Digital Twins

WAGENINGEN
UNIVERSITY & RESEARCH

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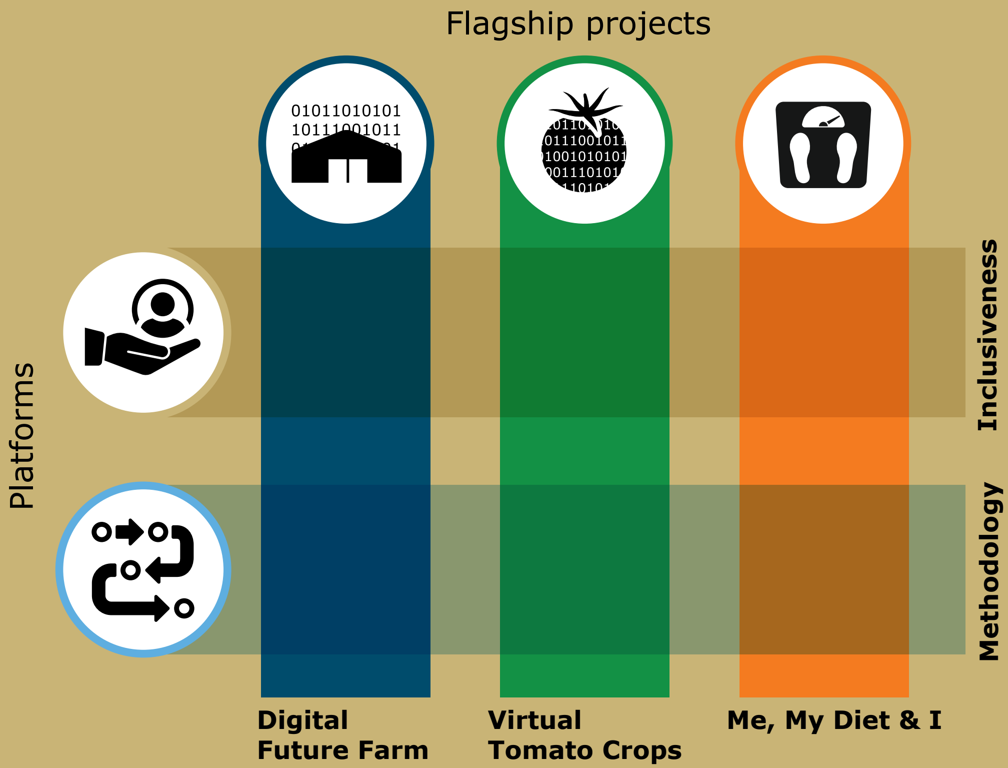
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Dear reader,

The mission of Wageningen University & Research (WUR) is “To explore the potential of nature to improve the quality of life”. WUR embraces the opportunities and challenges of data science and artificial intelligence for its mission.

As one of its initiatives, WUR has defined a strategic research programme “Digital Twins” that ran from 2018 to 2022. This programme aimed to explore and investigate the potential of digital twins in the green life sciences. In particular, we focused on the question whether and how digital twin characteristics, applicable to non-living systems, can as well be applied in our domain of the green life sciences. In addition, we intended to assess whether these digital twin characteristics provide benefits compared to other – more conventional - methods. For example, do digital twins provide a better understanding and thus a better ability for deciding how to obtain desired outcomes for the systems and processes investigated?

With this publication we share the outcomes of this digital twins research programme.
It illustrates promising benefits of applying digital twins in the domain of green life sciences.
But we are not ready yet: further research is needed, among others data driven modeling to simulate the complex character of living objects and processes and to develop approaches that limit the amount of required input data.

As such, you may consider this booklet as an intermediate outcome and by the same token an invitation to further research on digital twins in the domain of green life sciences!

