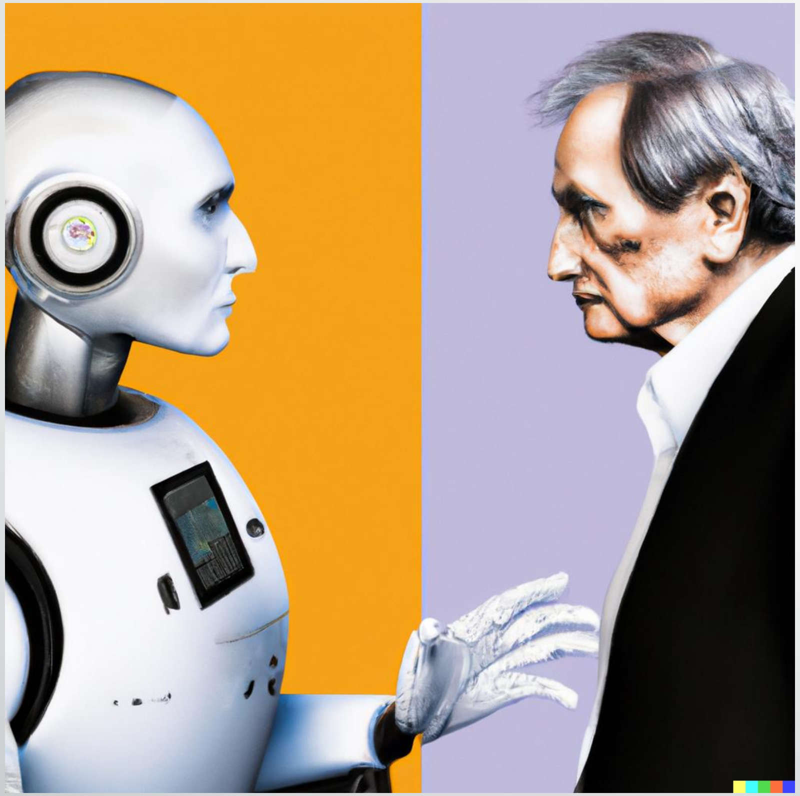
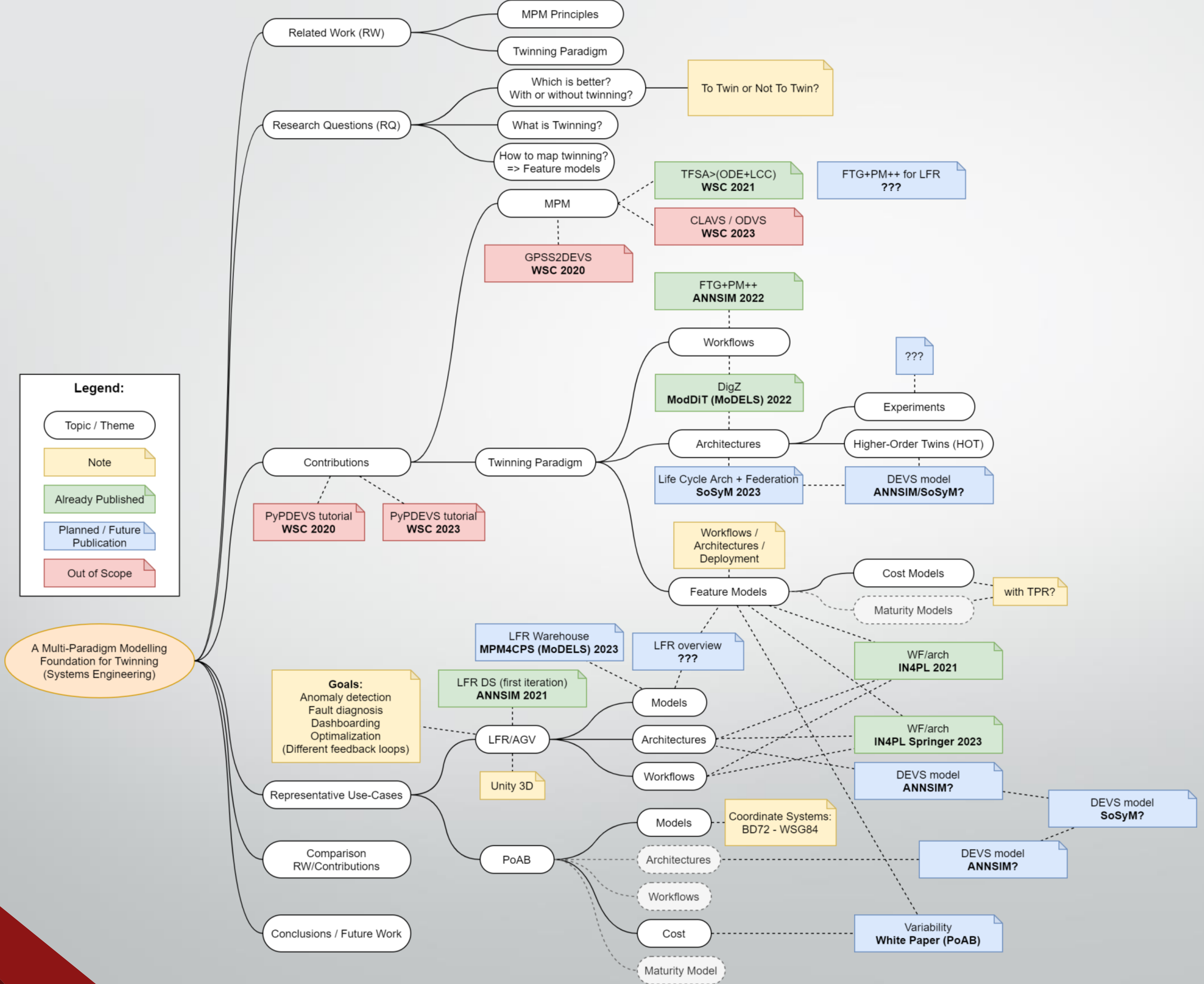
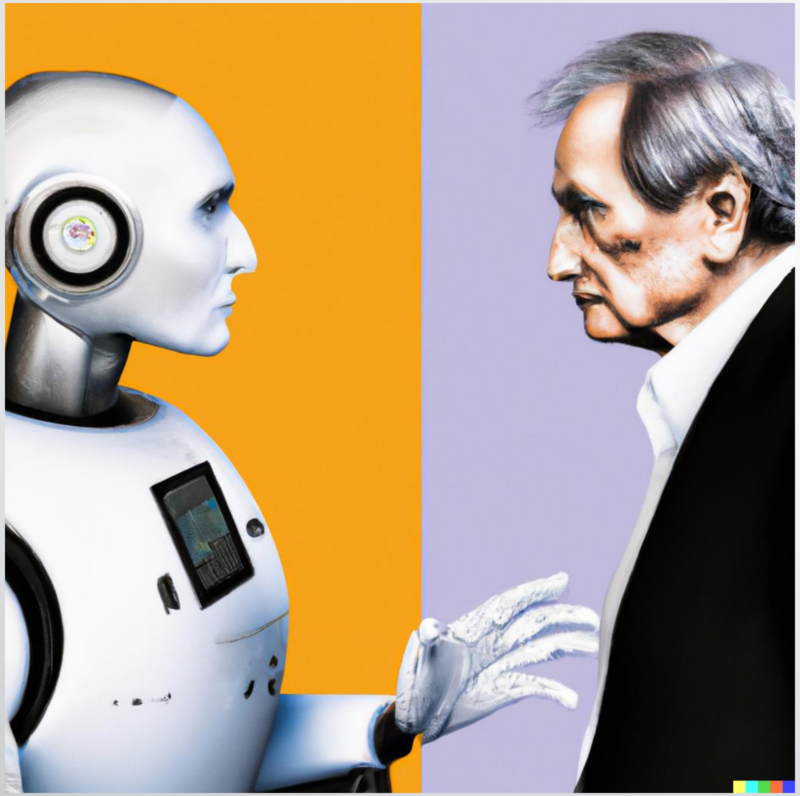


The Design and Architectures of Digital Twins

Randy Paredis

Image generated with DALL-E 2 using "alan alda meeting himself as a robot digital art" as prompt.

