Digital Twin
Virtual Tomato Crops

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

Real tomato crop

Data processing
Parameter/state estimation

Update model

Greenhouse model

Virtual tomato crop

Sensing and phenotyping

G×E×M plant model

Control & decision support
Genotype selection

Stakeholders:
growers, breeders, consultants, suppliers

Sensors

Genotypes

Parameter/state estimation

Management

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Data processing
Bringing scientists together

**data visualisation**
Wander - Bart Knuiman

**plant physiology**
Elias Kaiser, Nastassia Vilfan

**phenotyping technologies**
Rick van de Zedde, Harm Bartholomeus

**digital twin**

**socio-economics**
Marc-Jeroen Bogaardt

**greenhouse & climate modelling**
Gert-Jan Swinkels

**data management**
Peter Roos

**3d plant measurements**
Gert Kootstra, Bolai Xin

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

**experimental design & statistics**
Daniela Bustos Korts

**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. Optimal climate control
2. Optimal lighting conditions
3. Shading screens
4. Air handling units:
   - heating
   - cooling
   - ventilation

Plant to camera conveyor system
- Belts with automatic weighing and watering
- Separate imaging stations:
  - RGB/3D hyperspectral
  - Chlorophyll fluorescence

Camera to plant gantry systems
- >175 scales including individual watering/nutrient regimes per plant
- Combined with:
  - 3D/multispectral imaging
  - Thermal imaging

All electric
Heat cold storage
No natural gas
Data acquisition
Data acquisition

- 2 experiments in NPEC
  Spring/summer 2021
  Autumn 2021
- Climate measurements
- Plant measurements
  - Destructive (weekly)
  - Imaging (3x per week)
  - Photosynthesis
    Optical properties
Volumetric intersection – 3D point cloud
general information

date: 2021-09-29
growing days: 0

plant parameters
height: 41 mm
width: 271 mm
biomass: 7 cm²
solidity: 0.45
Manual measurements – Ground truth

Klokhuis documentary:
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.
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Parameter/state estimation

Stakeholders:
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
Modelling light interception in the FSP model
Dynamic plant model

Cultivar: Merlice
Digital Twin concept

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WAGENINGEN UNIVERSITY & RESEARCH
Plant model updating

Fitting from manual measurements

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

Model parameterization

Dynamic FSP model

Model updating
Model updating using 2D images

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

Plant model update from images using Bayesian optimisation
3D phenotyping pipeline

Estimated plant traits
- Stem length
- Internode length & diameter
- Leaf angle
- Phyllotactic angle

3D workshop on day 2
VTC Unity 3D implementation
Virtual reality exploration

Live demo during the drink sessions

Will Hurst - Quest2
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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
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
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

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

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

Contact: rick.vandezedde@wur.nl
Spatial effects change over time

Largest at the beginning and end of the experiment (max 28% of variation)

Gradients mostly driven by both doors
Data processing

From sensor data to plant traits

Bolai Xin

Raw Point Cloud

Semantic Labels

Deep Learning

Localisation

Instance Labels

Quantitative Structural Modeling

Object Points

Poisson Surface Reconstruction

Stemwork Model

Leaf Surface Mesh

Phenotypic 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