Arthur Mol
Rector Magnificus Wageningen University & Research

LAI Observations
Fertilizations
LAI (m2 leaf / m2 soil)
0
1
2
3
4
5
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct

Getting a grip on nitrogen in arable farming

What is the current nitrogen content in crops and soil? And what is the prediction for the future based on weather forecasts? With these questions in mind, we built a digital twin for an arable farm. The dynamic model we have developed, is connected to the Farm of the Future. This is our pilot site in Lelystad, the Netherlands. Using biweekly drone images, we indicate the leaf size of crops, expressed in the Leaf Size Index. All these measurements are synchronised in the digital twin. Besides estimating current and future nitrogen levels in crops and soil, it can also be used to estimate the effect of alternative management scenarios, especially regarding fertilisation and irrigation. The digital twin allows farmers to conduct better farm management, based on up-to-date information.

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01011010101
10111001011
FarmMaps
Animal groups
Group name
Created date
Avg grass intake
Quantity
droge koeien
10/18/22
10.00
10
Jongvee
10/17/22
7.10
15
kalveren
10/18/22
5.00
10
Melkkoeien
5/31/22
7.00
50
Back

Real-time insight into dairy farm status

At agro-innovation centre De Marke, we do research into clean, profitable dairy farming. We developed a digital twin of this research centre, based on the model made for arable farming. Currently, satellite observations are used to estimate how much nitrogen the grass absorbs. Based on these observations, the digital twin is synchronised. By linking it directly to De Marke's farm management information system, the digital twin will soon also be fed with up-to-date data on herd size, age and parity, ration composition and the grassland calendar. And by using data on milk production and quality, we will also soon be able to synchronise the dairy model. The added value for the farmer? A comprehensive real-time overview of the state of crops, soils and livestock on the farm regarding nitrogen. And the ability to make better short- and long-term decisions.

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Machine learning and data assimilation for better predictions and decisions

To get grip on the nitrogen cycle, arable and dairy farms use growth models. These models describe the condition of a crop and its expected yield. These are generic models, based on general physical principles of crop growth. For example, they do not consider local crop and soil conditions. As part of the Digital Future Farm, a digital twin aiming to better tune existing models to the location in question, we use machine learning to combine generic knowledge from models with site-specific data. These include historical and current measurements of crop variables and soil conditions. We also used data-assimilation as a tool to incorporate data from actual observations into existing models, in this case for grass and potatoes. In this digital twin, we used the so-called ensemble Kalman filter, a calculation method to reduce interference in series of measurements. By combining model knowledge and data from observations, farmers can better estimate the condition of their crops, soils and livestock. And as the models are adjusted based on actual observations, the uncertainty decreases further.

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New tool to limit
nitrogen surplus

Many farmers use the so-called WOFOST crop growth model as a nitrogen management tool. In the Digital Future Farm, we extended this generic model with modules to limit nitrogen surplus. Thus, we managed to successfully reproduce the model data from two large trials of winter wheat. Different fertiliser levels were used in these trials. We then used the model to determine whether the nitrogen surplus on wheat fields in the Dutch province of Flevoland could be reduced without soil depletion or yield loss. This turned out to be the case, and by at least 49%. This can be done by closing the yield gap, applying less nitrogen to the land or a combination of both strategies. With the help of the comprehensive model, arable farmers can therefore get to work in concrete ways to reduce nitrogen in their fields.

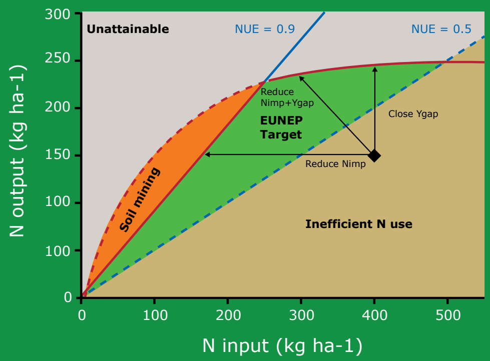

Figure 1 shows how this relates to the criteria of the EU Nitrogen Expert Panel (EUNEP) in the different investigated scenarios. N outputs for a given input are either unattainable (above maximum possible N amounts under N and water limited growth conditions), lead to soil mining (NUE > 0.9 kg kg-1) or inefficient N use (NUE < 0.5), or fall within the EUNEP criteria. The red dotted line represents the simulated N output under water and N limited growth conditions. The blue dotted lines represent N outputs for a given N input when NUE = 0.5 kg kg-1 and when NUE = 0.9 kg kg-1. The solid red line represents the upper boundary of N output that can be obtained without mining the soil. The diamond represents an example N amount in the grains. The arrows show how much N input can be reduced while maintaining the same yield without soil mining and how much the amount of N in grains can be increased by closing the yield gap..