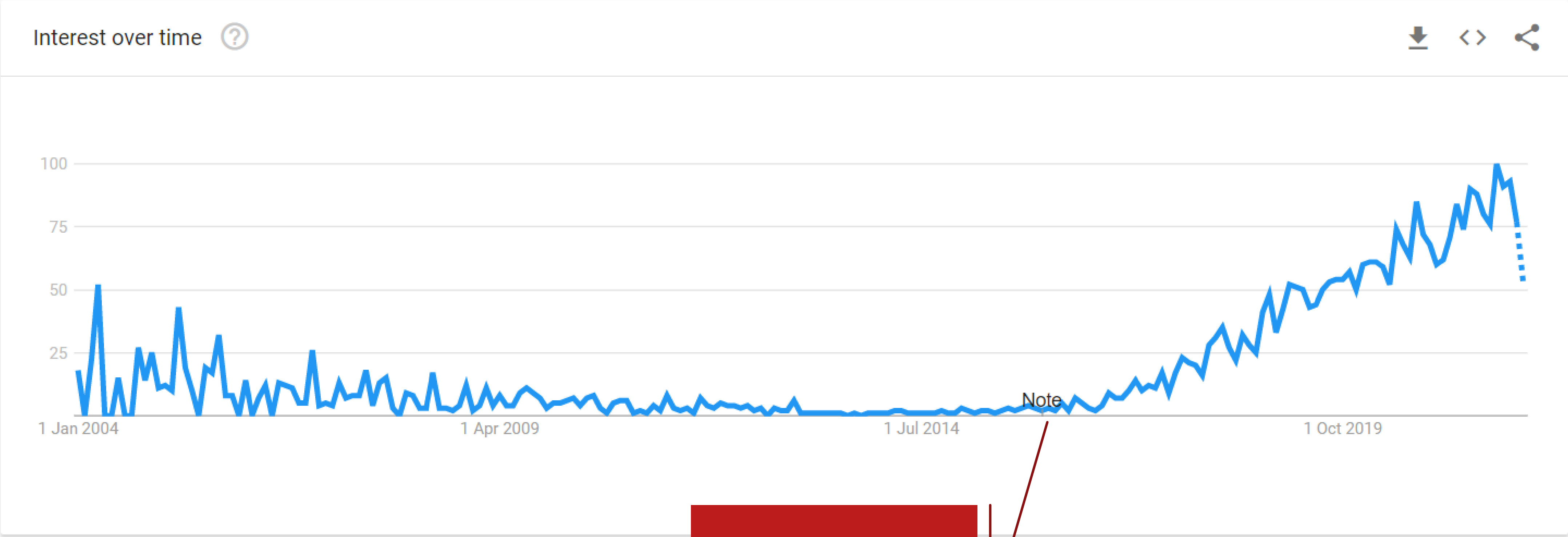

Legend:
Topic / Theme
Note
Already Published
Planned / Future Publication
Out of Scope
A Multi-Paradigm Modelling Foundation for Twinning (Systems Engineering)
Related Work (RW)
MPM Principles
Twinning Paradigm
Research Questions (RQ)
Which is better? With or without twinning?
To Twin or Not To Twin?
What is Twinning?
How to map twinning? => Feature models
Contributions
MPM
TFSA>(ODE+LCC) WSC 2021
FTG+PM++ for LFR ???
CLAVS / ODVS WSC 2023
GPSS2DEVS WSC 2020
Twinning Paradigm
FTG+PM++ ANNSIM 2022
Workflows
???
DigZ ModDiT (MoDELS) 2022
Experiments
Architectures
Higher-Order Twins (HOT)
Life Cycle Arch + Federation SoSyM 2023
DEVS model ANNSIM/SoSyM?
PyPDEVS tutorial WSC 2020
PyPDEVS tutorial WSC 2023
Workflows / Architectures / Deployment
Feature Models
Cost Models
with TPR?
Maturity Models
LFR Warehouse MPM4CPS (MoDELS) 2023
LFR overview ???
WF/arch IN4PL 2021
Goals: Anomaly detection Fault diagnosis Dashboarding Optimalization (Different feedback loops)
LFR DS (first iteration) ANNSIM 2021
Models
LFR/AGV
Architectures
WF/arch IN4PL Springer 2023
Workflows
DEVS model ANNSIM?
Unity 3D
DEVS model SoSyM?
Representative Use-Cases
Models
Coordinate Systems: BD72 - WSG84
PoAB
Architectures
DEVS model ANNSIM?
Comparison RW/Contributions
Workflows
Conclusions / Future Work
Cost
Variability White Paper (PoAB)
Maturity Model



The Design and Architectures of Digital Twins

Randy Paredis

Image generated with DALL-E 2 using "alan alda meeting himself as a robot digital art" as prompt.



Better system for data collection

Accessed: 7 January 2022

Country-Relative Popularity Scale:
100 = most popular,
50 = half as popular

Interest by region

Region

Rank	Region	Interest
1	South Korea	100
2	St Helena	46
3	Singapore	37
4	Hong Kong	22
5	Norway	21
6	Germany	20
7	Finland	17
8	Austria	17
9	Switzerland	15
10	United Arab Emirates	13
11	Netherlands	13
12	Japan	13
13	China	12
14	Taiwan	12
15	Belgium	11

Accessed: 7 January 2022

Application Domains

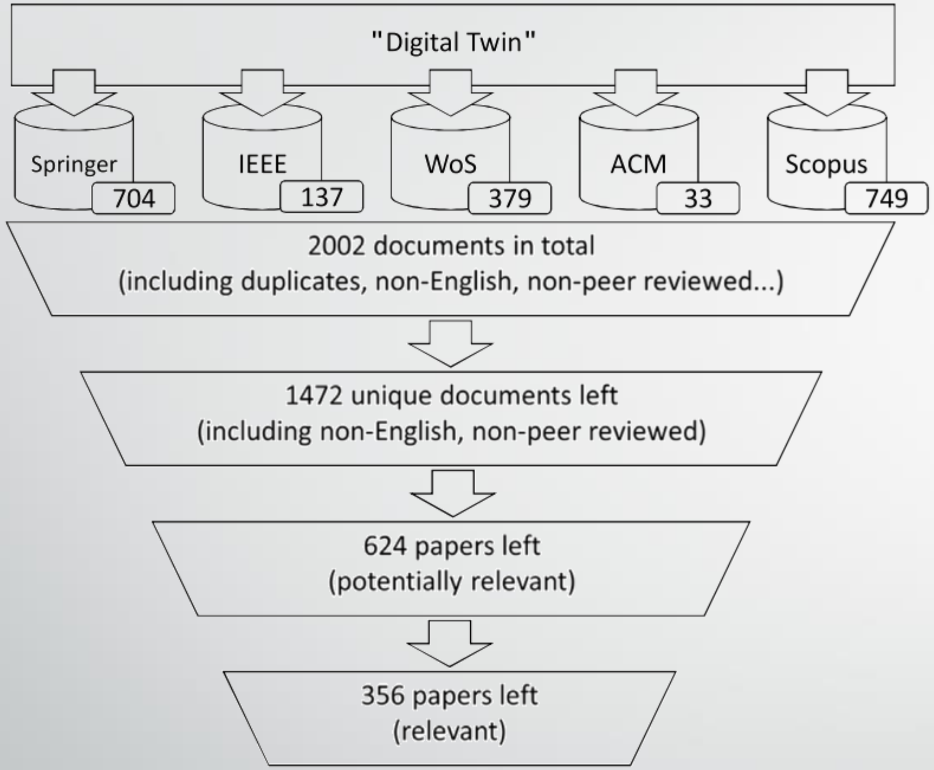


Fig. 2. Data collection initially produced 1472 unique documents, out of which 356 were identified as relevant for our study.

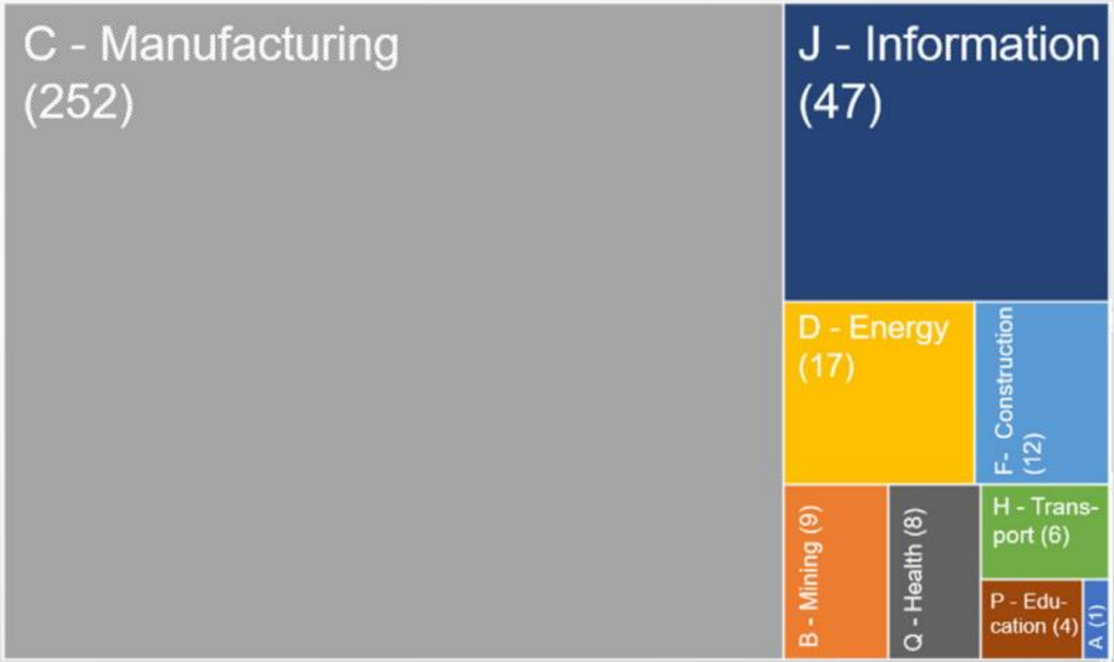


Fig. 5. Application domains of Digital Twins.

M. Dalibor, N. Jansen, B. Rumpe, D. Schmalzing, L. Wachtmeister, M. Wimmer and A. Wortmann. 2022. "*A cross-domain systematic mapping study on software engineering for digital twins*". *Journal of Systems and Software* vol 193. pp.111361.

