Digital Twins

Foundations, applications, and the state of the art

Asst. Prof. Dr. Istvan David

McMaster University, Canada

istvan.david@mcmaster.ca | istvandavid.com

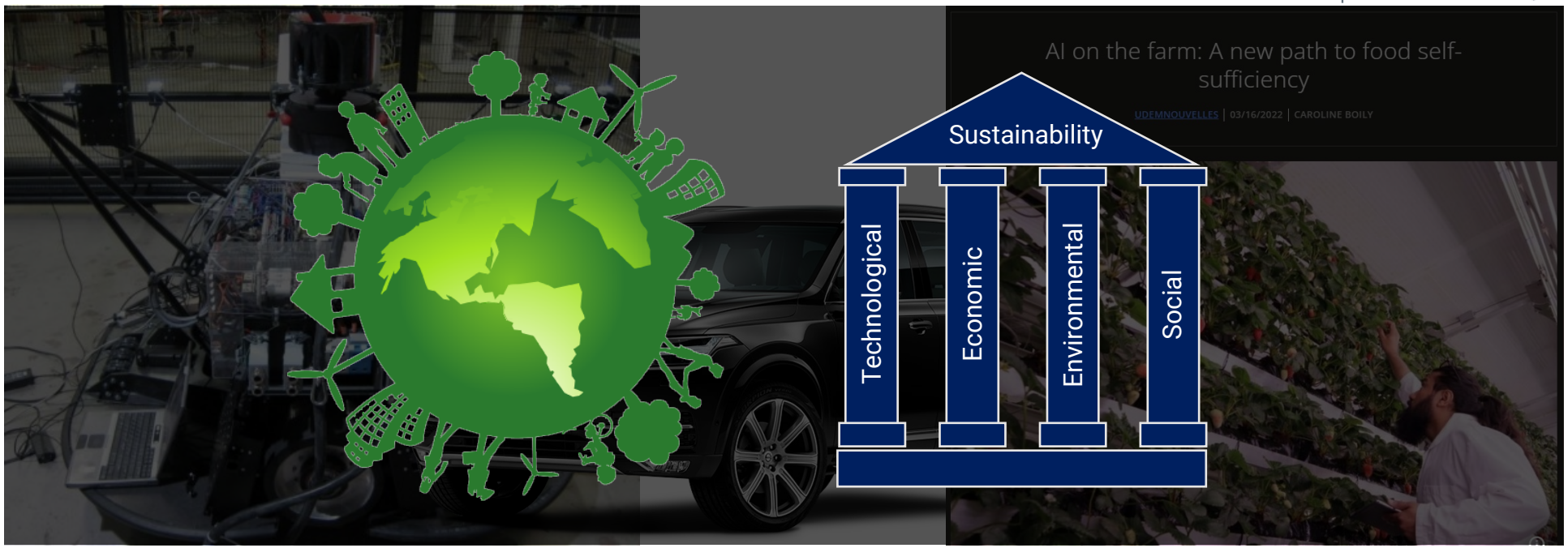
November 17, 2023

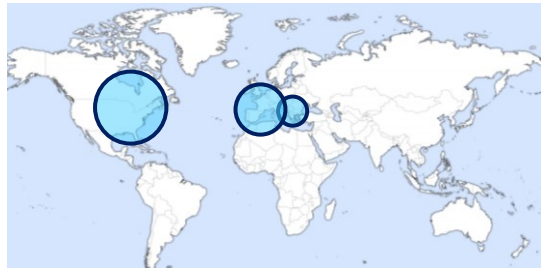
Dr. Istvan David

Sustainable Systems and Methods

ENGINEERING Computing & Software

McMaster University





MSc in Business Inf. Systems (2014)
MSc in Computer Engineering (2013)
BSc in Computer Engineering (2011)
Budapest Tech (BME), Hungary

R&D Software Engineer (2012–2014)
Mentor Graphics, Hungary

modeling and simulation
engineering processes

PhD in Computer Science (2014–19)
University of Antwerp, Belgium

Head of Digital Innovation (2019–2020)
Trigo Group, Hungary/France

IVADO Postdoctoral Laureate 2021

digital twins for C(B)PS
reinforcement learning

Postdoctoral researcher (2021–2023)
Université de Montréal, Canada

digital twins and sustainability
energy-aware systems

Assistant Professor (2023–)
McMaster University, Canada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Guelph
Kitchener
Cambridge
Milton
Oakville
Listowel
Stratford
St. Marys
Ingersoll
Tillsonburg
Simcoe
St. Catharines
Niagara Falls
Niagara-on-the-Lake
Lockport
Welland
Amherst
Buffalo
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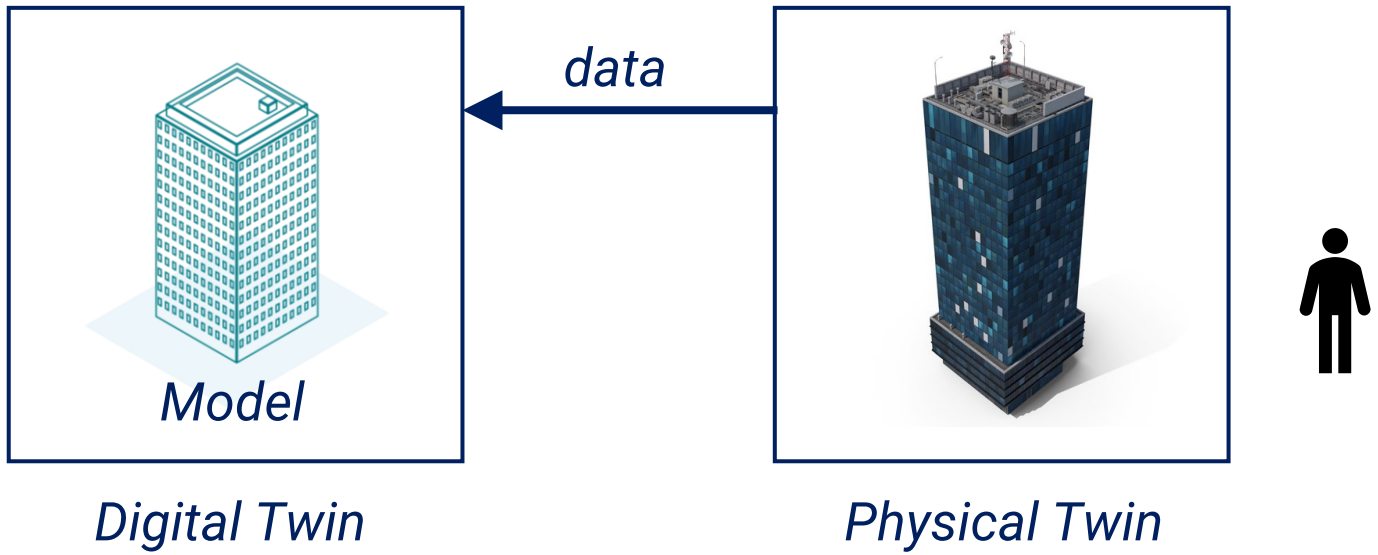
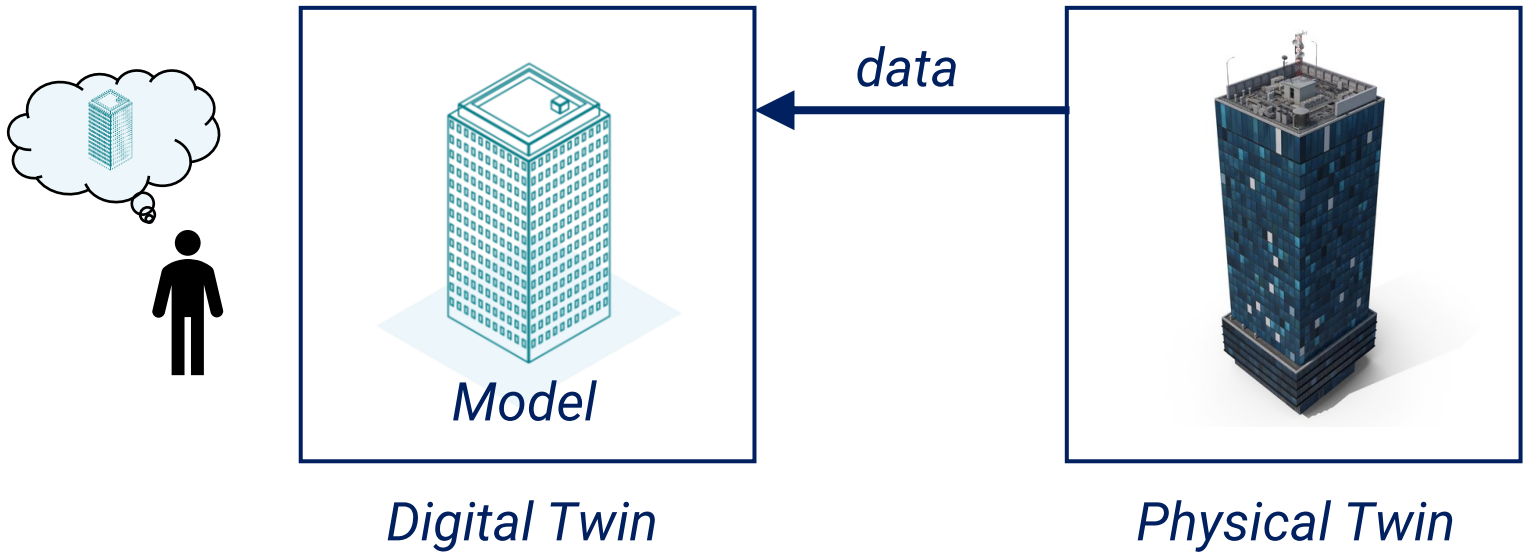
Digital twins

