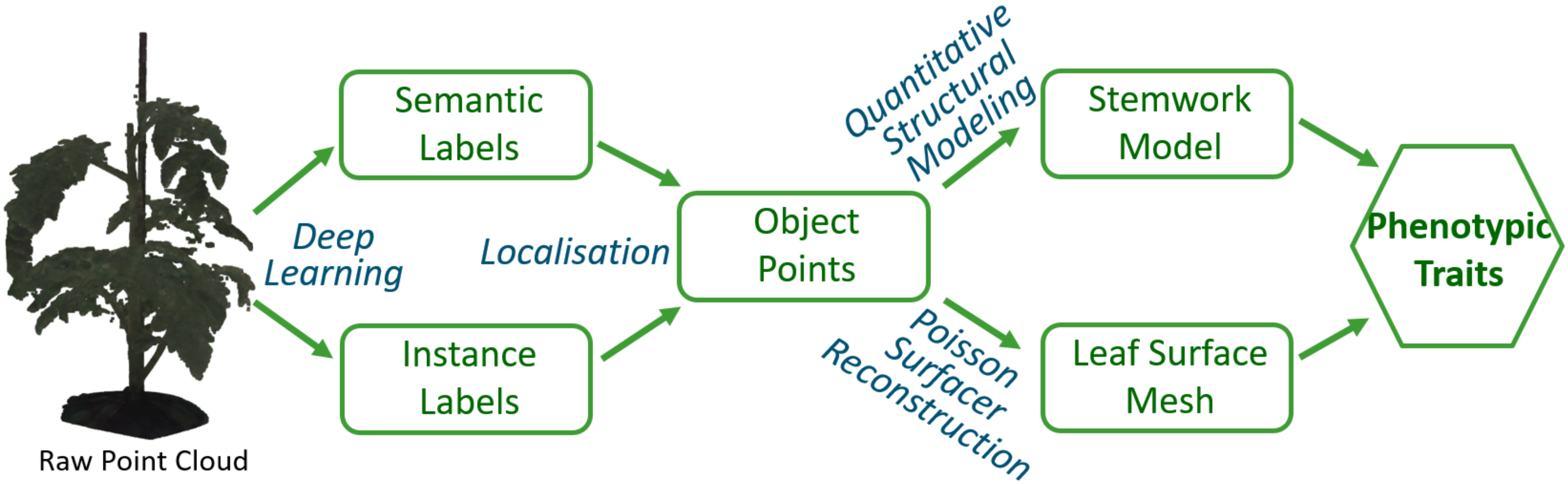
(door to C5)