Digital Twins consist of three components, a physical product, a virtual representation of that product, and the bi-directional data connections that feed data from the physical to the virtual representation, and information and processes from the virtual representation to the physical. **[1]**

The **Digital Twin** is a set of virtual information constructs that fully describes a potential or actual physical manufactured product from the micro atomic level to the macro geometrical level. At its optimum, any information that could be obtained from inspecting a physical manufactured product can be obtained from its Digital Twin. **[2]**

A **Digital Twin** is an integrated multi-physics, multi-scale, probabilistic simulation of a vehicle or system that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its flying twin. The digital twin is ultra-realistic and may consider one or more important and interdependent vehicle systems. **[5]**

Digital Twins are a virtual representation of the physical objects, processes and real-time data involved throughout a product life-cycle. **[3]**

A **Digital Twin** is an ultra-realistic virtual counterpart of a real-world object. **[4]**

A **Digital Twin** is a coupled model of the real machine that operates in the cloud platform and simulates the health condition with an integrated knowledge from both data driven analytical algorithms as well as other available physical knowledge. **[7]**

A **Digital Twin** is an ultra-realistic, cradle-to-grave computer model of an aircraft structure that is used to assess the aircraft's ability to meet mission requirements. **[6]**

Digital Twins is a unified system model that can coordinate architecture, mechanical, electrical, software, verification, and other discipline-specific models across the system lifecycle, federating models in multiple vendor tools and configuration-controlled. **[8]**

Digital Twins are software systems comprising data, models and services to interact with a CPPS for a specific purpose. **[9]**

... and many more!

[1] D. Jones et al. 2020. "*Characterising the Digital Twin: A systematic literature review*". In *CIRP Journal of Manufacturing Science and Technology*.
[2] M. Grieves. 2017. "*Digital Twin: Mitigating Unpredictable, Undesirable Emergent Behavior in Complex Systems*". In *Transdisciplinary Perspectives on Complex Systems*.
[3] W. D. Lin and M. Y. H. Low. 2019. "*Concept and implementation of a cyber-physical digital twin for a SMT line*". In *2019 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)*.
[4] H. Park et al. 2019. "*Challenges in Digital Twin Development for Cyber-Physical Production Systems*". In *Cyber-Physical Systems. Model-Based Design*.
[5] E. Glaessgen and D. Stargel. 2012. "*The digital twin paradigm for future NASA and U.S. Air Force vehicles*". In Proc. 53rd AIAA/ASME/ASCE/AHS/ASC Struct. Struct. Dyn. Mater. Conf.
[6] B. T. Gockel et al. 2012. "*Challenges with Structural Life Forecasting using Realistic Mission Profiles*". In *53rd AIAA/ASME/ASCE/AHS/ASC Struct. Struct. Dyn. Mater. Conf.*
[7] J. Lee. et al. 2013. "*Recent advances and trends in predictive manufacturing systems in big data environment*". In *Manufacturing Letter 1*.
[8] M. Bajaj, D. Zwemer and B. Cole. 2016. "*Integrating System Models with Architecture to Geometry*". In *AIAA Sp. Forum*.
[9] P. Bibow et al. 2020 "*Model-Driven Development of a Digital Twin for Injection Molding*". In *CAiSE 2020. LNCS*.

Digital Twin Definitions

A collection of definitions of digital twins

As a side result of the largest literature survey on digital twins to date,

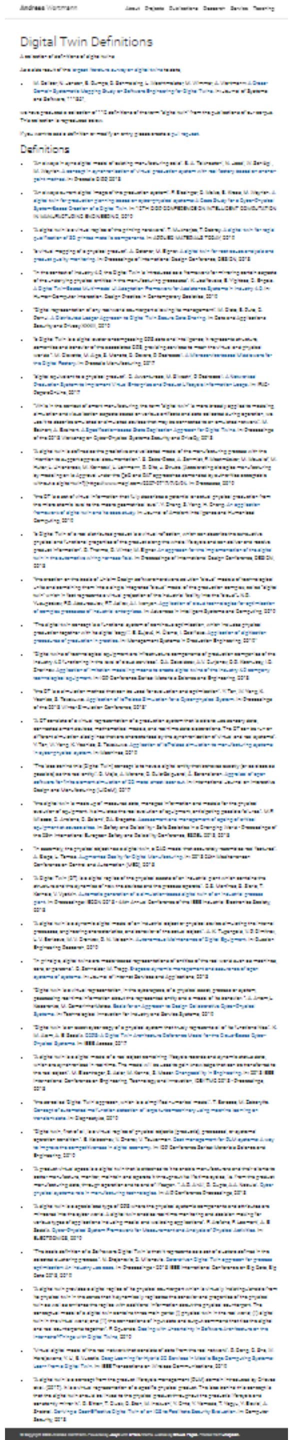
- M. Dalibor, N. Jansen, B. Rumpe, D. Schmalzing, L. Wachtmeister, M. Wimmer, A. Wortmann: A Cross-Domain Systematic Mapping Study on Software Engineering for Digital Twins. In: Journal of Systems and Software, 111361,

we have produced a collection of 112 definitions of the term “digital twin” from the publications of our corpus. This collection is reproduced below.

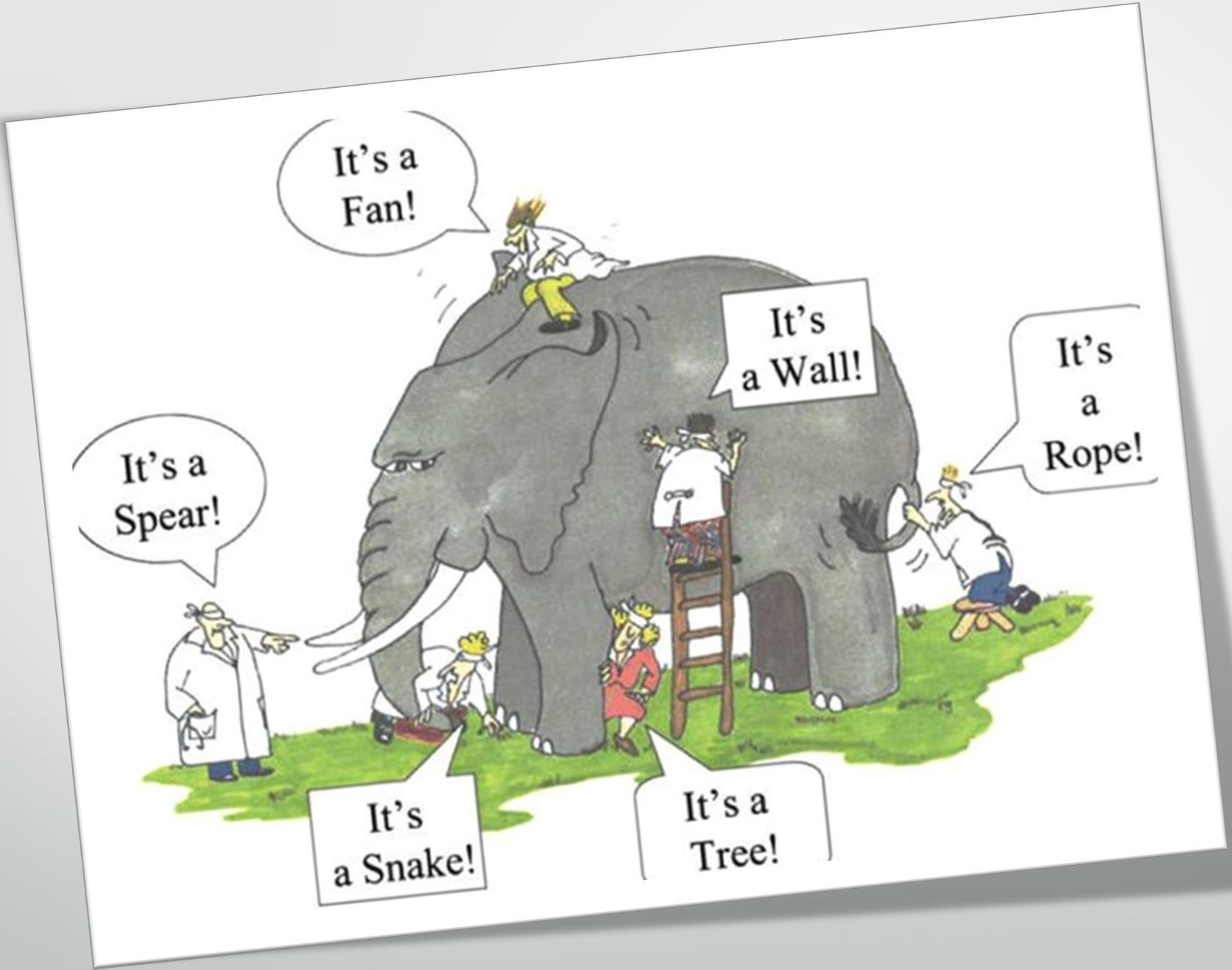
If you want to add a definition or modify an entry, please create a pull request.