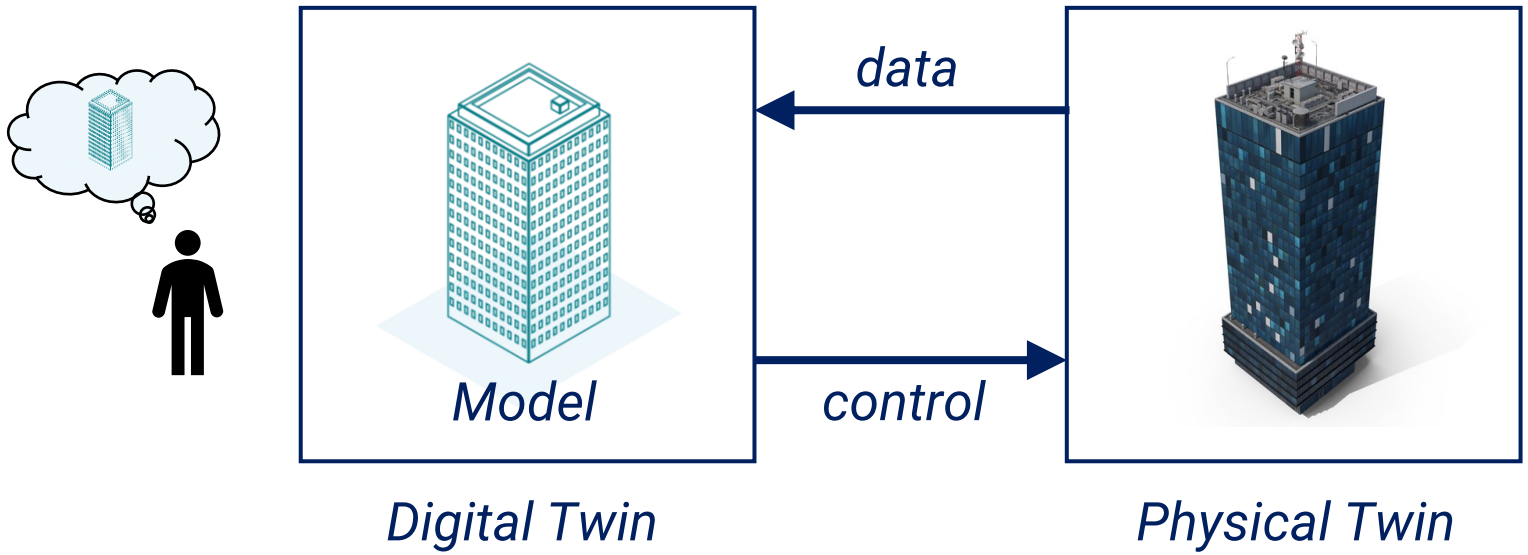
Digital twinning



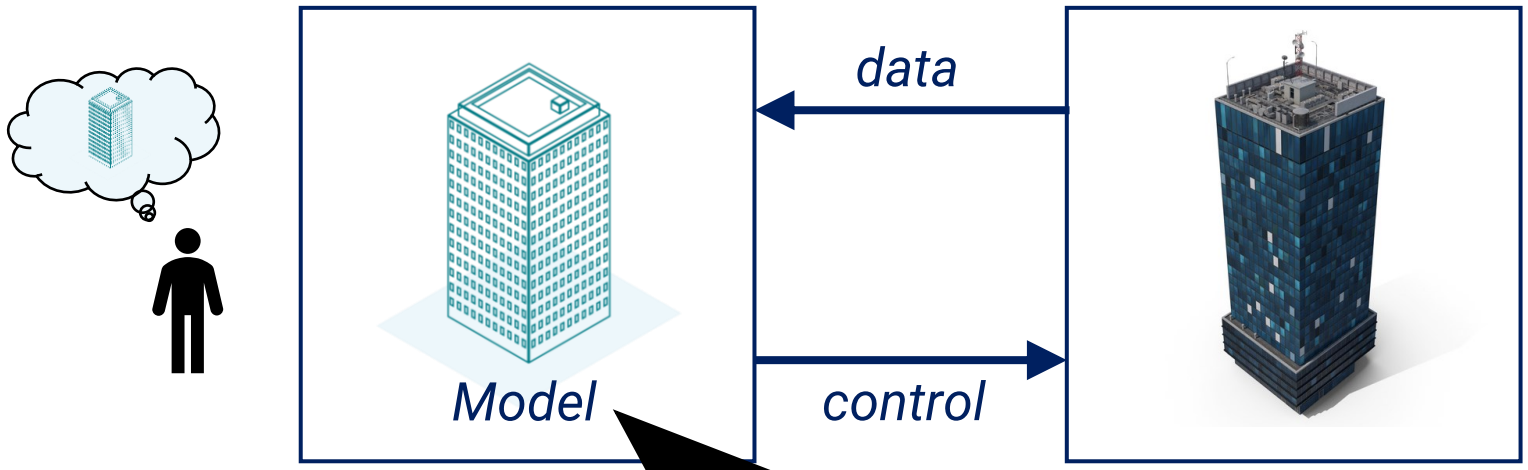
Digital twinning

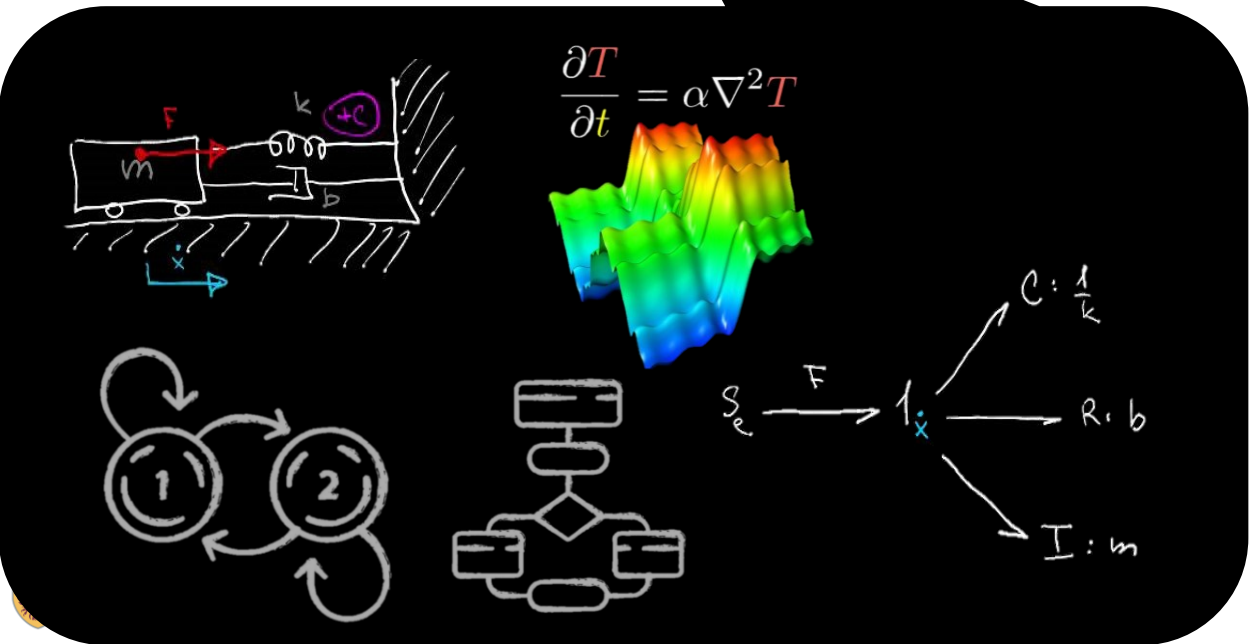


Digital twinning

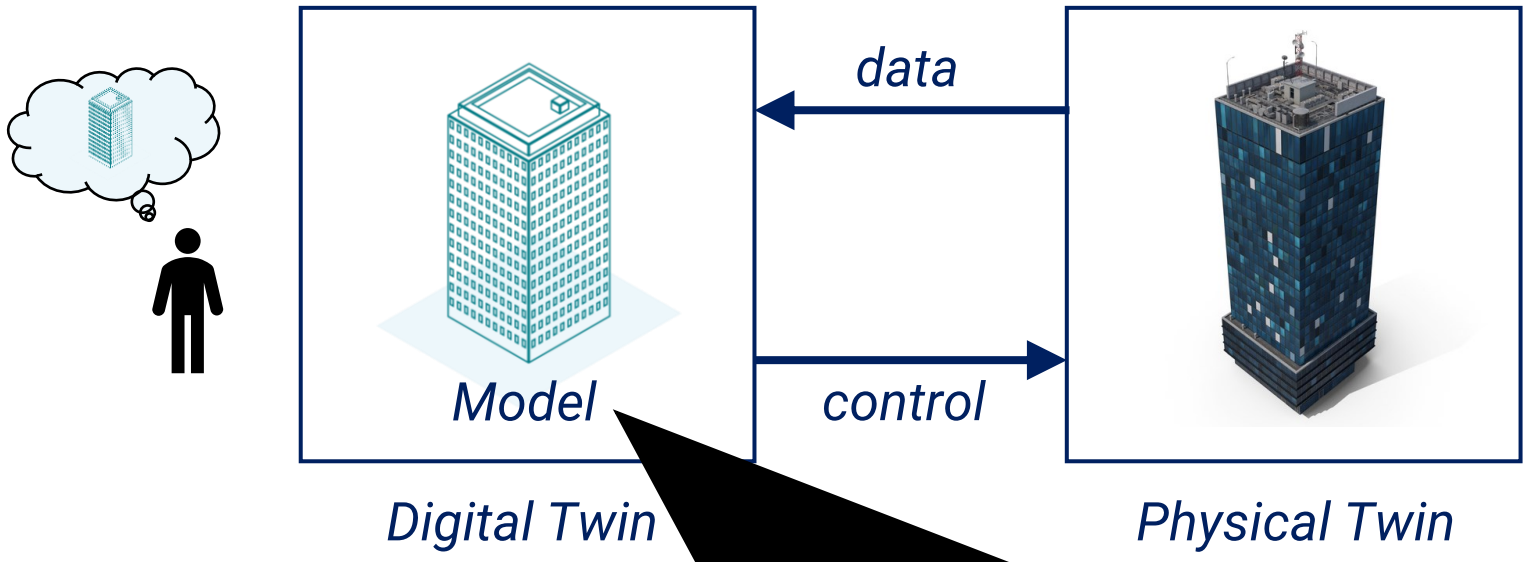


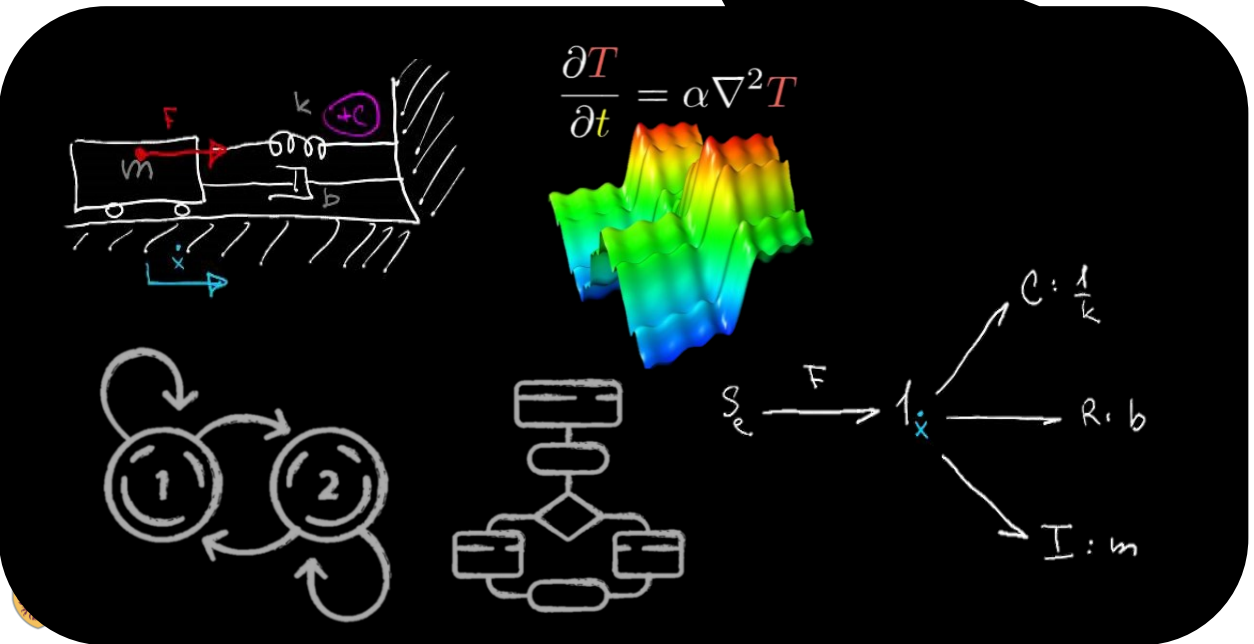
Digital twinning

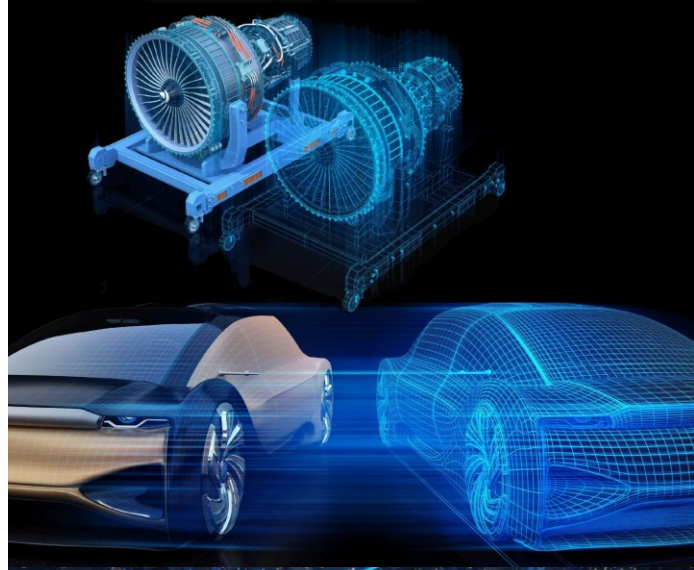


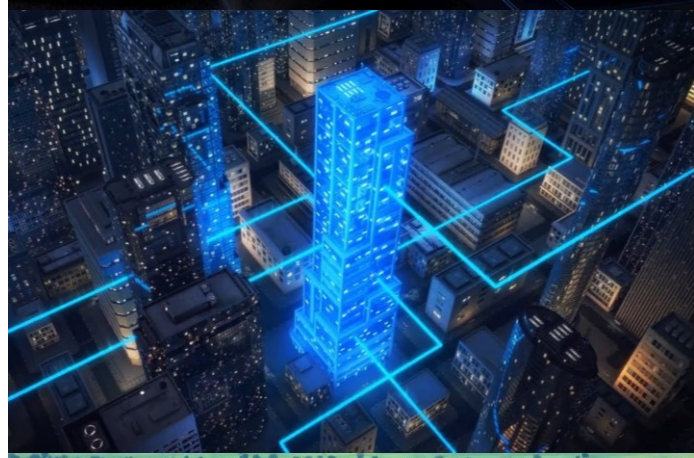


Digital twinning



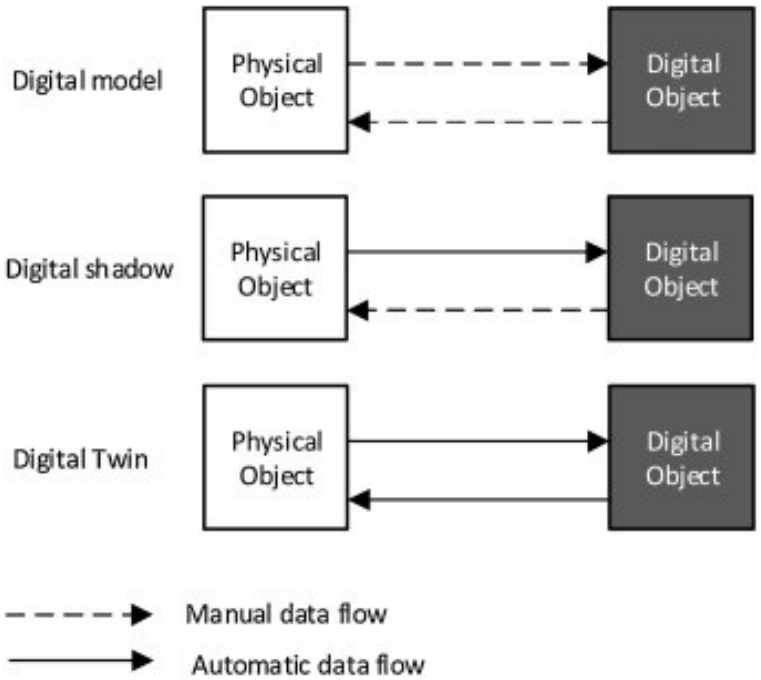




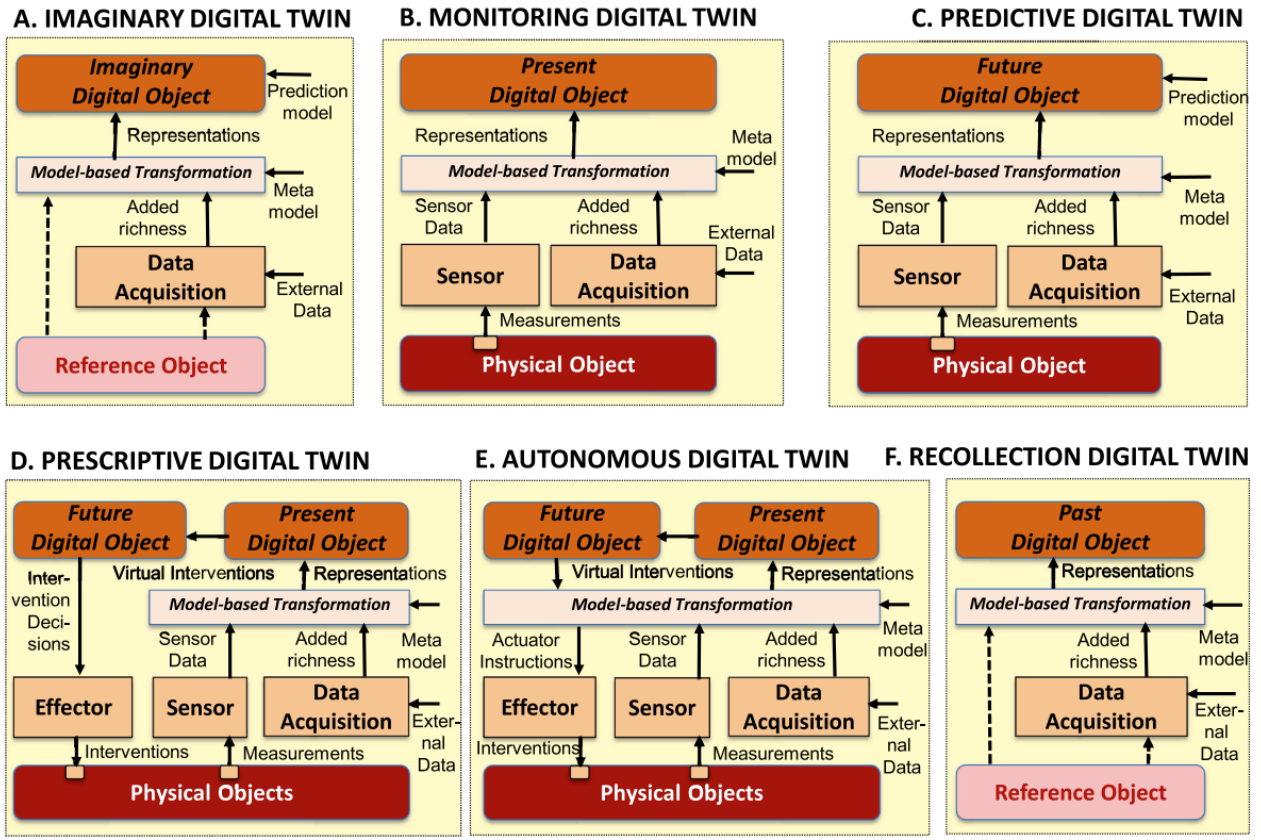


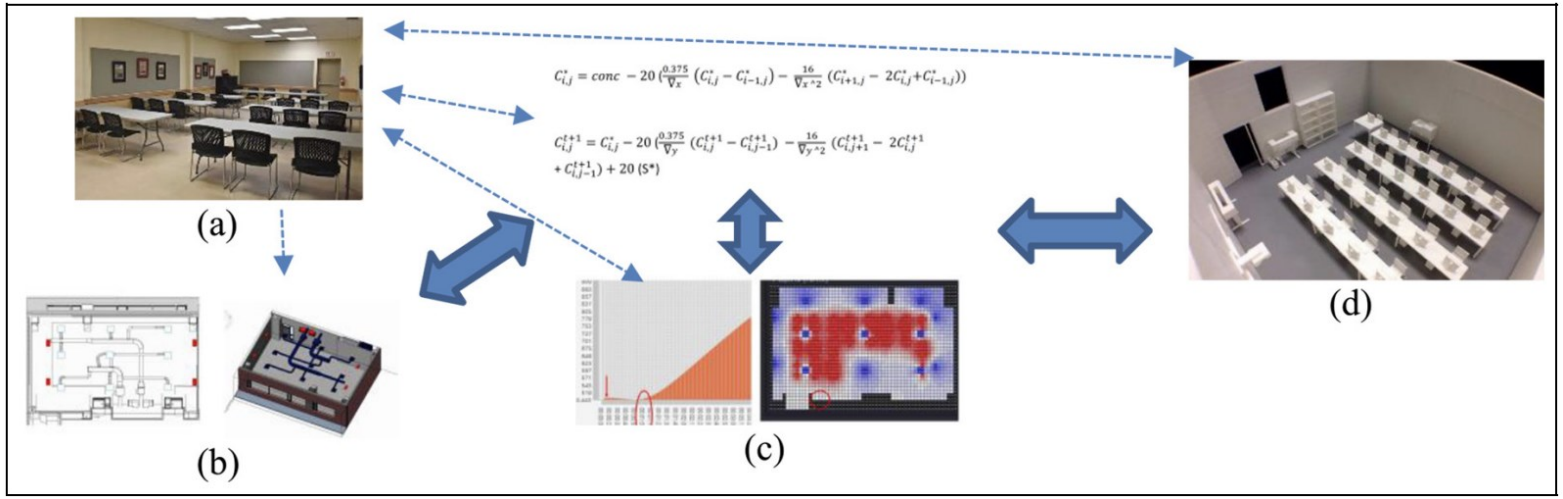