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A clear picture of the nitrogen balance

In the Digital Future Farm, all kinds of farm processes are captured in models that are in turn linked. These models are synchronised in real time with data from sensors, such as satellites. To keep control of a farm's nitrogen balance, all flows and quantities of nitrogen that occur throughout the year need to be clearly visualised. Not only the current situation, but also cumulative quantities and predicted outcomes. The results are translated into KPIs for nitrogen at field, herd and farm level. Through clear visualisations, the farmer can better manage the nitrogen balance and thus deliver better performance. A good way of presenting output is to use the so-called Sankey diagram, in which flows and quantities are shown proportionally.

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Figure 1 and 2 show the flows on a farm schematically including the KPI’s,

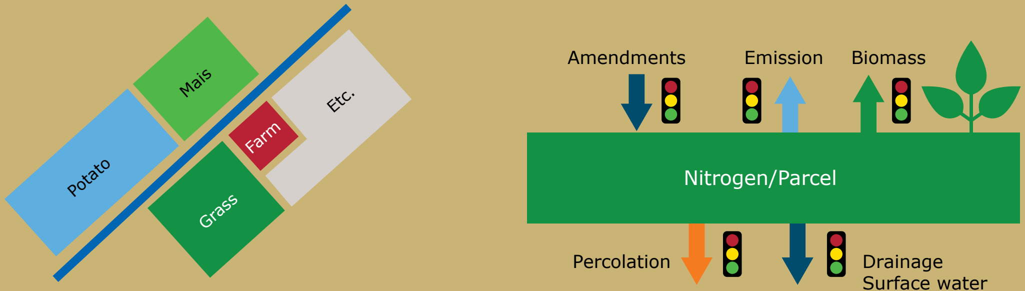

Figure 1 Flows of nitrogen on an arable farm schematically

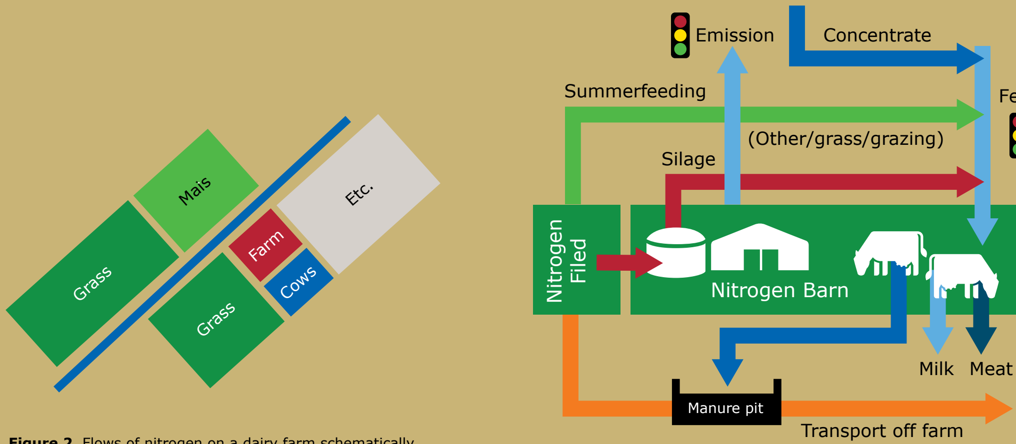

Figure 2 Flows of nitrogen on a dairy farm schematically

The virtual tomato crop

A digital twin of a tomato crop that accurately predicts performance and resource use efficiency. That is the aim of the Virtual Tomato Crops project. For this, we use a model that simulates crop yield, CO_2 uptake and use of nutrients, energy and water. This model is updated using real-time measurements of tomato plants and their growing conditions. Based on the predictions provided by the model, the tomato grower can adjust the management strategy and improved plant traits come into focus. Ultimately, the digital twin should lead to more efficient use of resources in the tomato greenhouse, lower costs and less dependence on inputs. As a result, tomato cultivation becomes more profitable.