Definitions

- “An always in sync digital model of existing manufacturing cells”. B. A. Talkhestani, N. Jazdi, W. Schlögl , M. Weyrich. A concept in synchronization of virtual production system with real factory based on anchor-point method. In: Procedia CIRP, 2018
- “An always current digital image of the production system”. F. Biesinger, D. Meike, B. Krass, M. Weyrich. A digital twin for production planning based on cyber-physical systems: A Case Study for a Cyber-Physical System-Based Creation of a Digital Twin. In: 12TH CIRP CONFERENCE ON INTELLIGENT COMPUTATION IN MANUFACTURING ENGINEERING, 2019



https://awortmann.github.io/research/digital_twin_definitions/



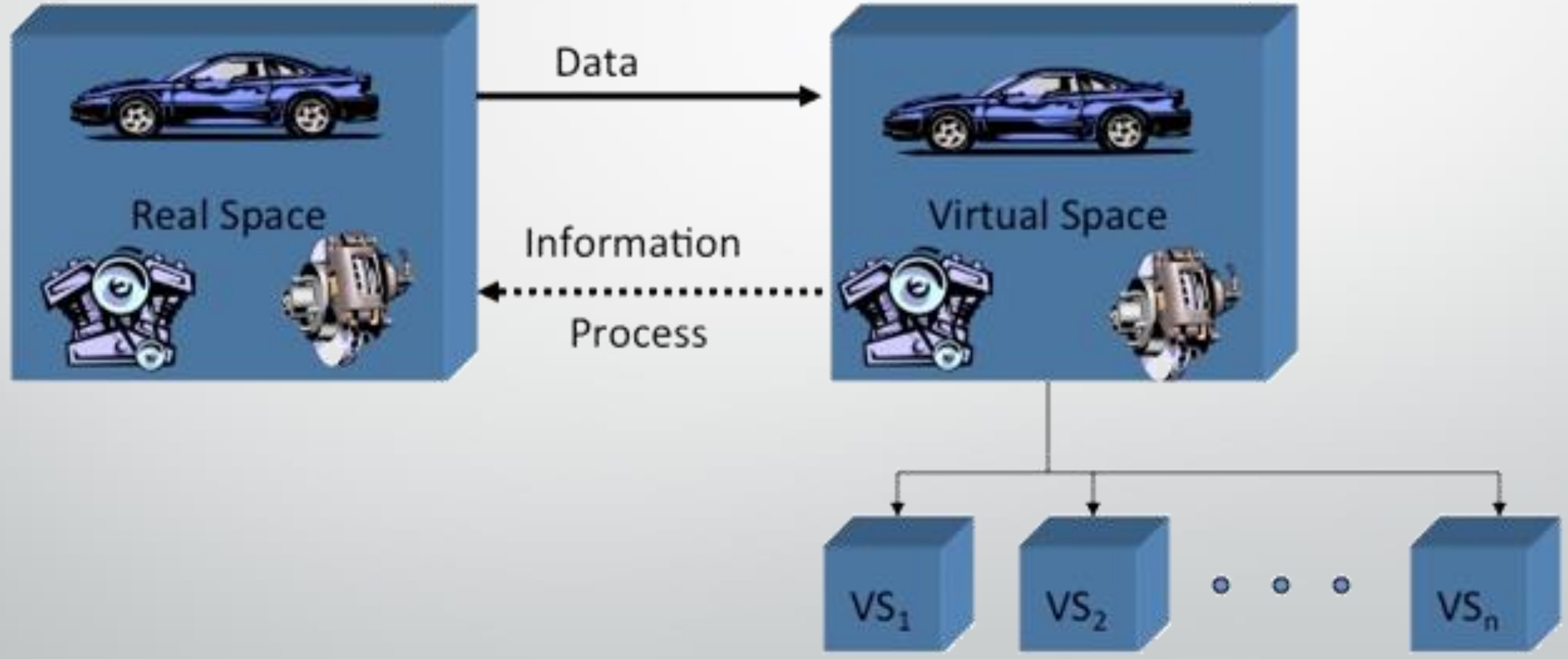
"*Blind Men and the Elephant*", John Godfrey Saxe (1816-1887)
Artist: G. Renee Guzlas

Architecture Models

Refining the Idea

2002

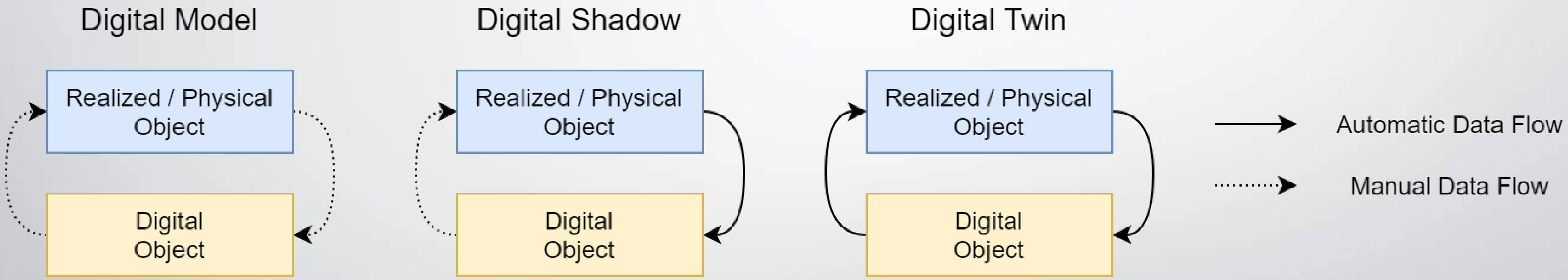
Conceptual Ideal for PLM



M. Grieves. 2016. "*Origins of the Digital Twin Concept*".

Digital Twin Variants

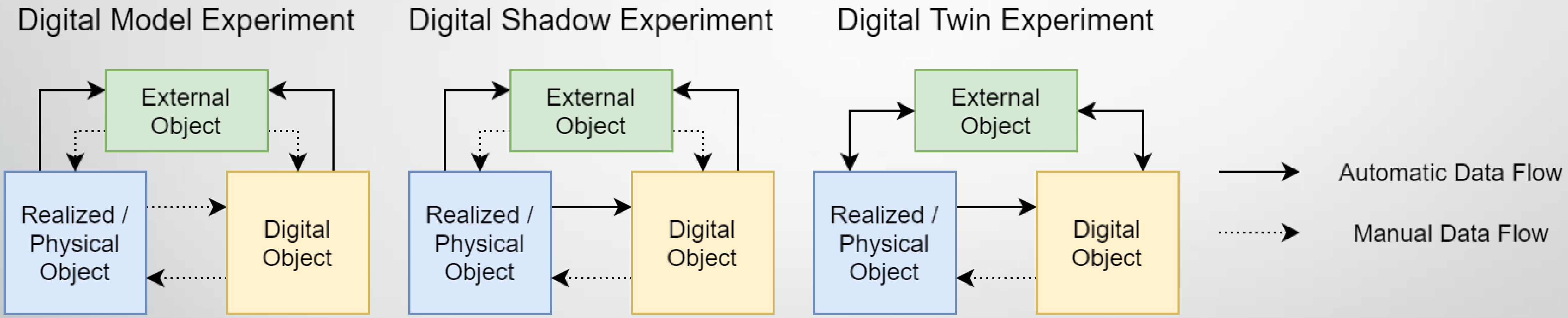
2018



W. Kritzinger, M. Karner, G. Traar, J. Henjes, and W. Sihn. 2018. "*Digital Twin in Manufacturing: A Categorical Literature Review and Classification*". *IFAC-PapersOnLine* vol. 51 (11), pp. 1016–1022.