Digital "X"

Verdouw et al., 2021



Kritzinger et al., 2018





A DEVS-based engine for building digital quadruplets

Daniella Niyonkuru and Gabriel Wainer

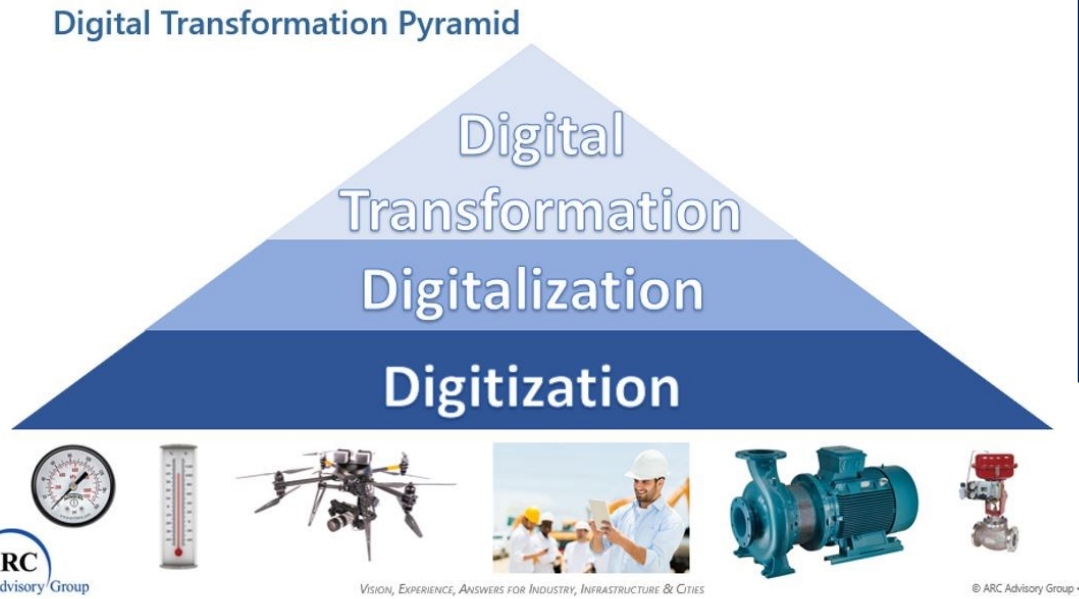
McMaster University

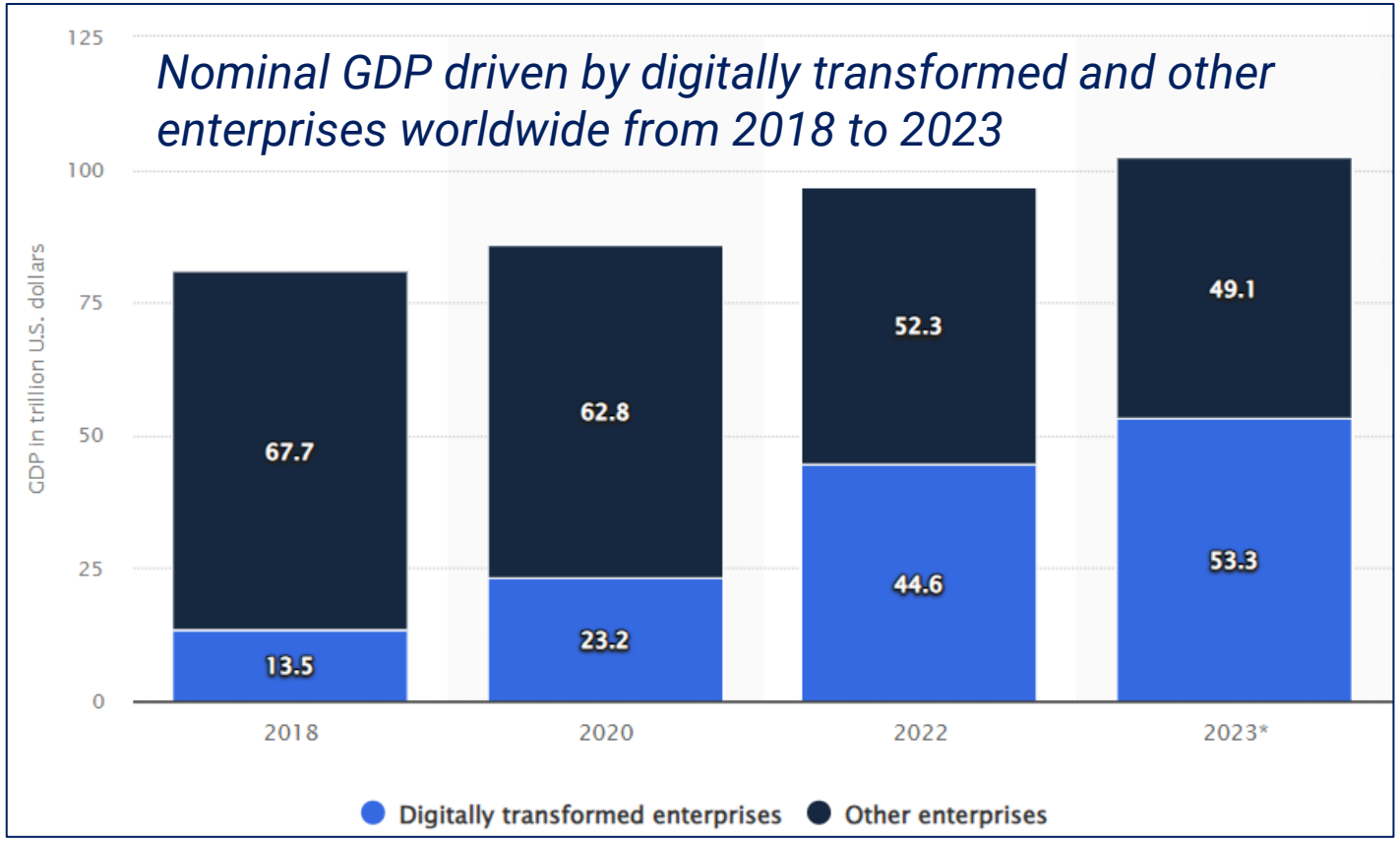
Digitalization and digital transformation

Industry 4.0 and 5.0

I5.0 complements the existing I4.0 approach by specifically putting research and innovation at the service of the transition to a **sustainable, human-centric** and **resilient European industry**