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PROGRESS
812
Consumed
-220
Burned
592
Net
FOOD DIARY
TRANING SCHEDULE
MICRONUTRIENTS CHART
Proteins 53.97
Carbs 32.18
Fats 95.34
42%
31%
27%

Me, my diet & I

A smart self-learning tool that provides automatically generated dietary advice. With the aim of preventing people from consuming too much fat and sugar and reducing health risks. That is the idea behind Me, My Diet & I. Using knowledge that is already available, we are exploring the possibilities of developing a digital twin that can be adapted to personal values and preferences. There is an urgent call for such a tool. Worldwide, a rise in overweight-related chronic diseases is seen. This results in a steep rise in healthcare costs. Allowing consumers to use this low-cost tool in their own environment puts them in control of their food choice behaviour and empowers them to make the healthy choice. As a result, their health improves and the pressure on healthcare decreases.

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Experiences in X-disciplinary working in digital twins development

The development of a digital twin requires close coordination between developers of technical components, experts and stakeholders. For future development projects, we want to know exactly which aspects in that collaboration are crucial for success. Therefore, we collect experiences of interdisciplinary cooperation between different science groups within Wageningen University & Research. For instance, we look at team building, but also at collaborative readiness, project management and the use of internal communication within the project. The recommendations extend beyond the development of digital twins: they are also applicable to projects that place the same demands on interdisciplinary collaboration.

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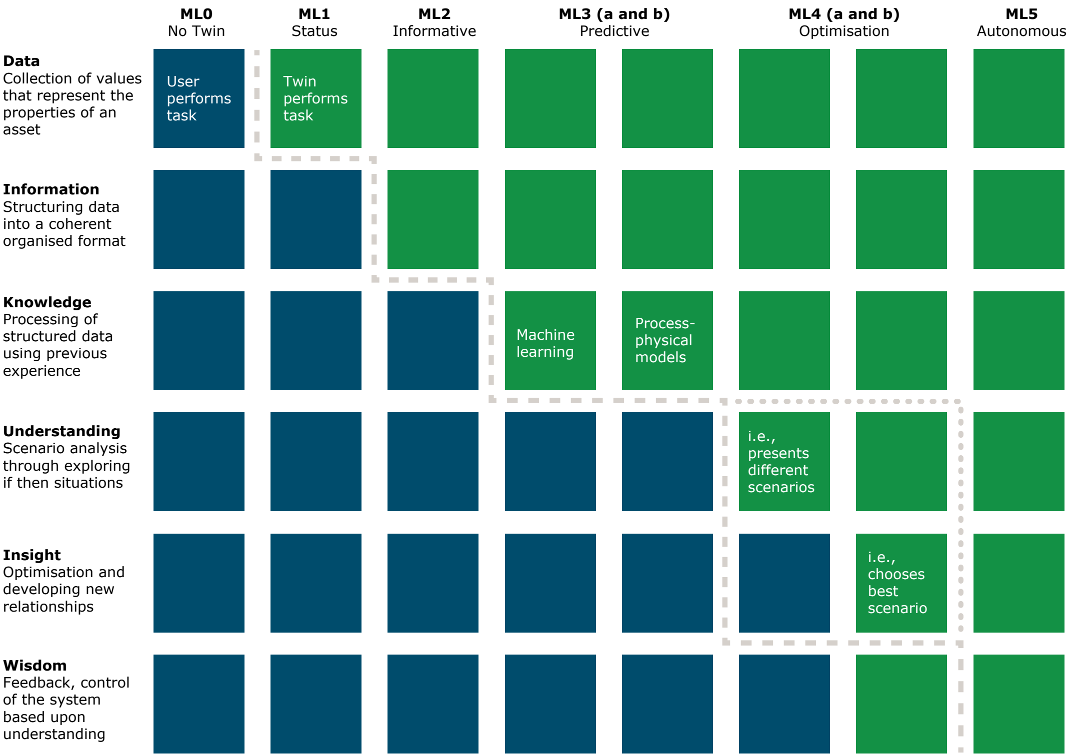
ML0
No Twin
ML1
Status
ML2
Informative
ML3 (a and b)
Predictive
ML4 (a and b)
Optimisation
ML5
Autonomous
Data
Collection of values that represent the properties of an asset
Information
Structuring data into a coherent organised format
Knowledge
Processing of structured data using previous experience
Understanding
Scenario analysis through exploring if then situations
Insight
Optimisation and developing new relationships
Wisdom
Feedback, control of the system based upon understanding
User performs task
Twin performs task
Machine learning
Process-physical models
i.e., presents different scenarios
i.e., chooses best scenario