Digital Twin Variants: Digital X

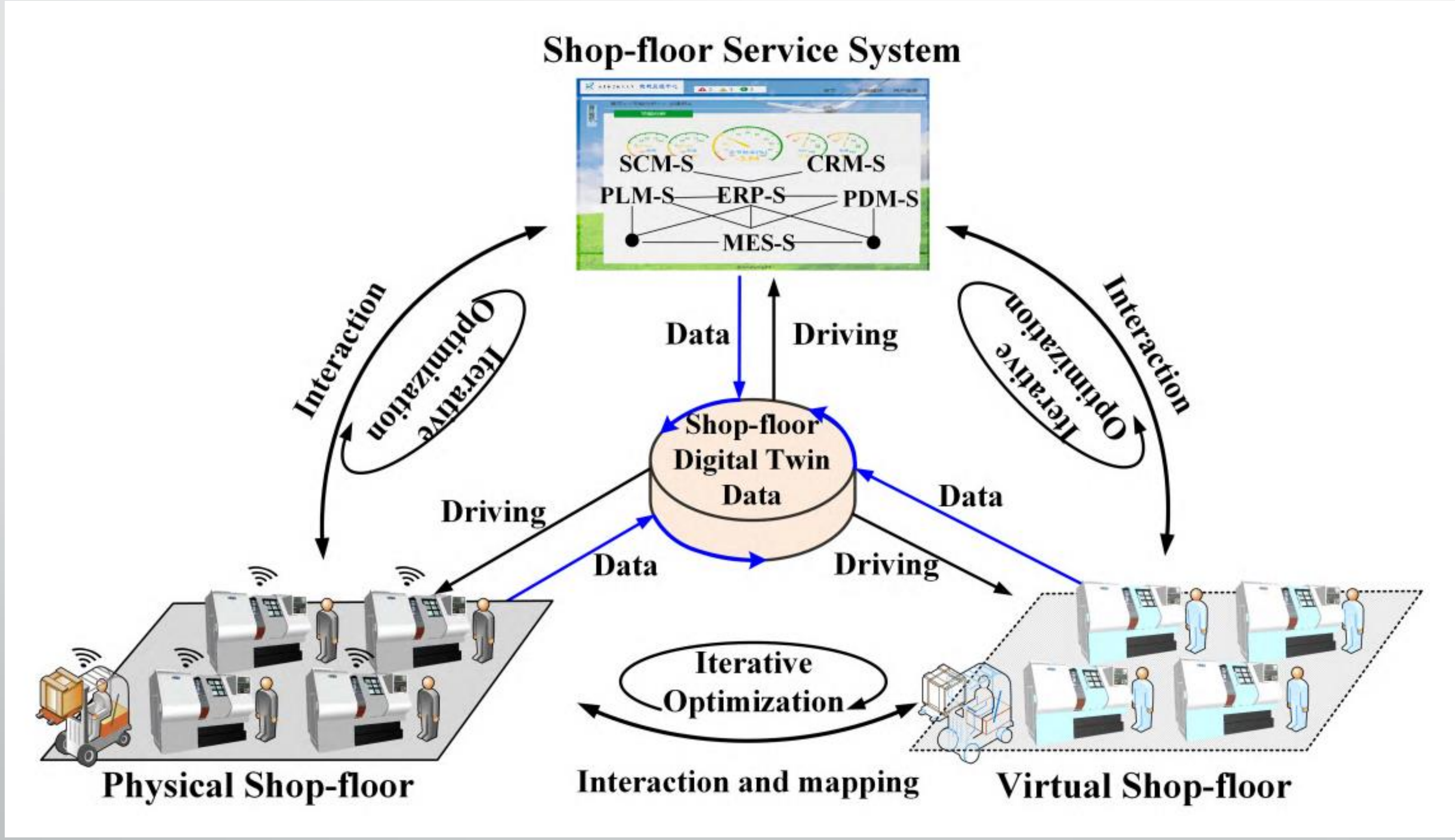
2021



R. Paredis, C. Gomes and H. Vangheluwe. 2021. "*Towards a Family of Digital Model/Shadow/Twin Workflows and Architectures*". In *Proceedings of the 2nd IN4PL*, pp. 174-182 .

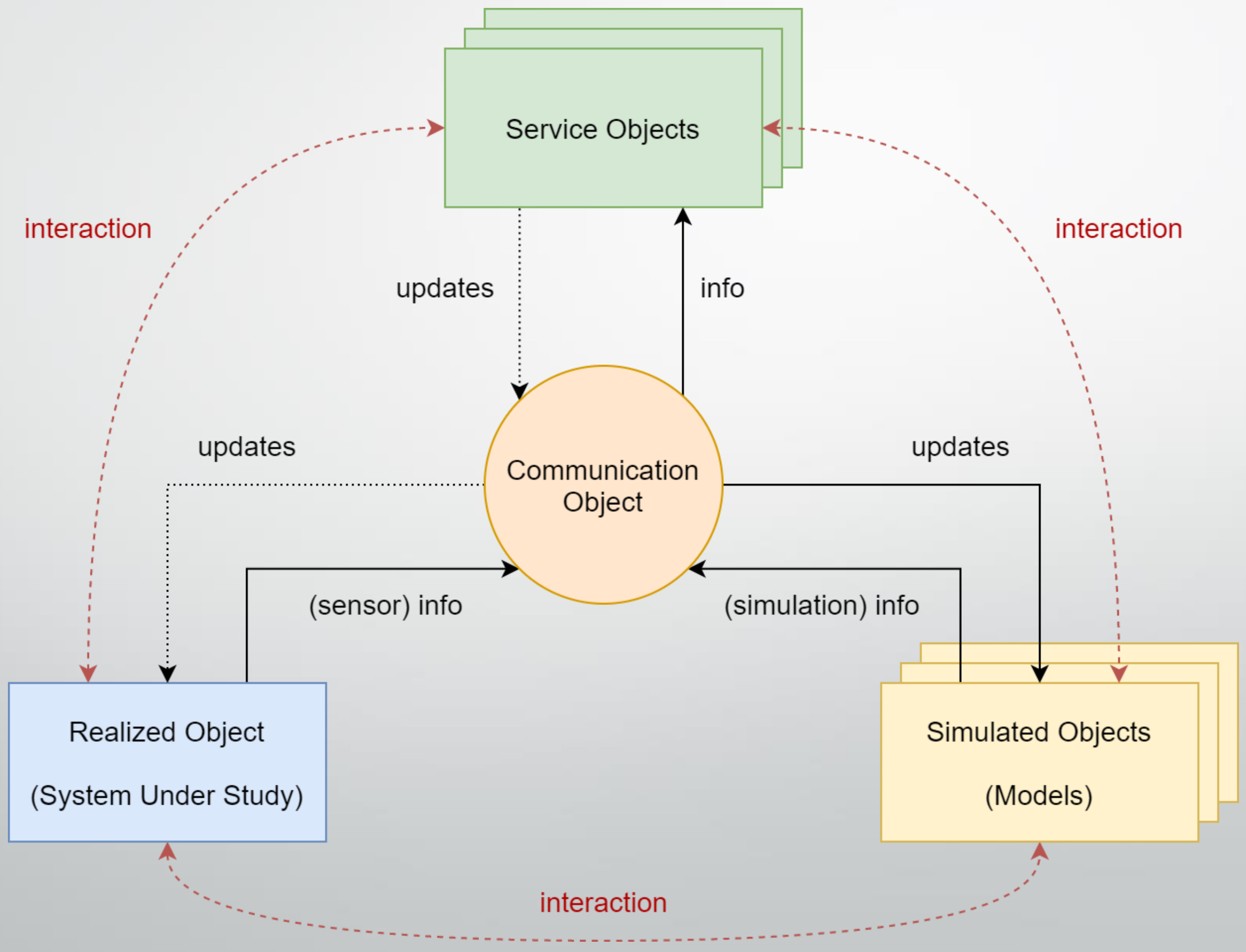
Digital Twin 5D Model

2017



F. Tao and M. Zhang. 2017. "*Digital Twin Shop-Floor: A New Shop-Floor Paradigm Towards Smart Manufacturing*". In *IEEE Access*, pp. 20418-20427 .

Digital Twin Adapted 5D Model

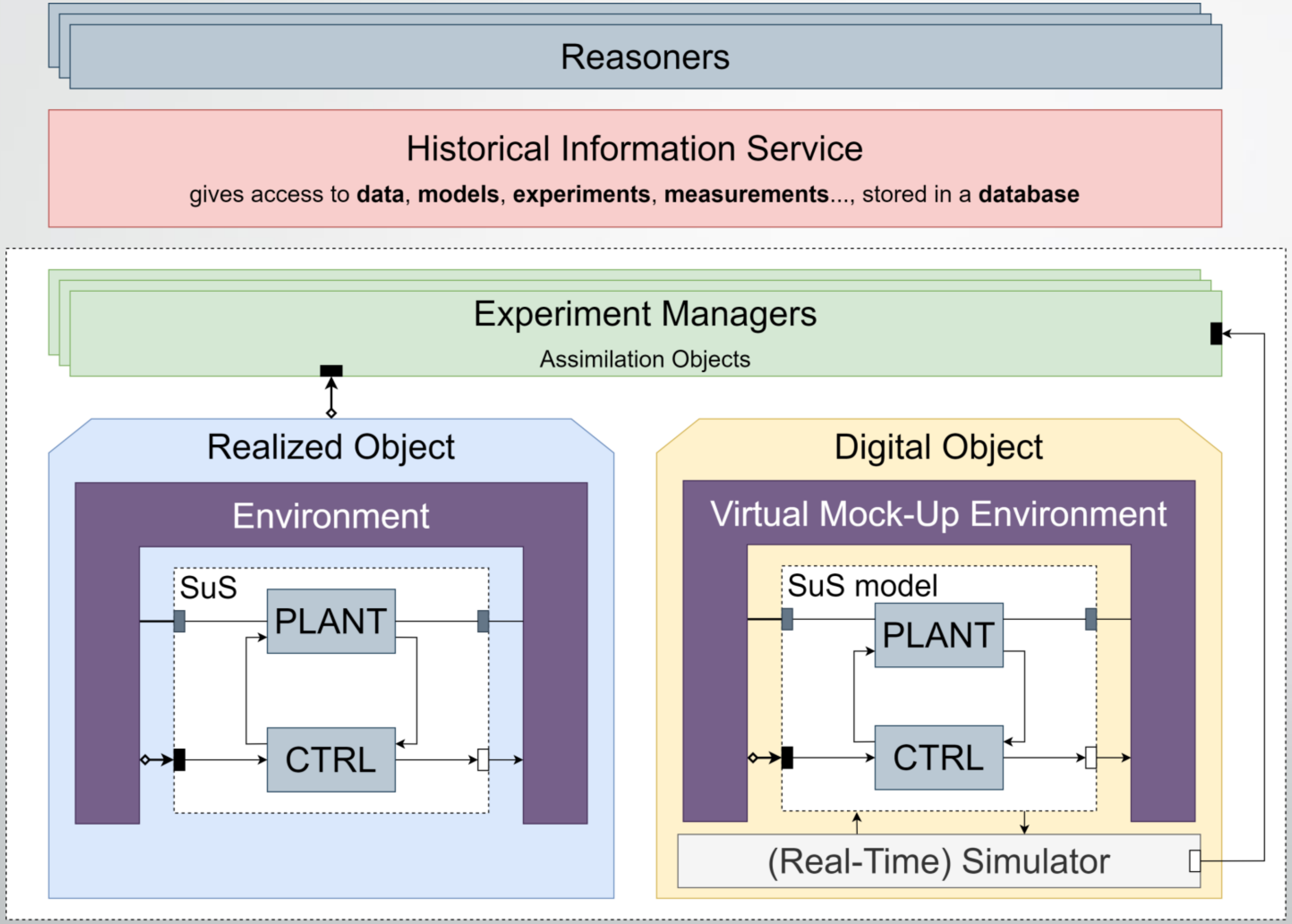


Variability

Choices, choices, choices.