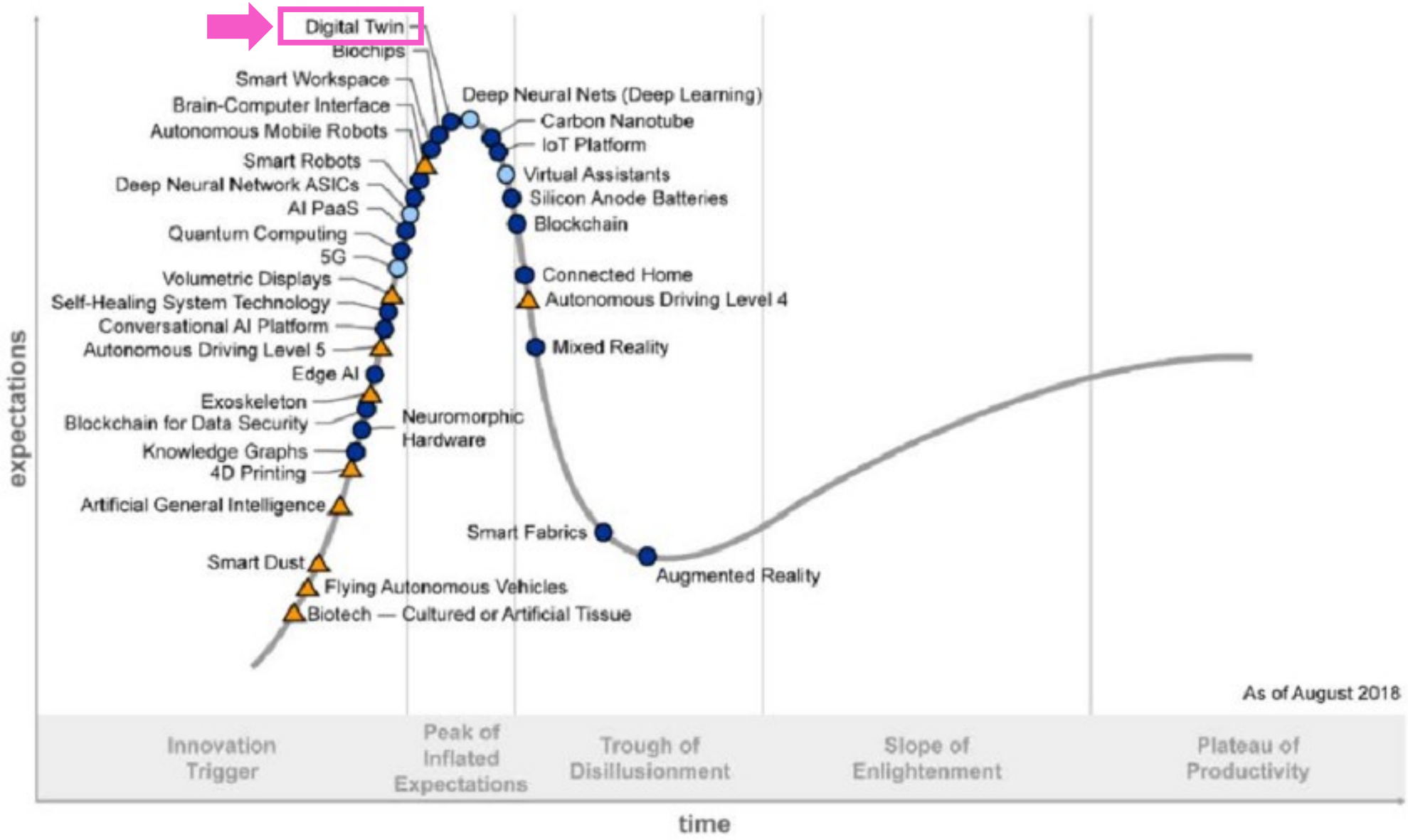
European Commission





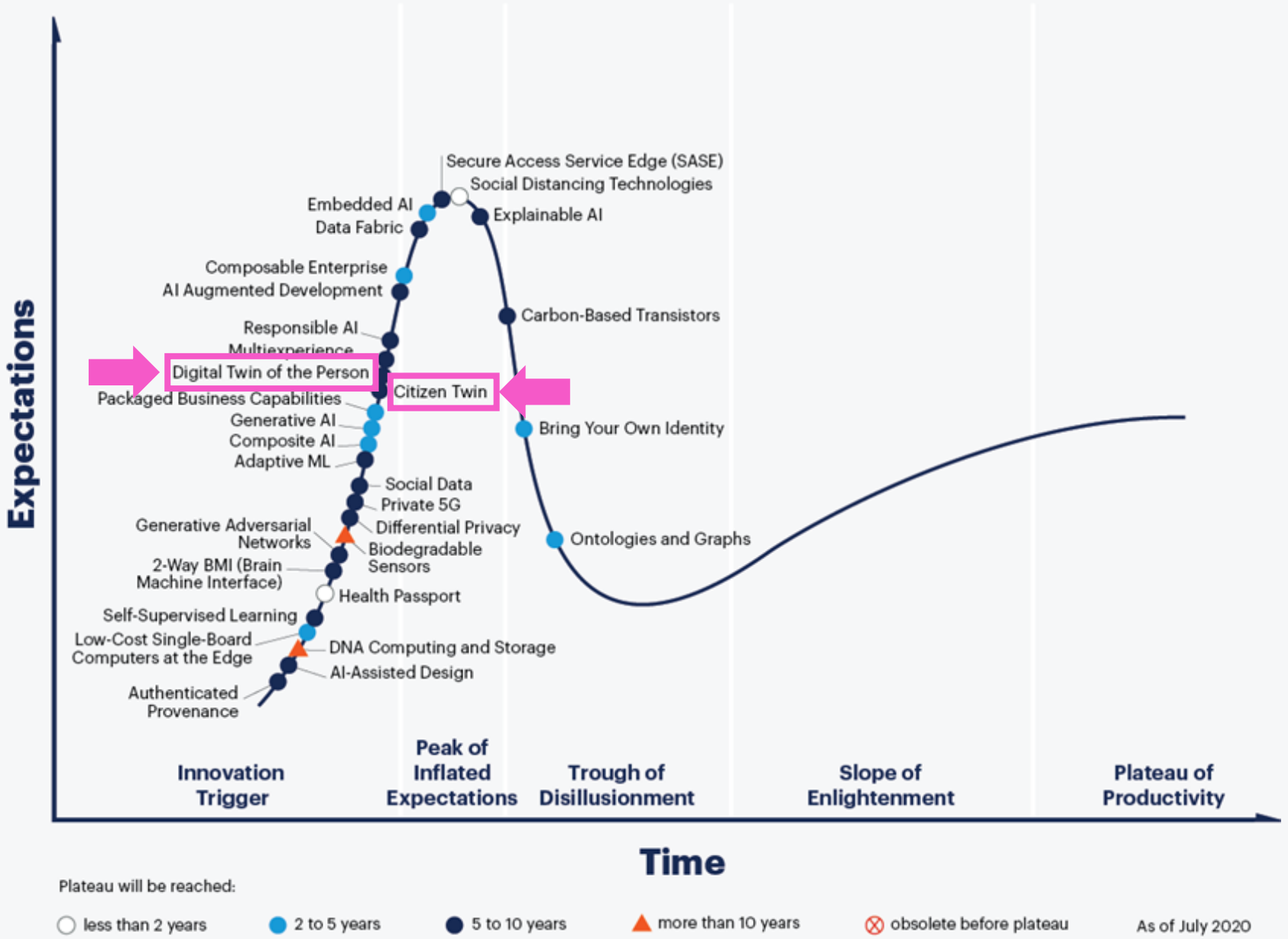
https://www.statista.com/statistics/1134766/nominal-gdp-driven-by-digitally-transformed-enterprises/

2018

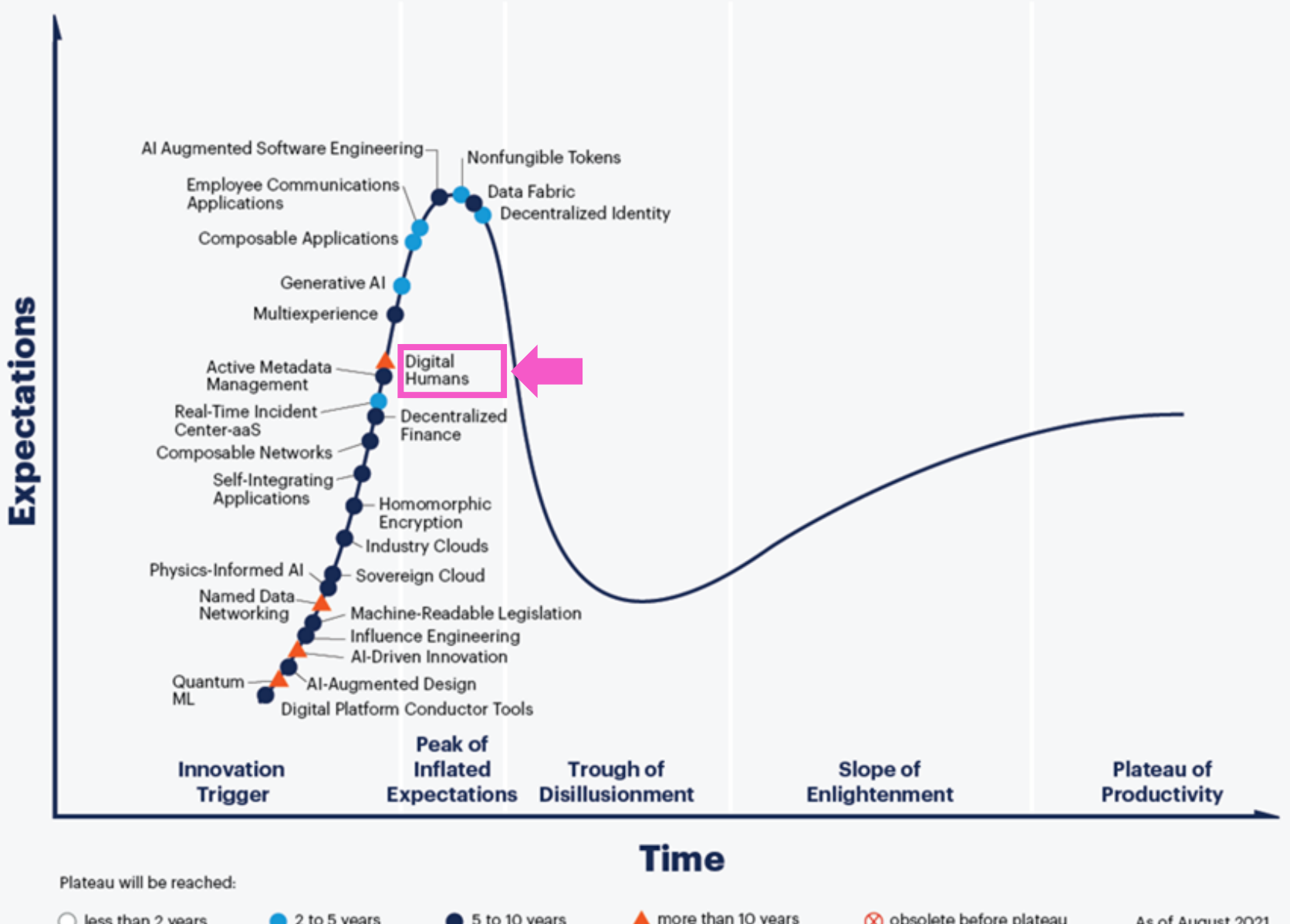

Digital Twin
Biochips
Smart Workspace
Brain-Computer Interface
Autonomous Mobile Robots
Smart Robots
Deep Neural Network ASICs
AI PaaS
Quantum Computing
5G
Volumetric Displays
Self-Healing System Technology
Conversational AI Platform
Autonomous Driving Level 5
Edge AI
Exoskeleton
Blockchain for Data Security
Knowledge Graphs
4D Printing
Artificial General Intelligence
Smart Dust
Flying Autonomous Vehicles
Biotech — Cultured or Artificial Tissue
Neuromorphic Hardware
Deep Neural Nets (Deep Learning)
Carbon Nanotube
IoT Platform
Virtual Assistants
Silicon Anode Batteries
Blockchain
Connected Home
Autonomous Driving Level 4
Mixed Reality
Smart Fabrics
Augmented Reality
expectations
As of August 2018
Innovation Trigger
Peak of Inflated Expectations
Trough of Disillusionment
Slope of Enlightenment
Plateau of Productivity
time
Plateau will be reached:
less than 2 years
2 to 5 years
5 to 10 years
more than 10 years
obsolete before plateau

Gartner Hype Cycle for Emerging Technologies, 2019

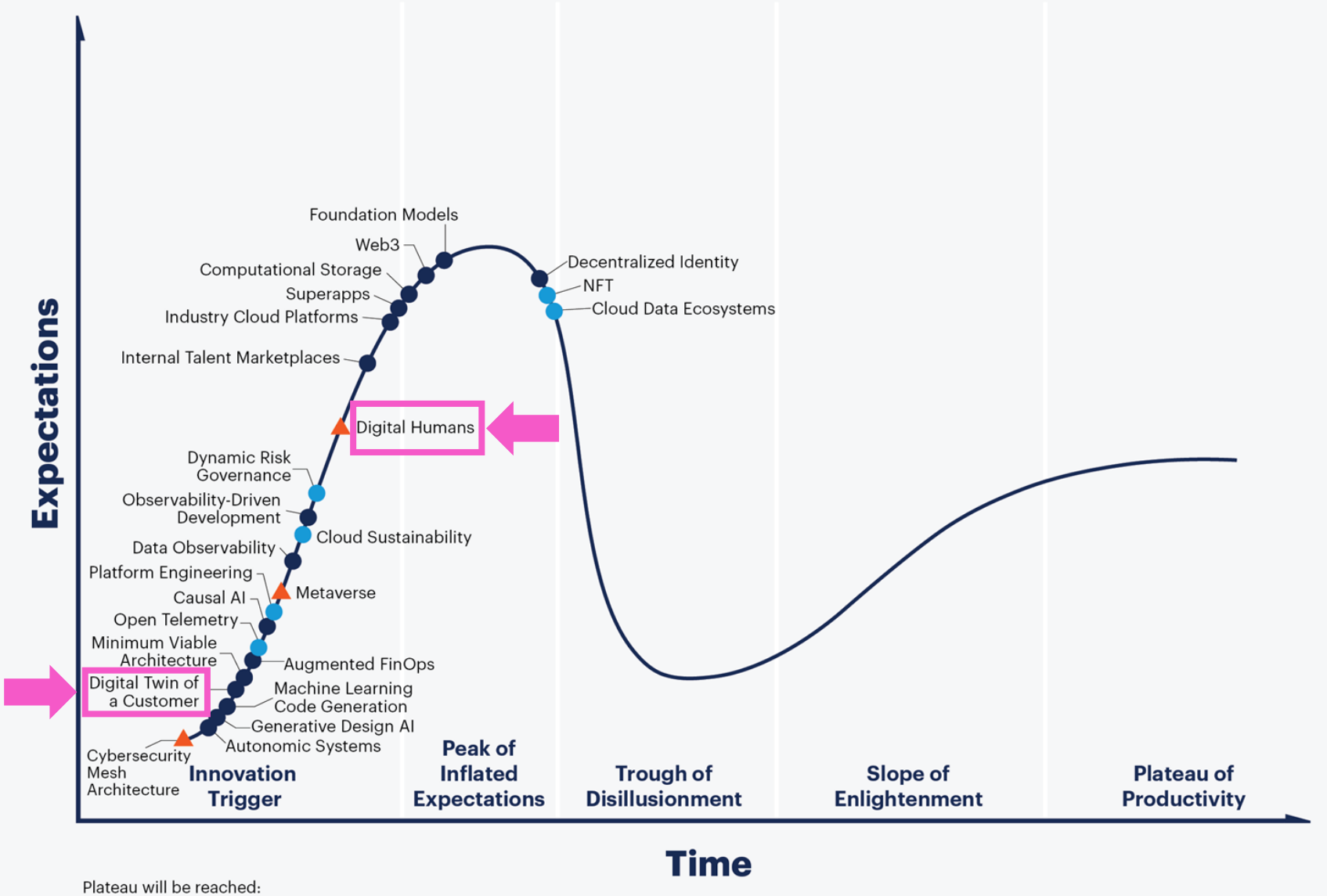
Hype Cycle for Emerging Technologies, 2020