How mature is your digital twin?

What is a digital twin anyway? There is no such thing as one definition. But it can be thought of as a physical object, process or phenomenon that has a virtual representation. Its goal is to develop knowledge that can help in decision-making through a two-way flow of information. What a digital twin exactly looks like, depends on the needs and goals of the end user. Every digital twin is therefore unique and it is precisely this great variety that can lead to miscommunication. We have mapped out which stages of maturity digital twins can be described by. Five levels of maturity were identified (see diagram). These stages allow interested parties to map the current state of a digital twin and to see along which iterative path it can be further developed.

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Adapting environments/ organisms
Personalized healthcare

Interactions with the natural environment

Balancing resolutions

In the virtual environment of a digital twin, physical processes are replicated. First, this requires creating a set of abstractions of these physical processes. After that, the digital twin can be fed with real world data. For this, choices must be made. For instance, resolutions must be sufficient to determine whether an object has moved in time or place, to distinguish objects semantically from each other or to determine whether a collection of data fits the model. Such choices are a delicate balancing act between sufficiently sampling the natural rhythms and patterns of the real world and the cost of higher, fine-grained resolutions. The aim of the Balancing resolutions project was to raise awareness about the effect of these choices. And furthermore to examine how datasets with different resolutions can be aligned and how to communicate with end users about choices made.

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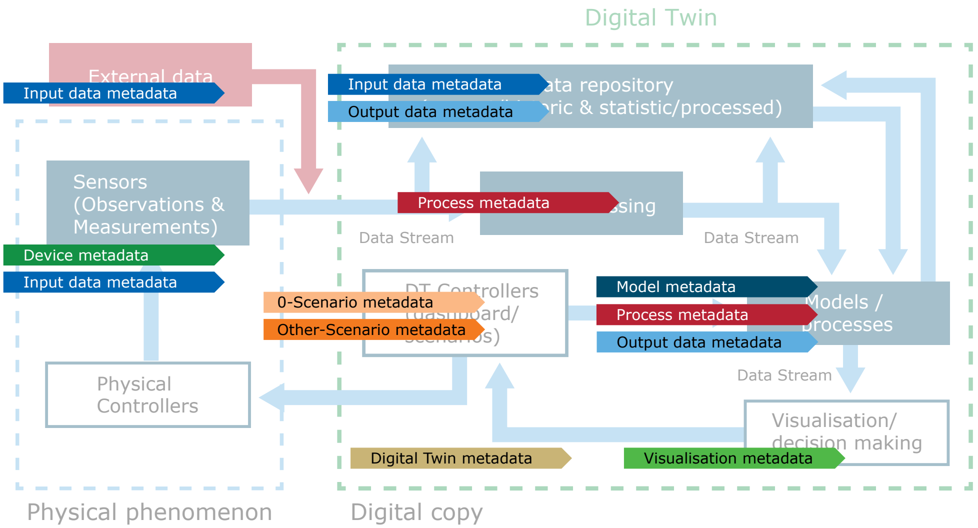
Exploring metadata