Digital Model

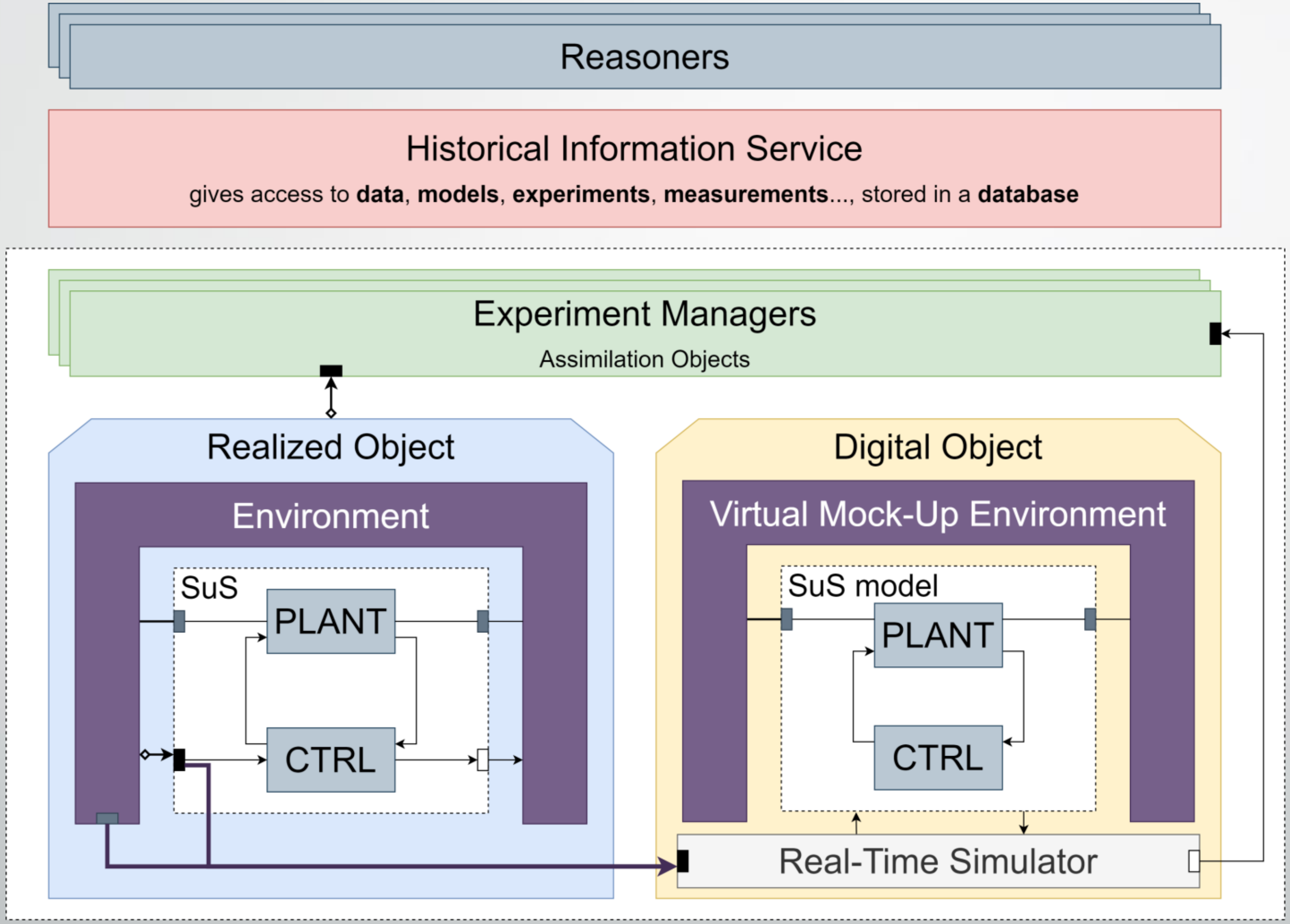
2022



R. Paredis and H. Vangheluwe. 2022. "*Towards a Digital Z Framework Based on a Family of Architectures and a Virtual Knowledge Graph*". In *Proceedings of the 25th MoDELS*, pp. 491-496.

Digital Shadow

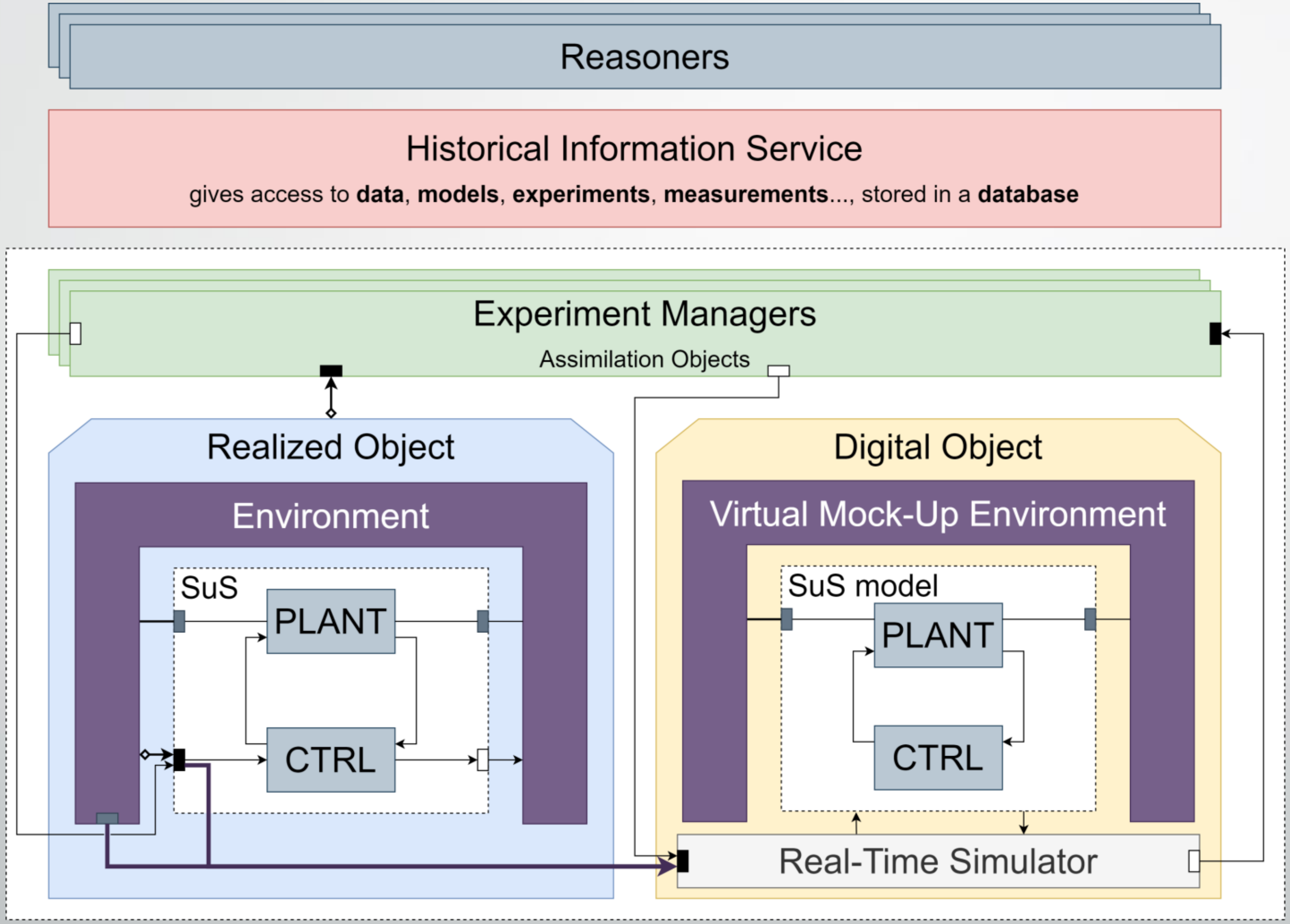
2022



R. Paredis and H. Vangheluwe. 2022. "*Towards a Digital Z Framework Based on a Family of Architectures and a Virtual Knowledge Graph*". In *Proceedings of the 25th MoDELS*, pp. 491-496.