Hype Cycle for Emerging Technologies, 2021



Hype Cycle for Emerging Tech, 2022

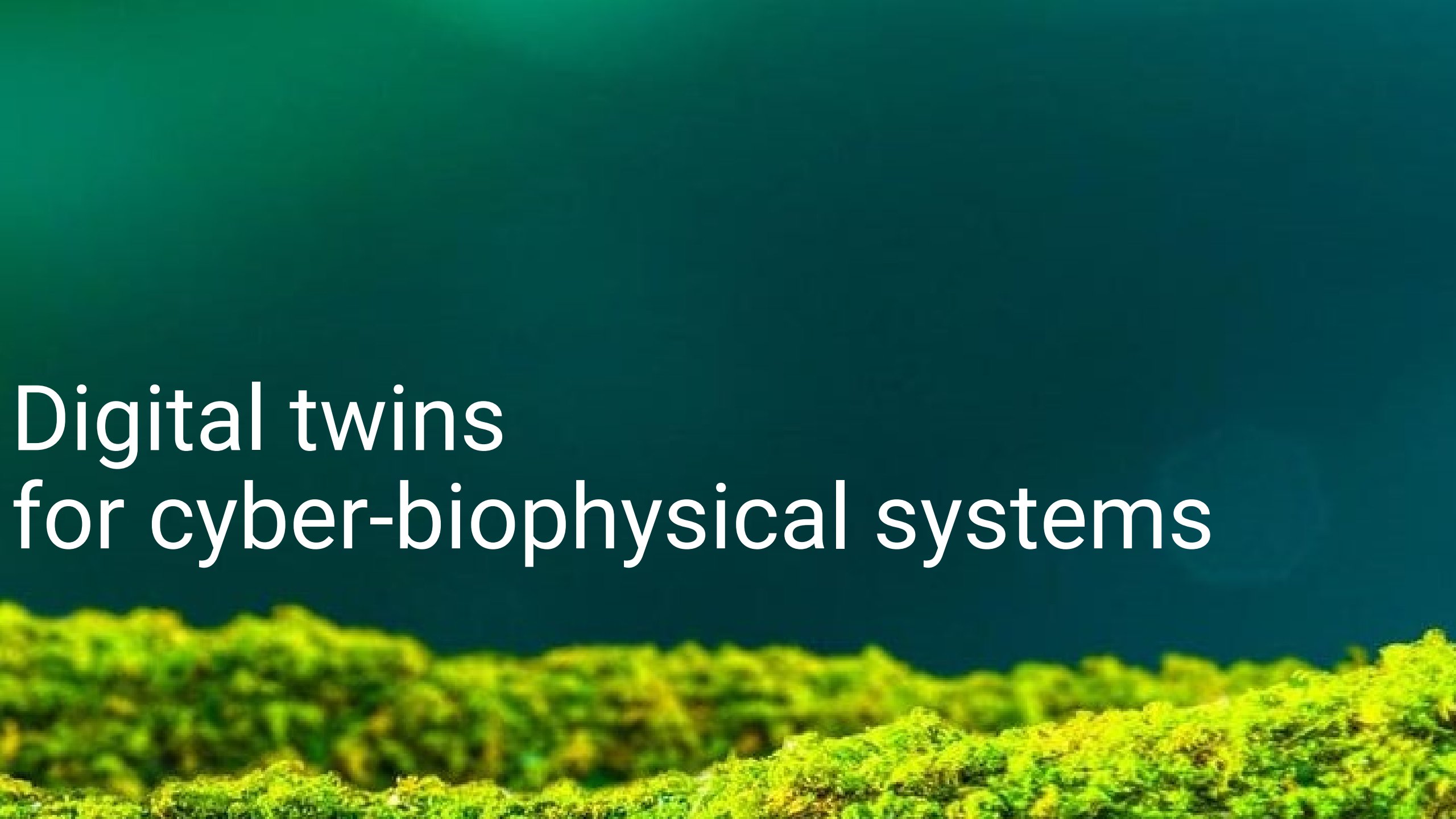


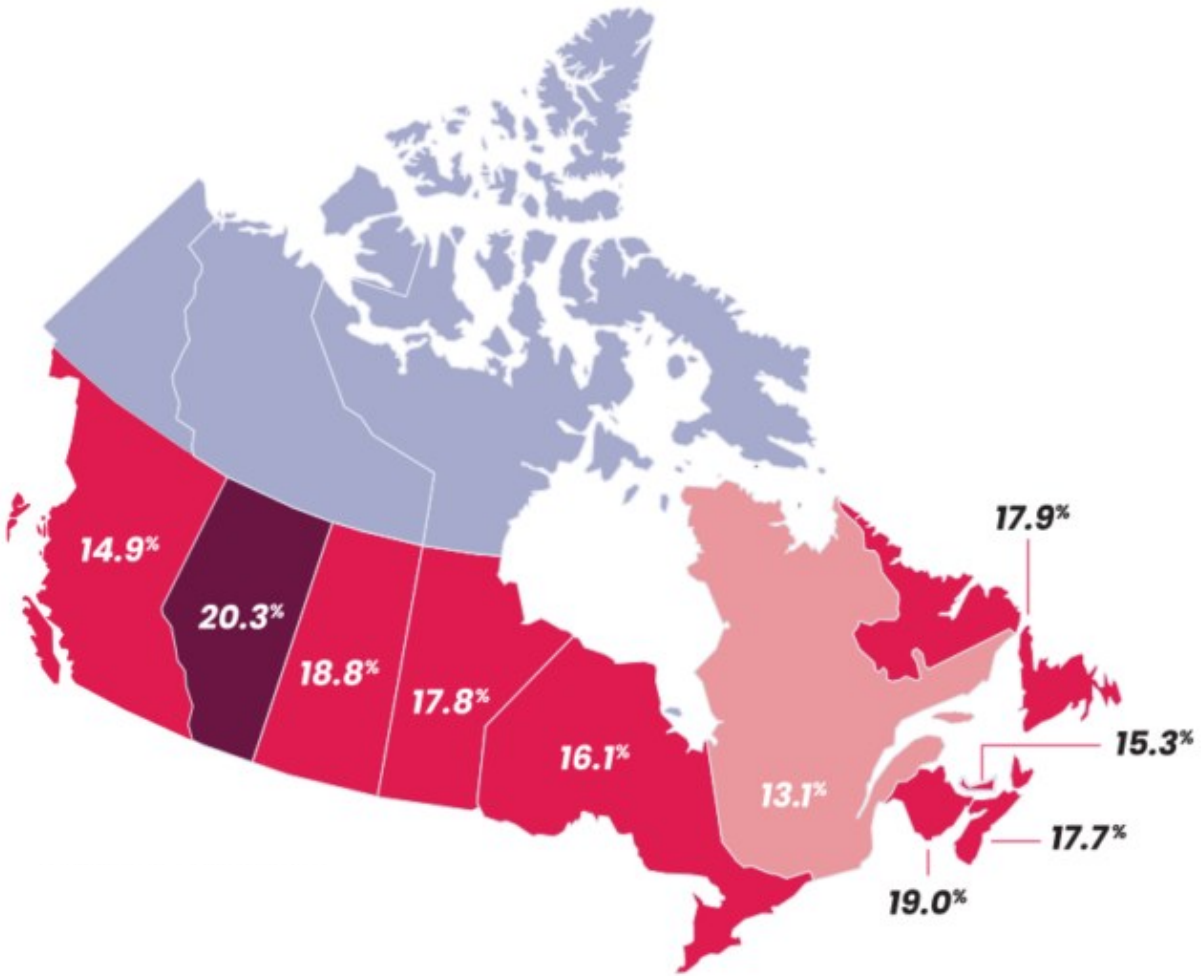
Plateau will be reached:

○ less than 2 years ● 2 to 5 years ● 5 to 10 years ▲ More than 10 years ⊗ Obsolete before plateau

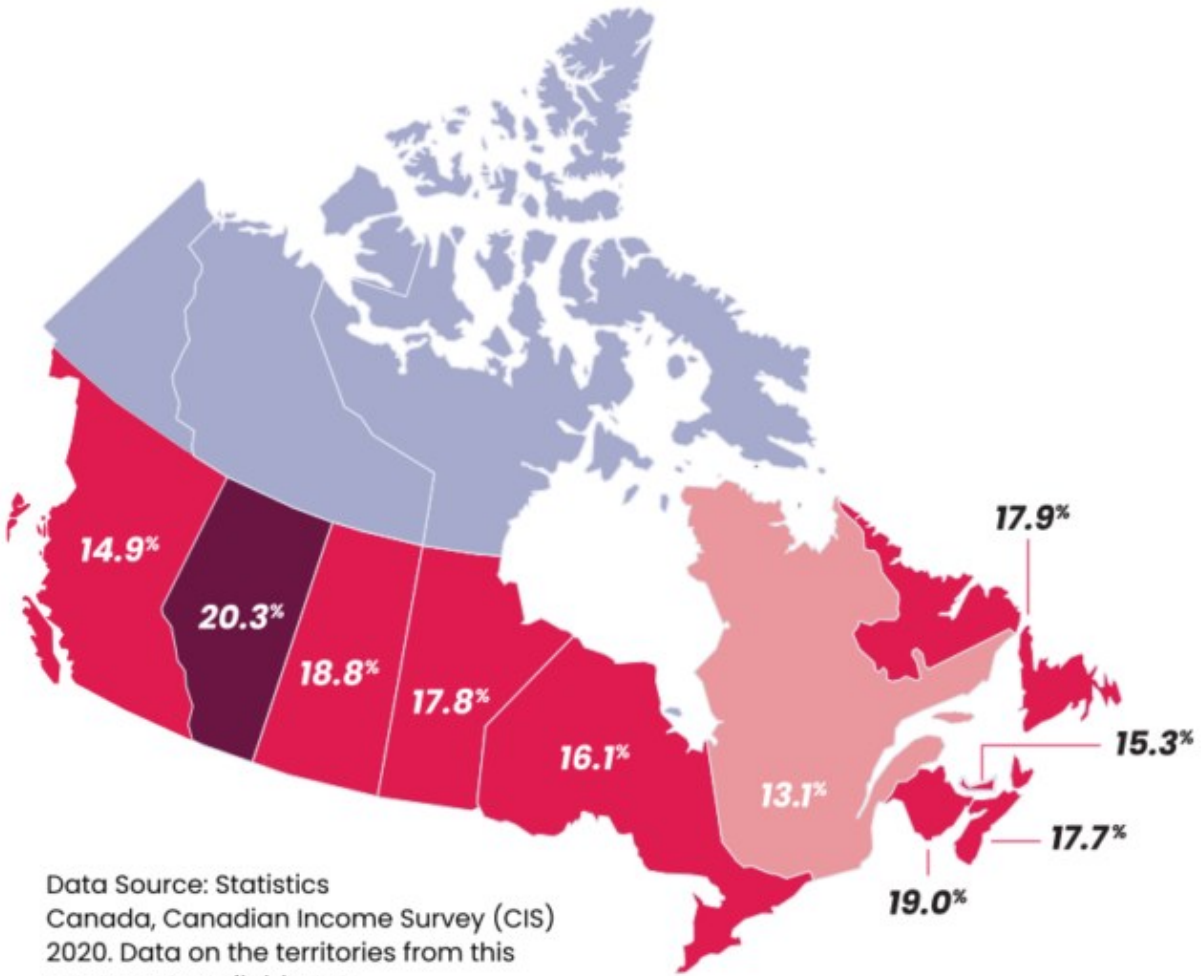
As of August 2022

Digital twins for cyber-biophysical systems




14.9%
20.3%
18.8%
17.8%
16.1%
13.1%
17.9%
15.3%
17.7%
19.0%

Prevalence of Household Food Insecurity by Province, 2021



Data Source: Statistics Canada, Canadian Income Survey (CIS) 2020. Data on the territories from this survey not available yet.

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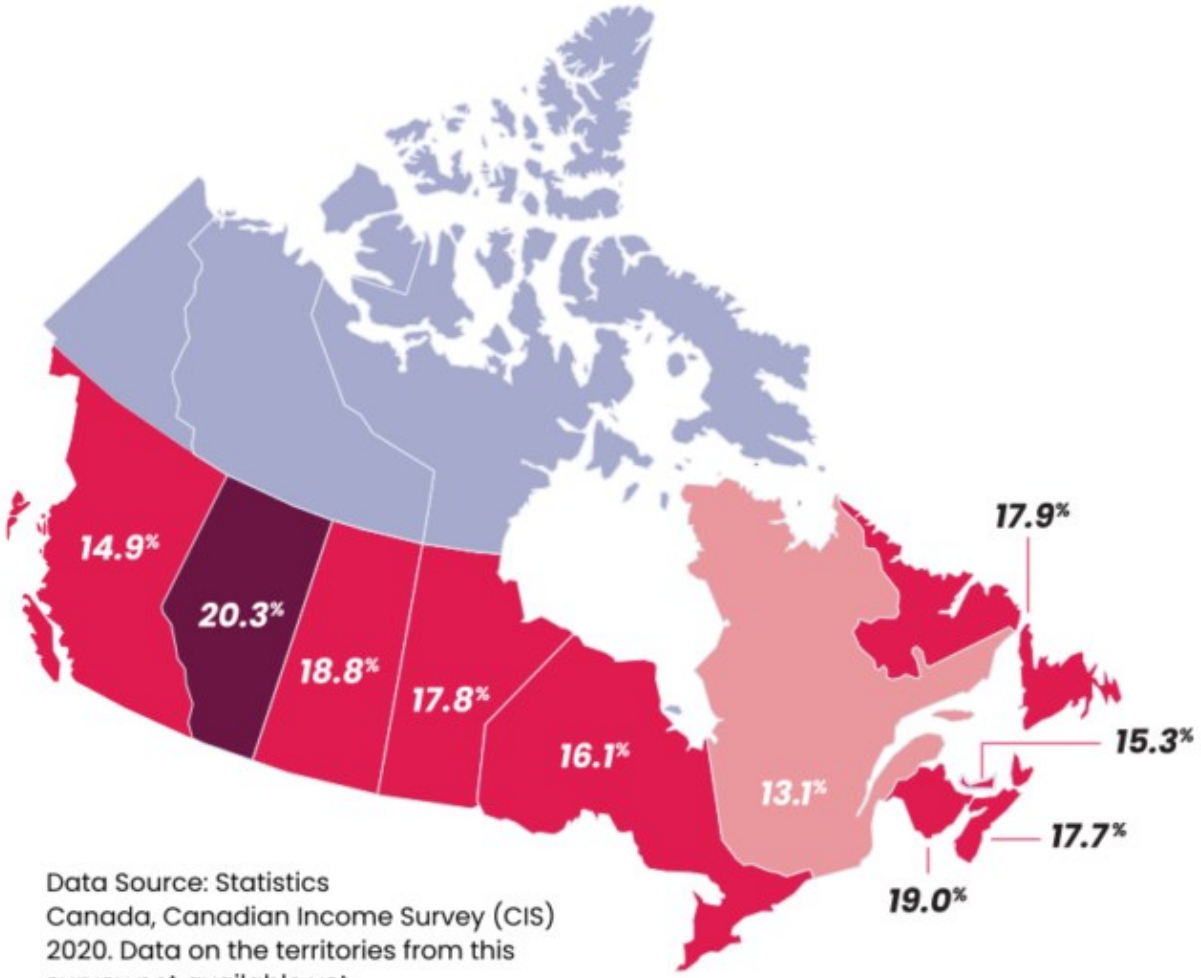
Prevalence of Household Food Insecurity by Province, 2021



Data Source: Statistics Canada, Canadian Income Survey (CIS) 2020. Data on the territories from this survey not available yet.