WAGENINGEN UNIVERSITY & RESEARCH

Data processing

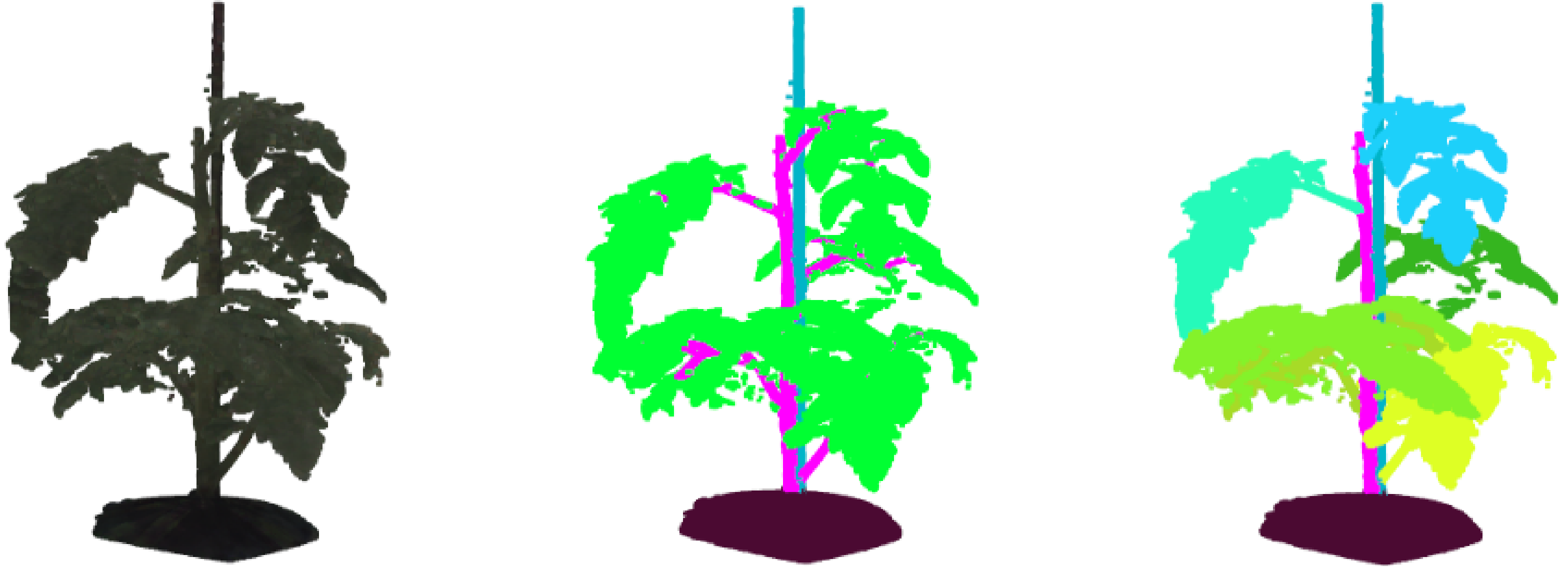
Bolai Xin

From sensor data to plant traits



Point cloud labeling

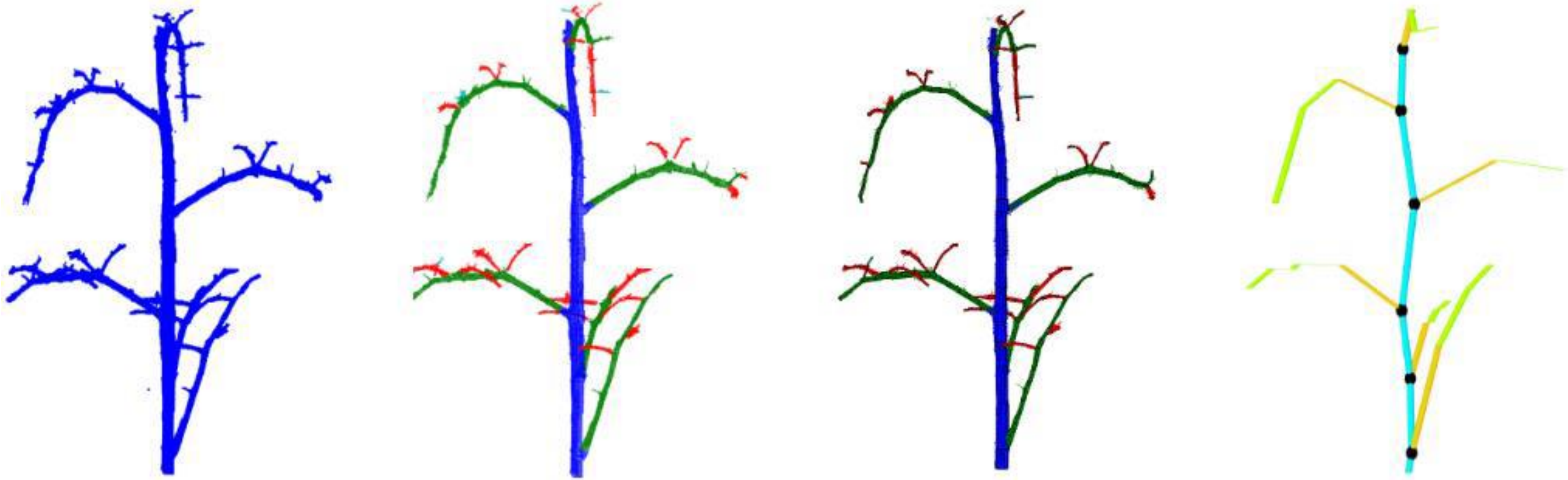
Backbone – PointNet ++



Original point cloud (left), point cloud with semantic labels (middle) and point cloud with instance labels (right).

Digital model of stemwork

Tree Quantitative Structural Modeling (TreeQSM)



Searching for root points and phyllotactic angles of leaves based on TreeQSM

Leaf surface reconstruction