Digital Twin

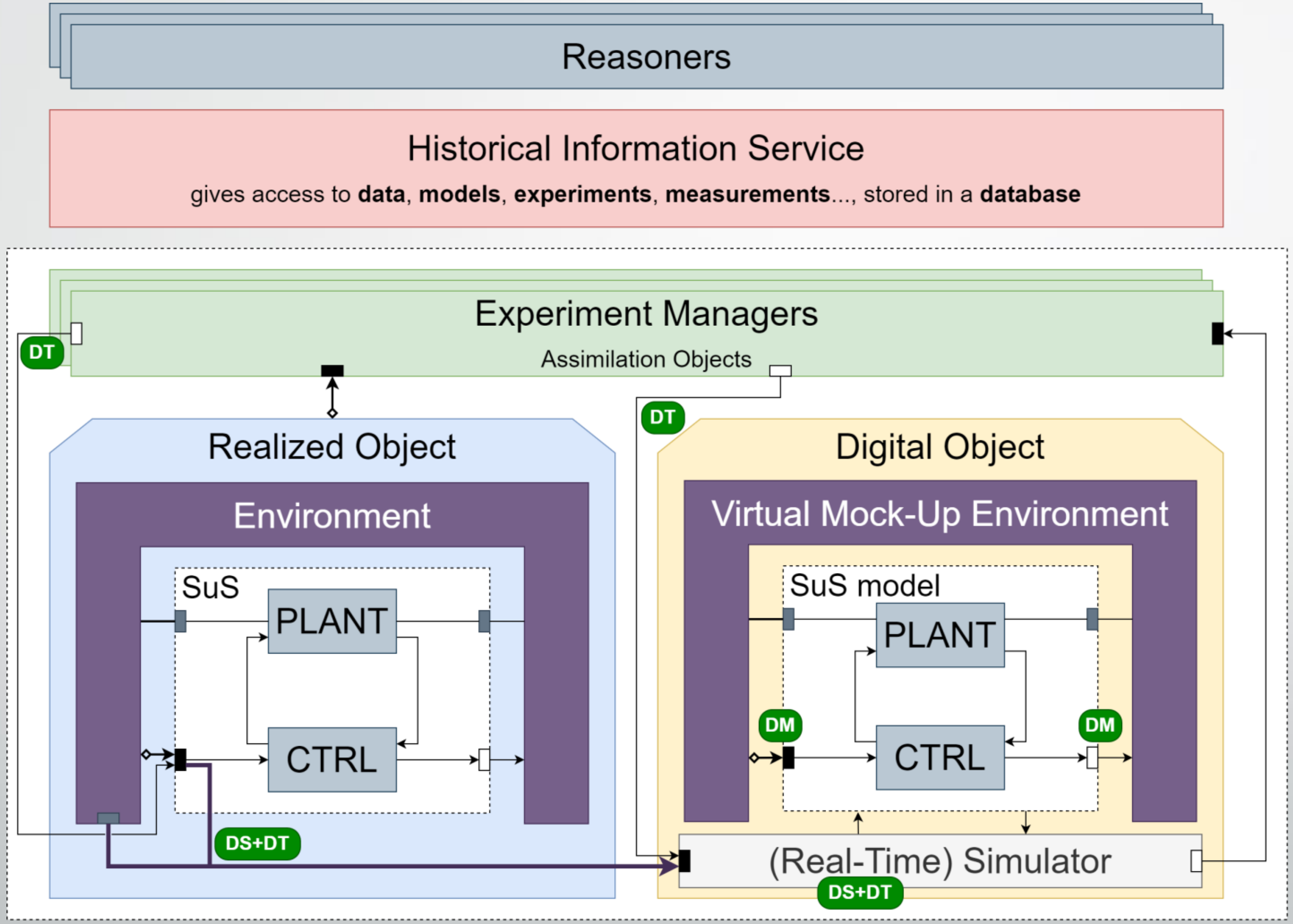
2022



R. Paredis and H. Vangheluwe. 2022. "*Towards a Digital Z Framework Based on a Family of Architectures and a Virtual Knowledge Graph*". In *Proceedings of the 25th MoDELS*, pp. 491-496.