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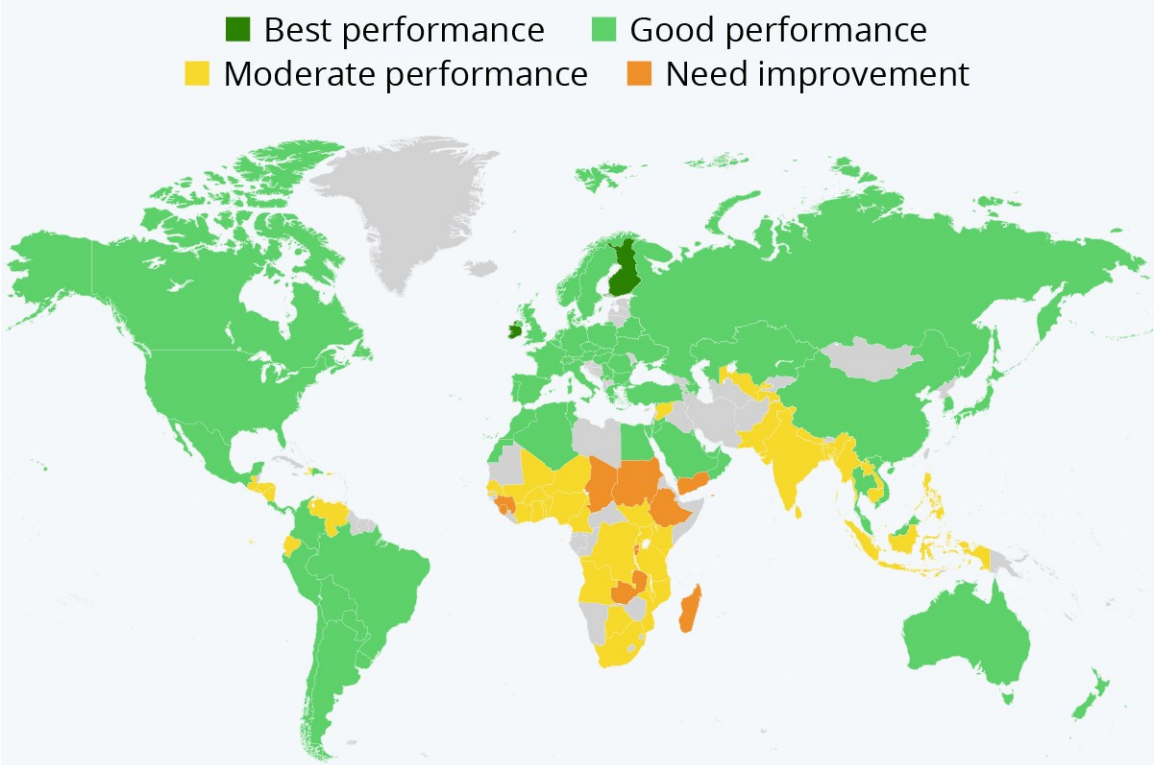
The Global State of Food Security

Best and worst performing countries for food security in 2020*

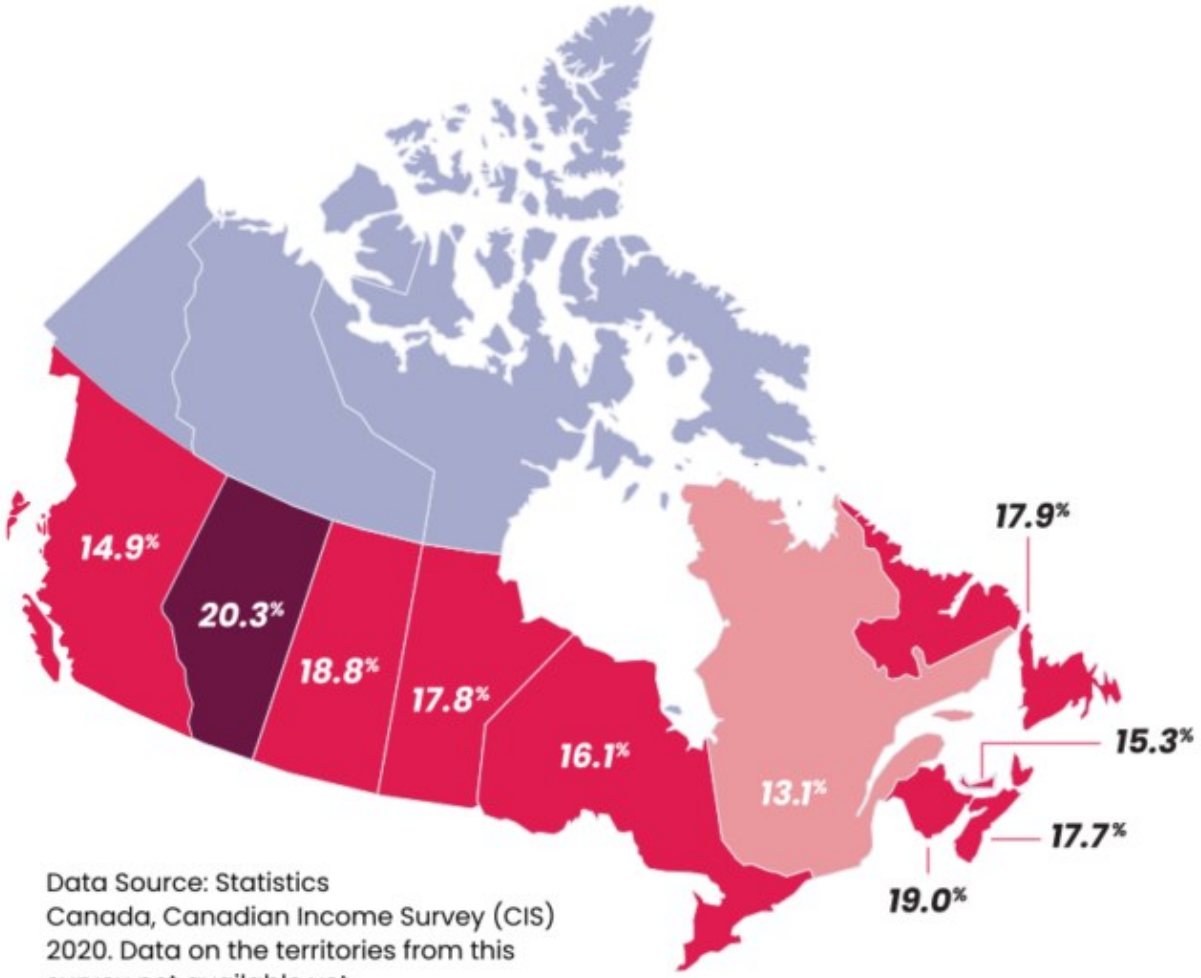


* Affordability, availability, safety, quality and natural resources of food based on 59 unique indicators across 113 countries.

Source: Economist Intelligence Unit

statista

Prevalence of Household Food Insecurity by Province, 2021



Data Source: Statistics Canada, Canadian Income Survey (CIS) 2020. Data on the territories from this survey not available yet.

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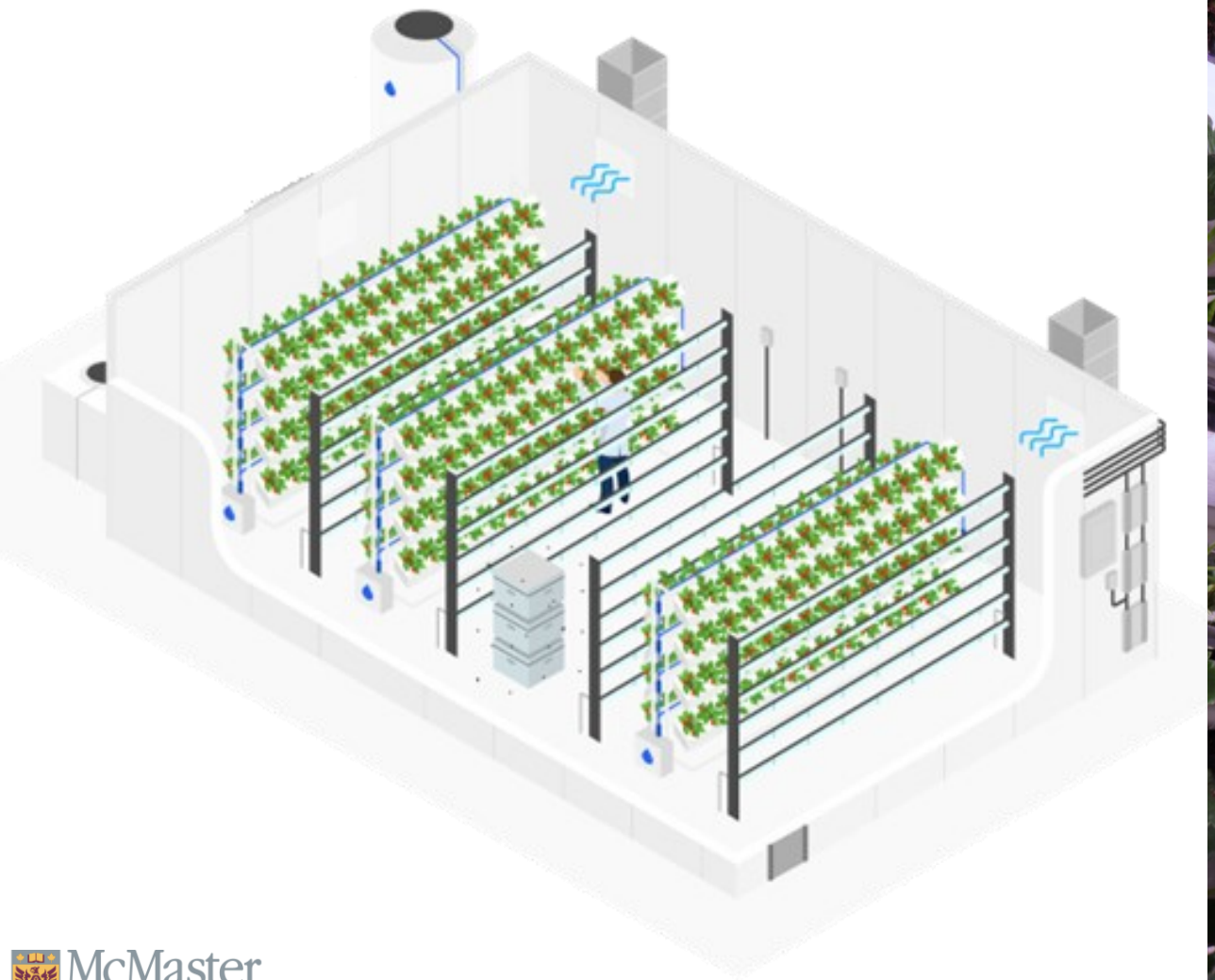
Controlled Environment Agriculture (CEA)



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The challenge of CEA: **control is hard**

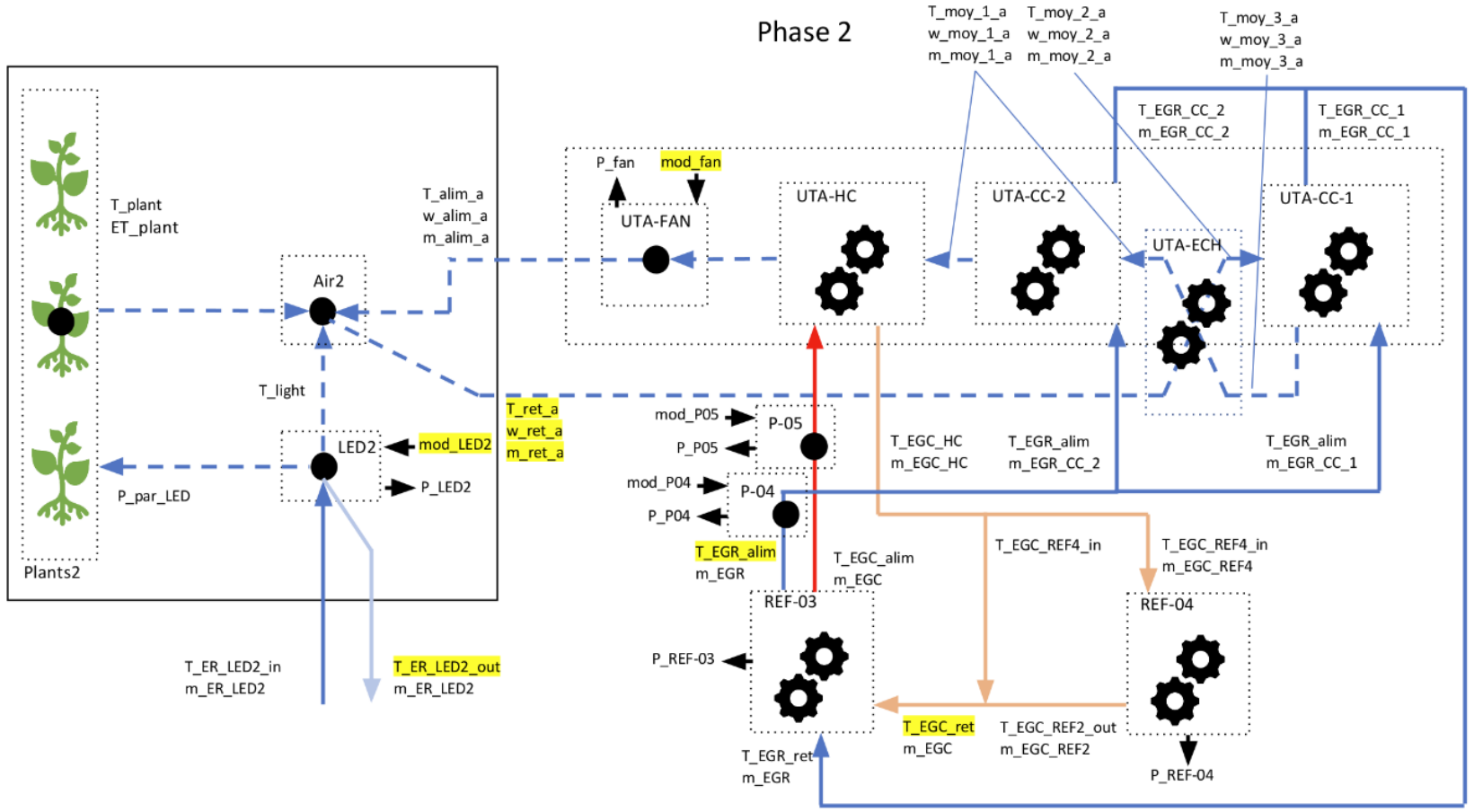
Maximize crop-to-energy ratio
Reduce waste