Digital Twins are driven by data. However, for data to have any value, it must be given meaning and have adequate documentation. Metadata, data about data, gives data meaning. It gives the user information about ownership, the origin and context of data, the application domain, usage, data type, units of measurement and much more. Metadata also has additional uses, for example as a source of validity and reliability through known



constraints on values. This may include upper and lower limits, for instance for temperature. This project focused on exploring metadata in Digital Twins so that our twin can be FAIR (Findable, Accessible, Interoperable, and Reusable).

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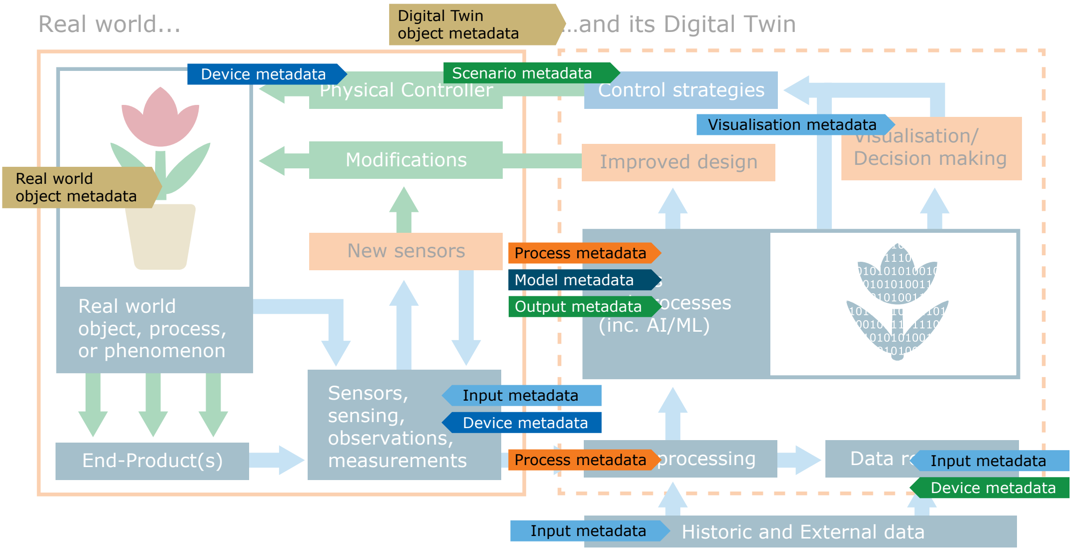