…

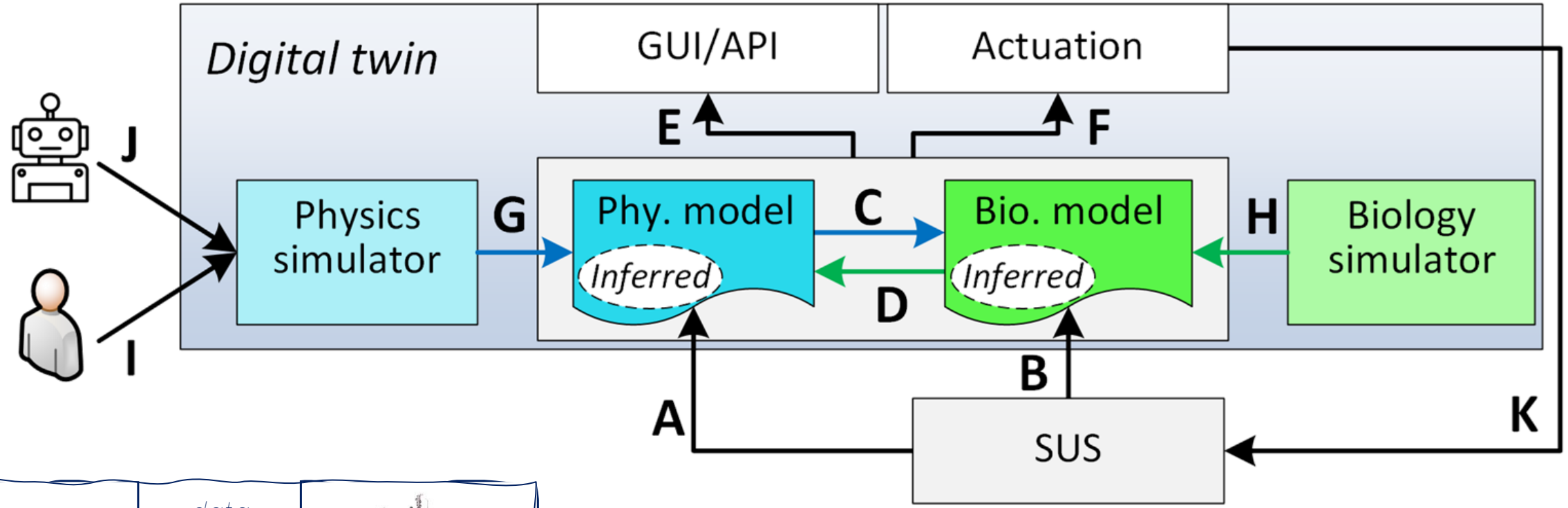
Each bush must produce 50 grams of  *per week*

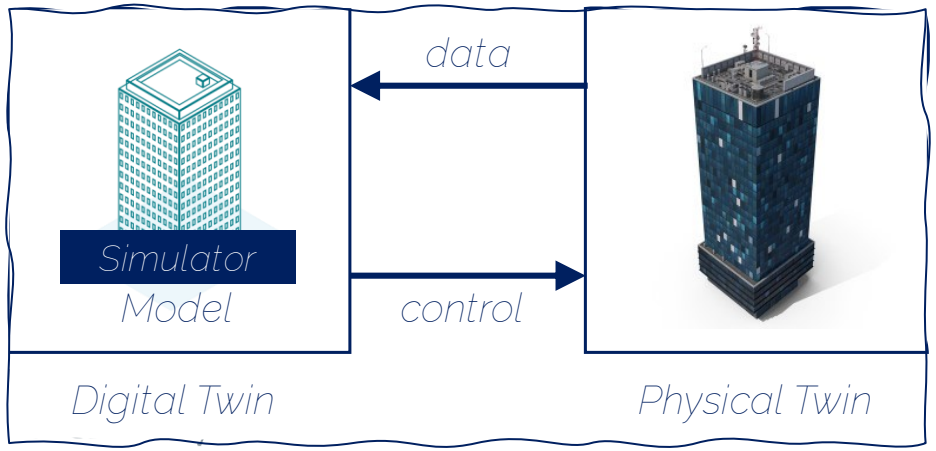
…starting two months from now

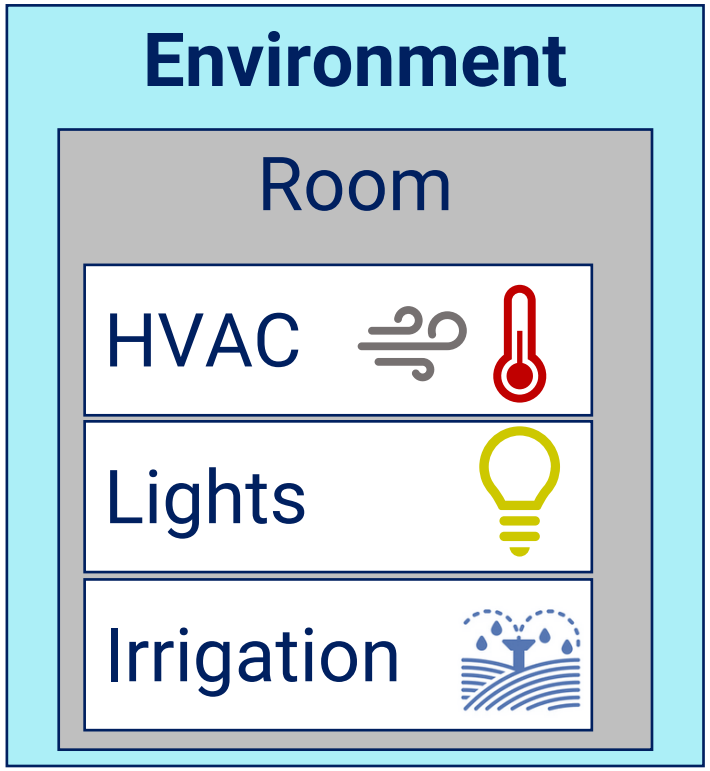
Expressing expert processes

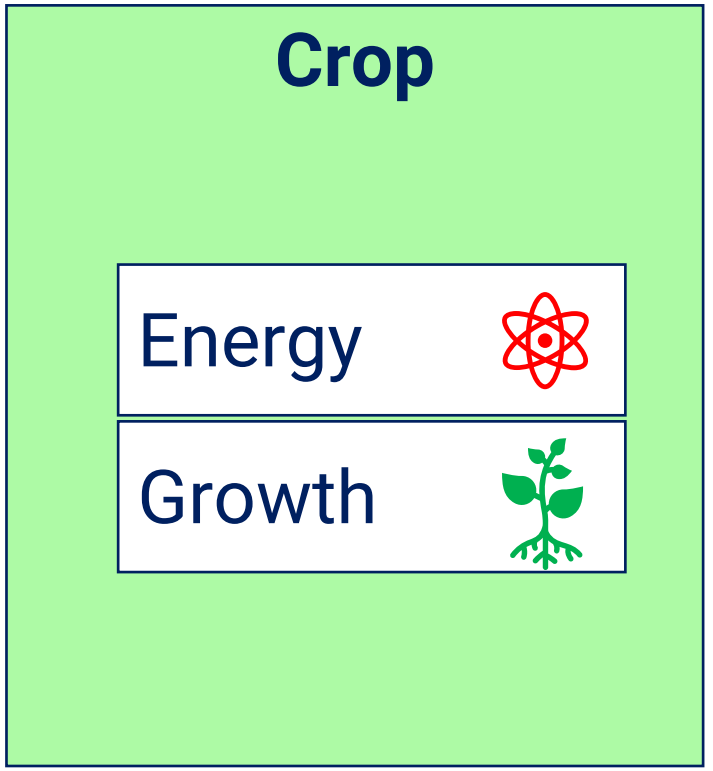


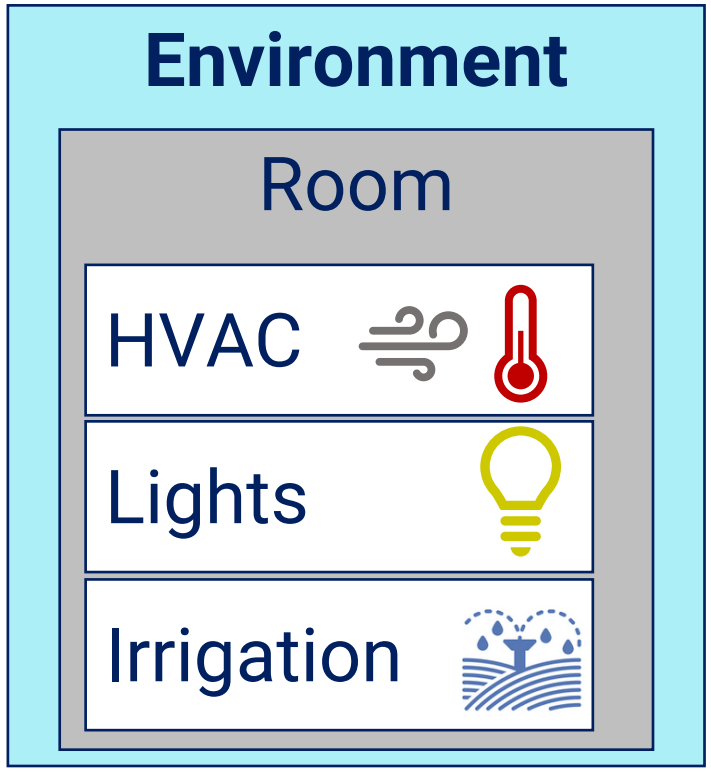
DT4CBPS: Conceptual framework and requirements