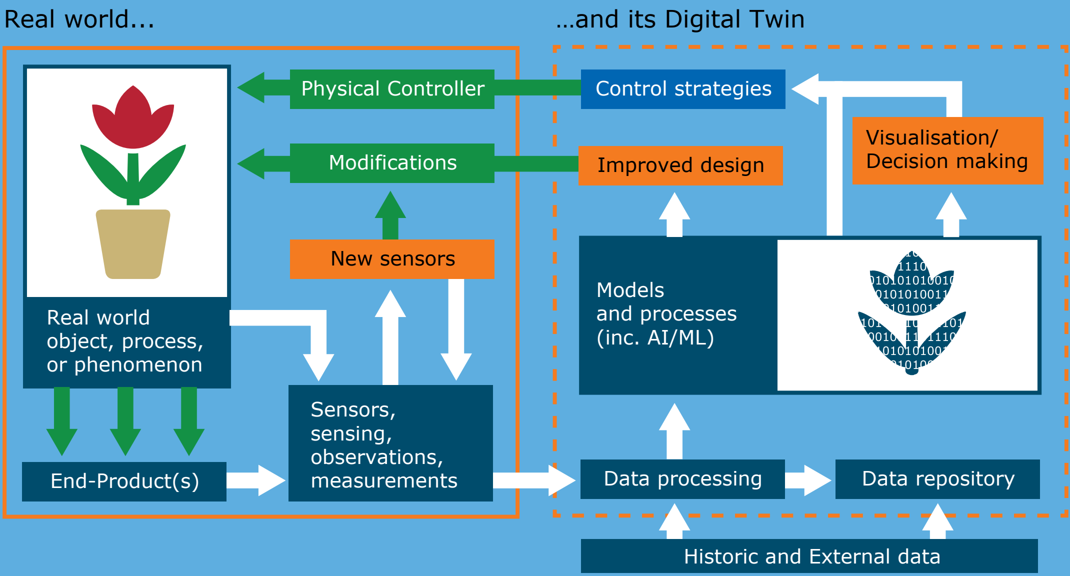

Figure 1 Components and processes of a Digital Twin. Schema developed by the Digital Twin Methodology Platform.

Designing your own digital twin

The technological back end of a digital twin is out of sight of the user. This back end consists of an array of sensors and technology for communication, data collection and management. All this should seamlessly work together. To build a representative twin, technical know-how is essential. However, this is not an easy task. We have set up the basics for designing your own digital twin. It explains the different levels such as how to build your own sensor, send data from one entity to the other, collect, interpret and predict interventions. The result is a comprehensive book (wur.gitlab.io/digitaltwin) that can be used for training or self-study on how to develop sensor and data-driven digital twins.

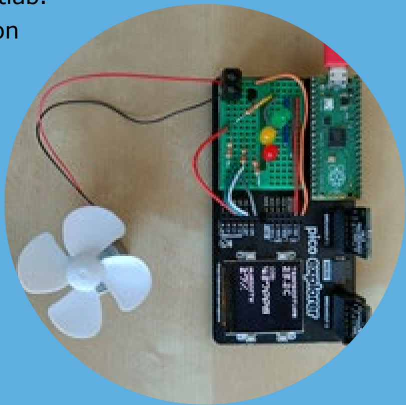

Figure 2 An Internet of Things sensor. An indoor air quality sensor consisting of a Raspberry Pico W, Pimoroni's Pico Explorer Base, Pimoroni's breakout sensors for temperature, humidity, pressure, volatile compounds and eCO_2, LEDs and a small fan. This IoT sensor serves as an example for data collection that serve as the basis for a Digital Twin.

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Alongside this, a proof-of-concept visualisation was developed of a Digital Twin of Wageningen campus. The proof-of-concept is a 3D animation of the spread of pollen on the Wageningen campus based on the weather conditions and the location of trees. The picture shows a still of the animation.

Cataloguing visualisation techniques

As a virtual representation of a real-world phenomenon, a digital twin requires some form of visualisation for interaction with users. Such visualisations provide the user with a means of understanding and communicating with the virtual twin. However, determining an effective visualisation is not an easy task, being dependent upon the purpose of the digital twin, the expected users, and the available data. We have catalogued visualisation techniques and discussed the different aspects of visualisation design. Alongside this, we developed a proof-of-concept visualisation of a digital twin of Wageningen campus. Finally, we made recommendations on best practice for the design process, cognitive fundamentals, design principles, and visualising uncertainty.

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End-user engagement to identify concerns

A digital twin has the potential to be of great value to users. But we need to think carefully about the social desirability, ethical acceptability and sustainability of this technology.
In a series of workshops with potential users - farmers, growers, consumers, government officials, dieticians - we explored the potential value of digital twins for their lives. The results are communicated to developers of digital twins. This enables them to consider ethical and societal concerns in the development. It is an important prerequisite for making something that will be valued by users.

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How to develop digital twins responsibly?

What are the potential societal, ethical and safety impacts of digital twins in the agri-food domain? We have investigated how to include societal values in the research and development process from the outset. What are the issues around collecting, selecting, combining and using data are at play? What concerns are there about the creation and use of knowledge? And what issues have to do with the implications of digital twins in particular contexts of use? The result is a table with questions for each theme. These questions help to better anticipate and reflect on potential impacts of digital twins in the agri-food domain.

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