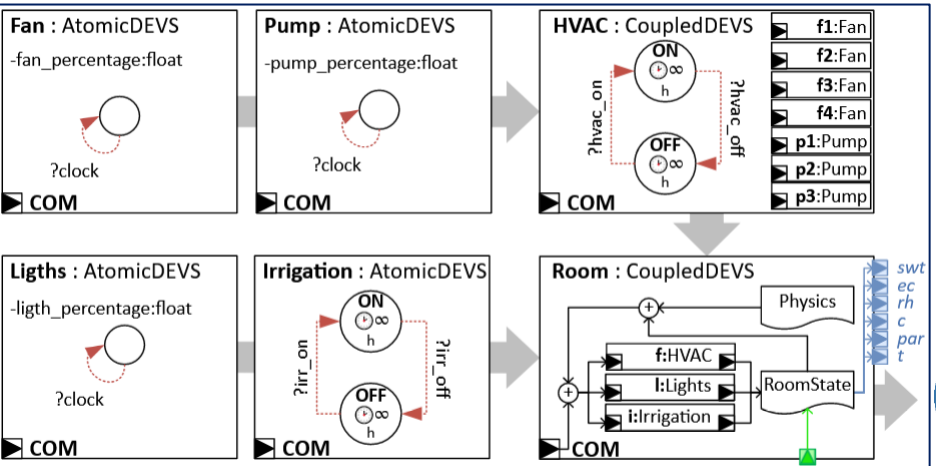

Environment
Room
HVAC
Lights
Irrigation


Crop
Energy
Growth

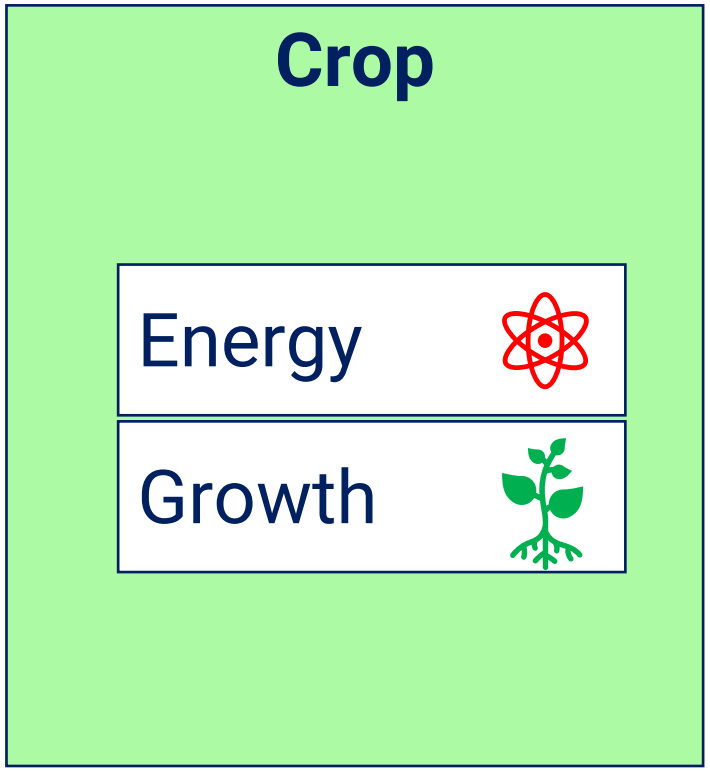


$$\frac{dy}{dt} = ky$$

MATLAB®



PythonPDEVS



Environment

Room

- HVAC
- Lights
- Irrigation

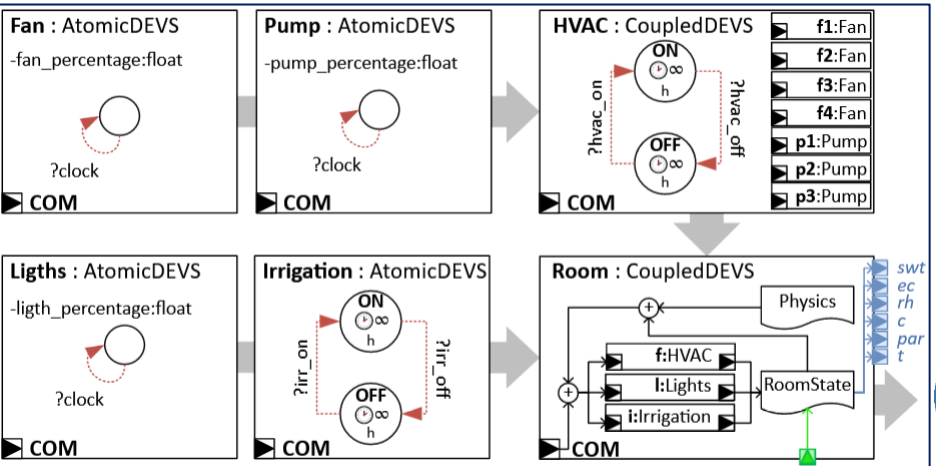
$$\frac{dy}{dt} = ky$$

MATLAB®

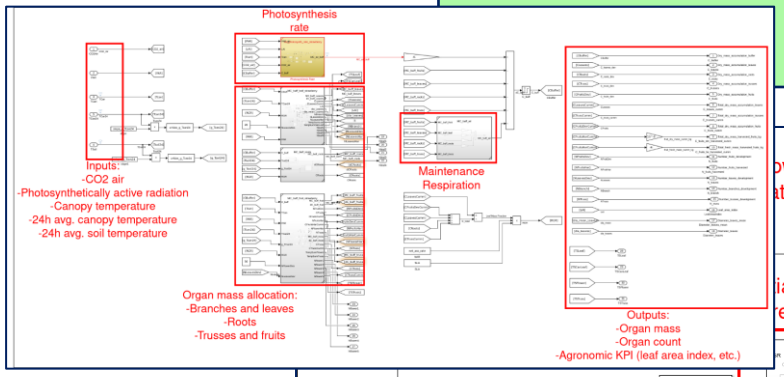
SIMULINK®

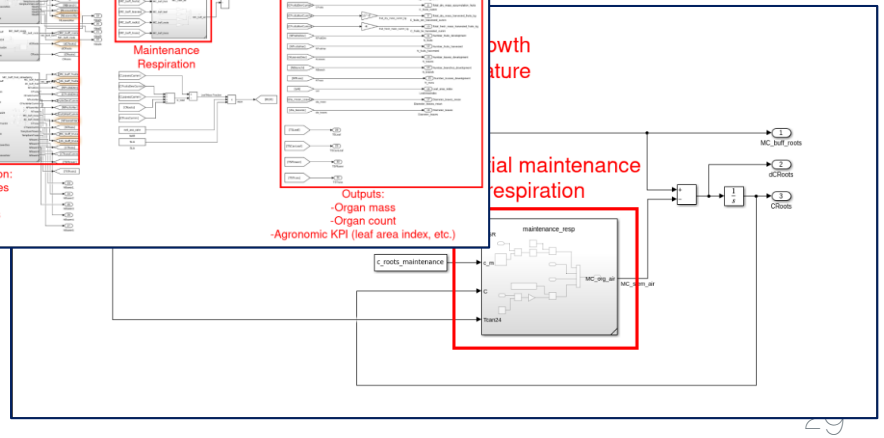
Crop

- Energy
- Growth



PythonPDEVS





Environment

Room

- HVAC
- Lights
- Irrigation

Negri, E., Fumagalli, L., Cimino, C. and Macchi, M. FMU-supported simulation for CPS digital twin. *Procedia manufacturing: 28*, pp.201-206, 2019.

fmi Functional Mock-Up Interface

fmi Functional Mock-Up Interface

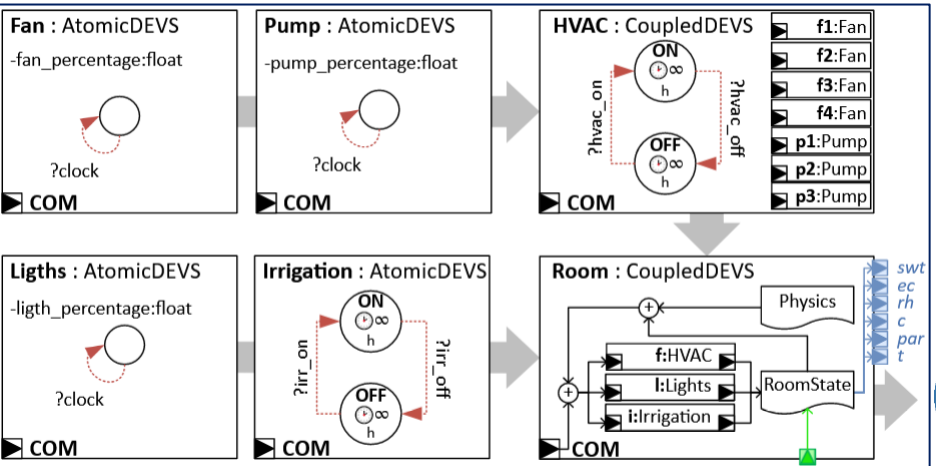
$$\frac{dy}{dt} = ky$$

MATLAB®

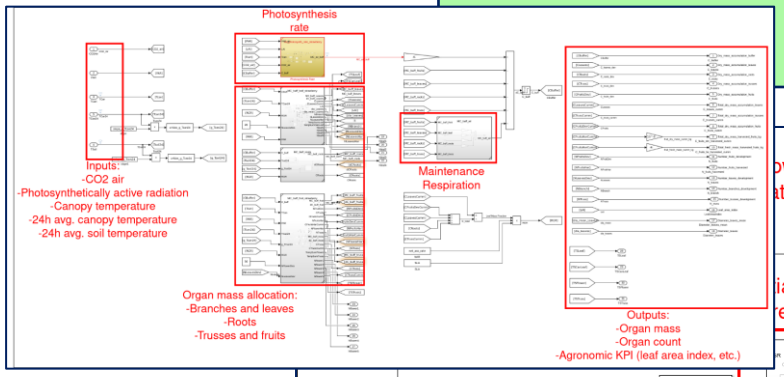
SIMULINK®

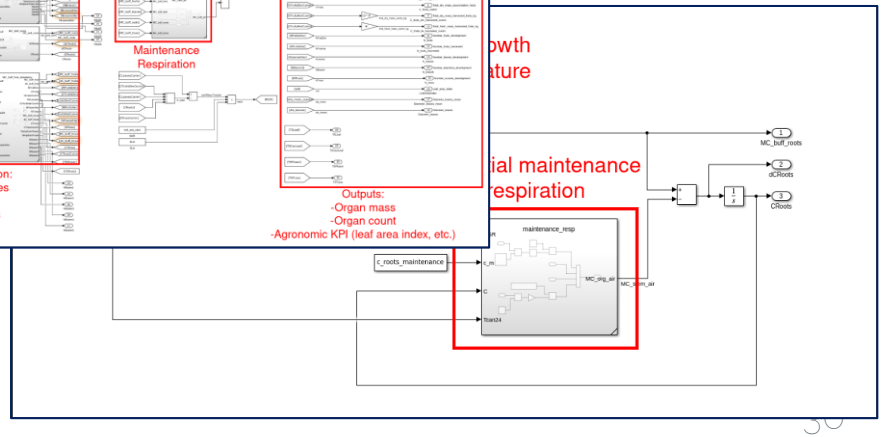
Crop

- Energy
- Growth



PythonPDEVS



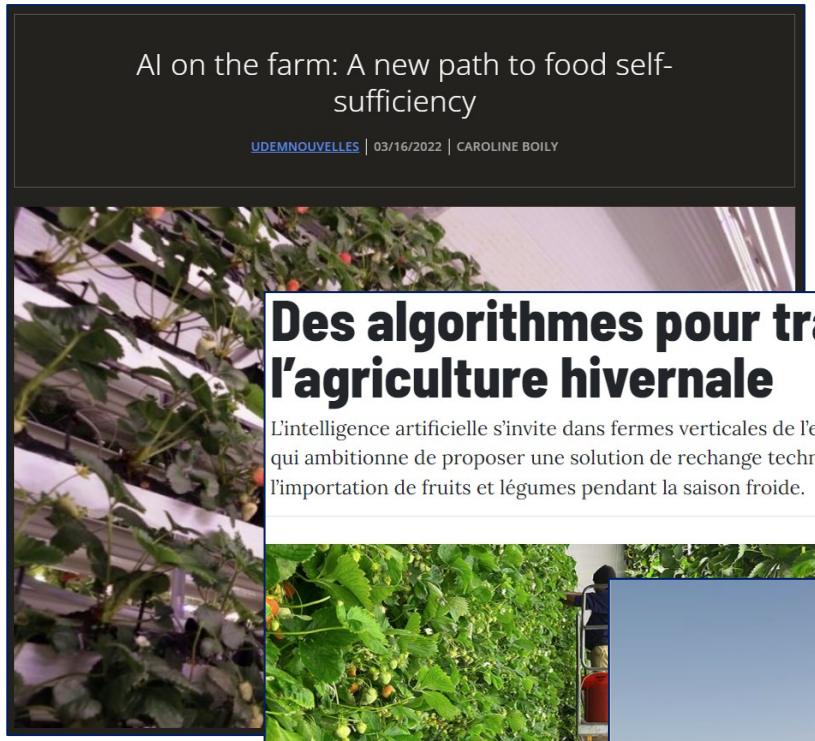


Digital Twins for Cyber-Biophysical Systems: Challenges and Lessons Learned

Istvan David*, Pascal Archambault*, Quentin Wolak*, Cong Vinh Vu*,
Timothé Lalonde†, Kashif Riaz†, Eugene Syriani*, Houari Sahraoui*
*DIRO, Université de Montréal, Canada – {firstname.lastname}@umontreal.ca
†Ferme d'Hiver Technologies, Canada – {tlalonde,kriaz}@fermedhiver.ca

Lessons learned

McMaster University



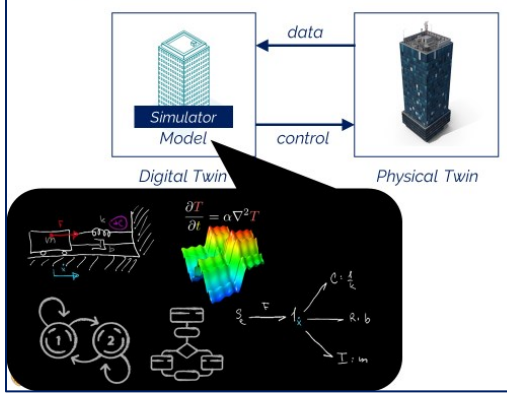
https://nouvelles.umontreal.ca/en/article/2022/03/16/ai-on-the-farm-a-new-path-to-food-self-sufficiency/

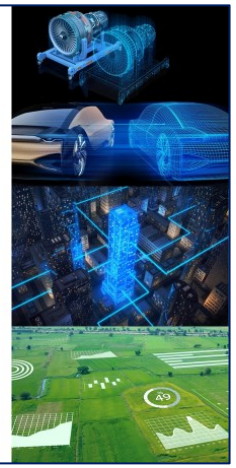
https://lactualite.com/techno/des-algorithmes-pour-transformer-lagriculture-hivernale/

https://mydigitalpublication.com/publication/?m=1281&i=805712&p=22&ver=html5

Digital Twins
Foundations, applications, and the state of the art

Digital twinning





Digitalization and digital transformation

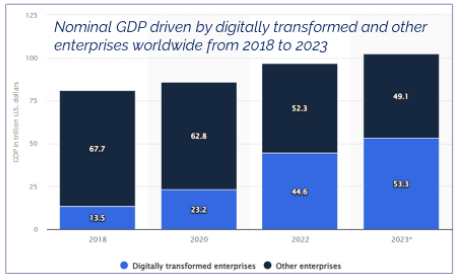
Industry 4.0 and 5.0

I5.0 complements the existing I4.0 approach by specifically putting research and innovation at the service of the transition to a **sustainable**, **human-centric** and **resilient European industry**

European Commission

Digital Transformation Pyramid

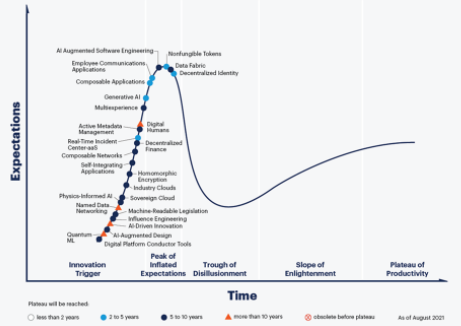
Nominal GDP driven by digitally transformed and other enterprises worldwide from 2018 to 2023



https://www.statista.com/statistics/1134766/nominal-gdp-driven-by-digitally-transformed-enterprises/

10

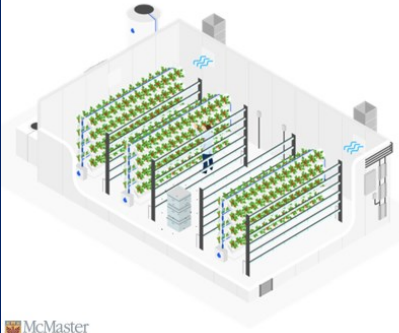
2021 Hype Cycle for Emerging Technologies, 2021



gartner.com

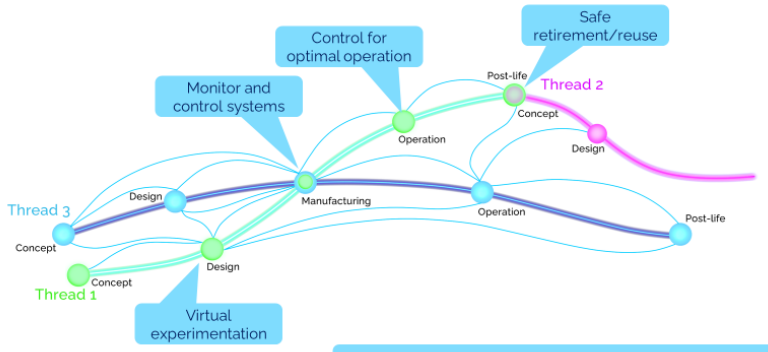
Gartner

Controlled Environment Agriculture (CEA)



McMaster University

Digital Twins along the Systems Engineering process

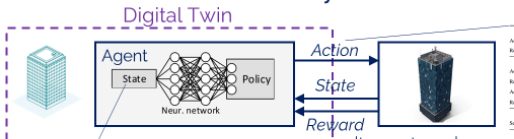


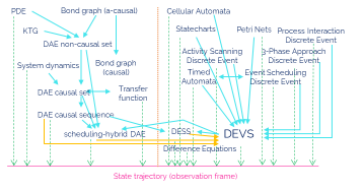
Digital thread ▶ Digital fabric

I. David, D. Bork, and G. Kappel, "Circular Systems Engineering", In: Software and Systems Modeling (2023)

McMaster University

Rapid development of Digital Twins: Simulator inference by reinforcement learning





- Istvan David and Eugene Syriani. "Automated Inference of Simulators in Digital Twins". In: Handbook of Digital Twins. To appear. CRC Press, 2023. isbn: 978-1-032-54607-0
- Istvan David and Eugene Syriani. "DEVS Model Construction as a Reinforcement Learning Problem". In: 2022 Annual Modeling and Simulation Conference (ANNSIM). IEEE, 2022, pp. 30–41.
- Istvan David, Jessie Galasso, and Eugene Syriani. "Inference of Simulation Models in Digital Twins by Re-inforcement Learning". In: MODELS-C 2021. IEEE, pp. 221–224.

38