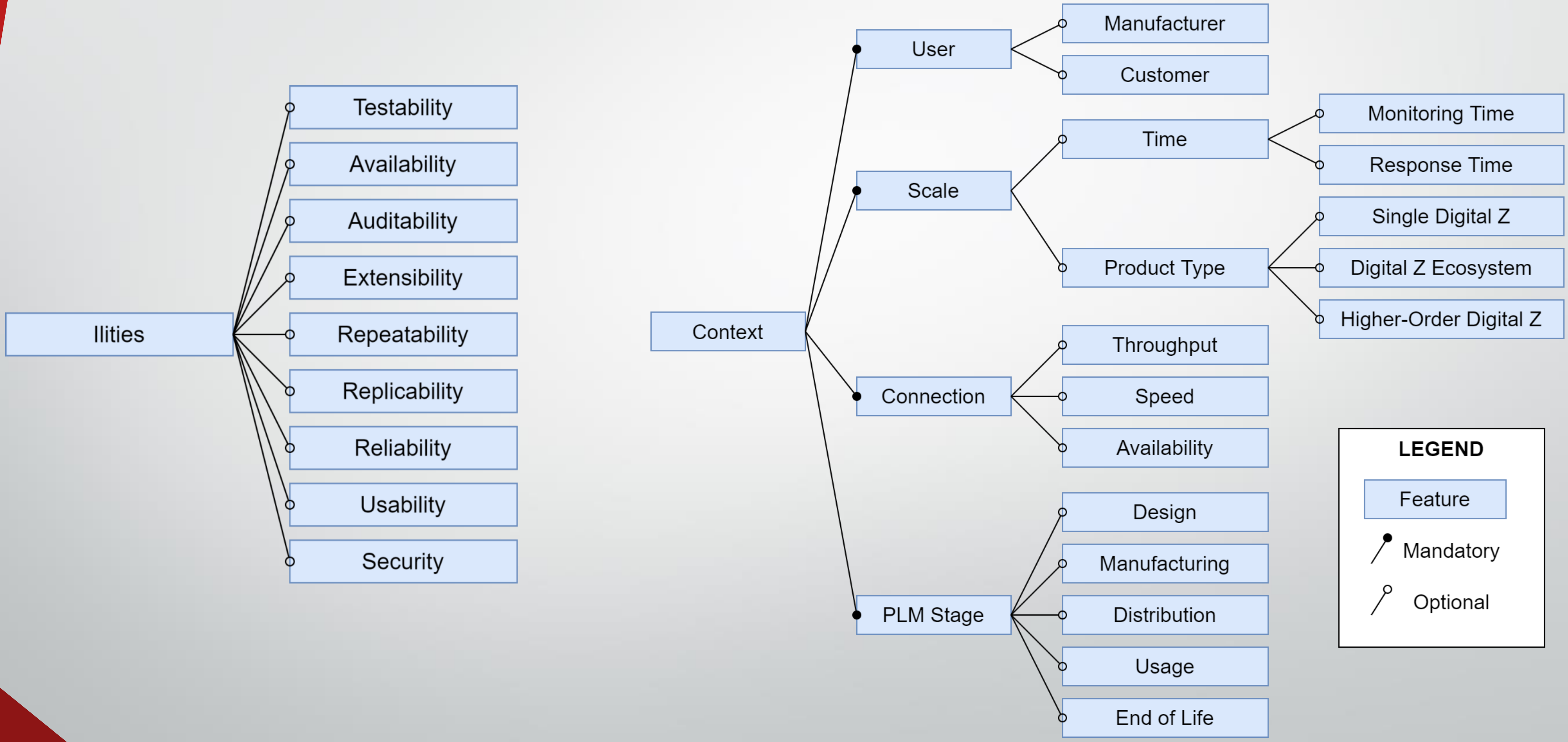
Digital T Architecture Variability

2022



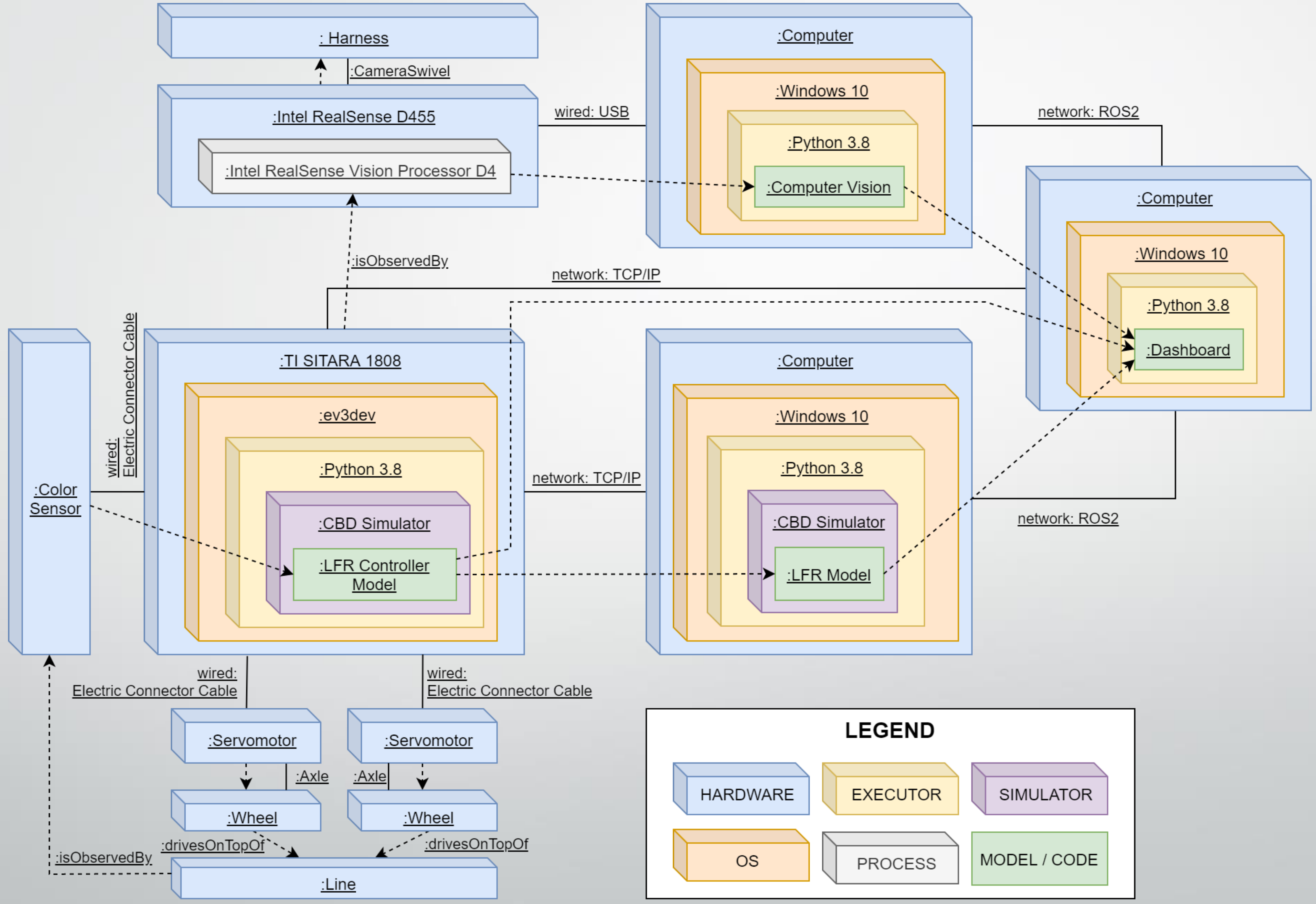
R. Paredis and H. Vangheluwe. 2022. "*Towards a Digital Z Framework Based on a Family of Architectures and a Virtual Knowledge Graph*". In *Proceedings of the 25th MoDELS*, pp. 491-496.

PoI Variability



R. Paredis, C. Gomes and H. Vangheluwe. 2023. "*A Family of Digital T Workflows and Architectures: Exploring Two Cases*". In *Communications in Computer and Information Science, vol 1855 - Innovative Intelligent Industrial Production and Logistics (IN4PL)*, Springer, pp. 93-109.

Deployment Variability

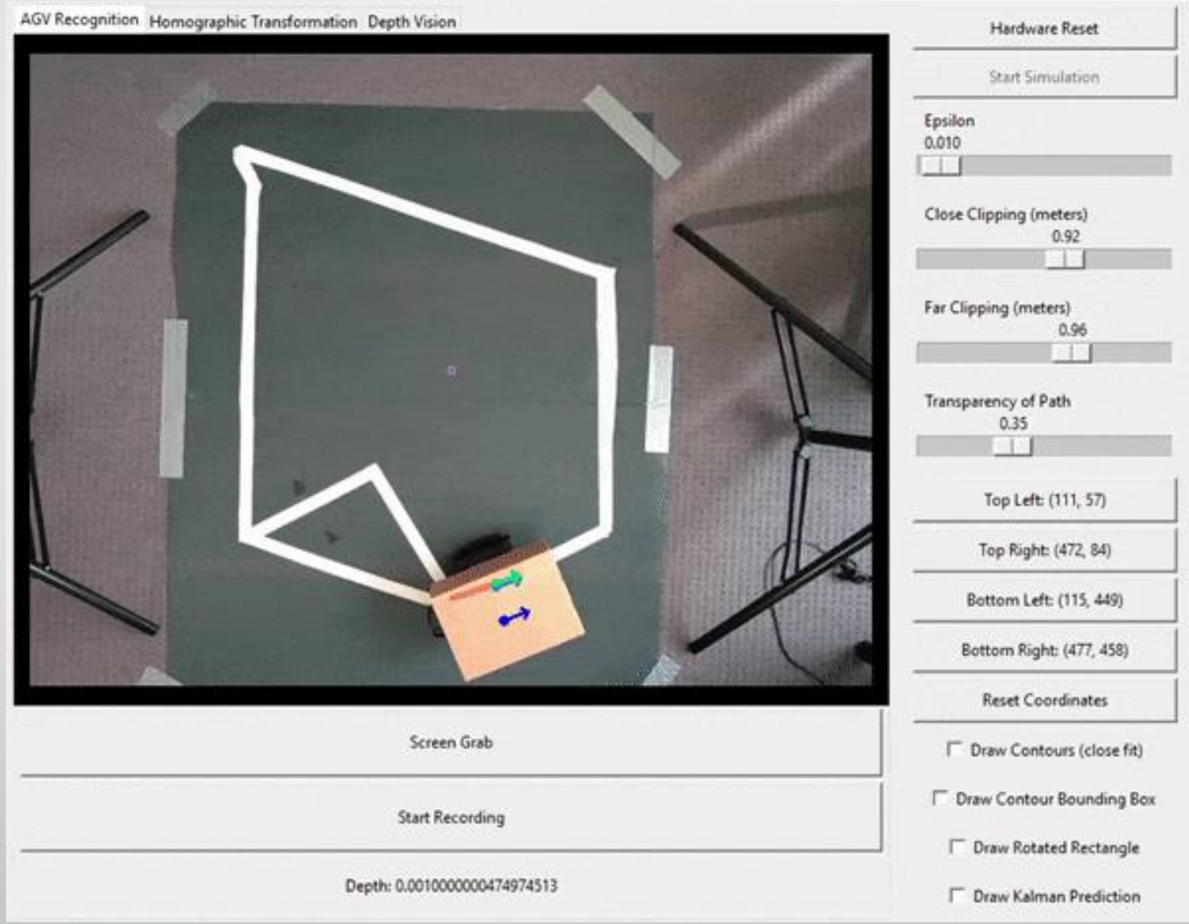


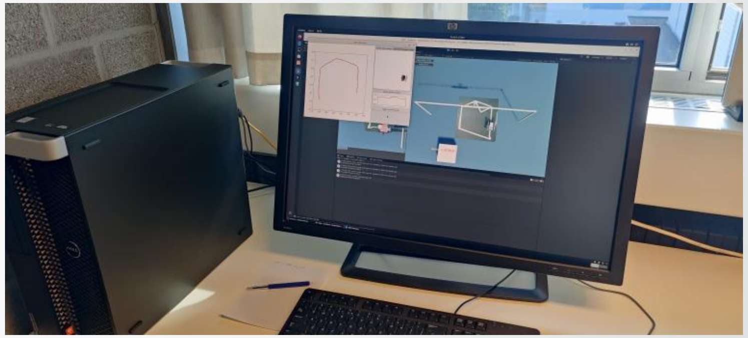
R. Paredis, C. Gomes and H. Vangheluwe. 2023. "*A Family of Digital T Workflows and Architectures: Exploring Two Cases*". In *Communications in Computer and Information Science, vol 1855 - Innovative Intelligent Industrial Production and Logistics (IN4PL)*, Springer, pp. 93-109.

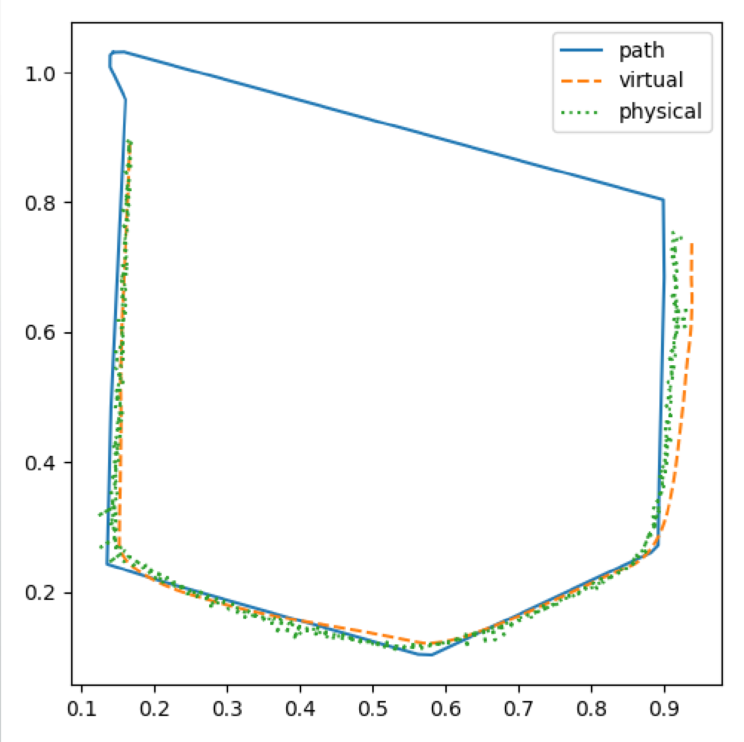
Some Use Cases

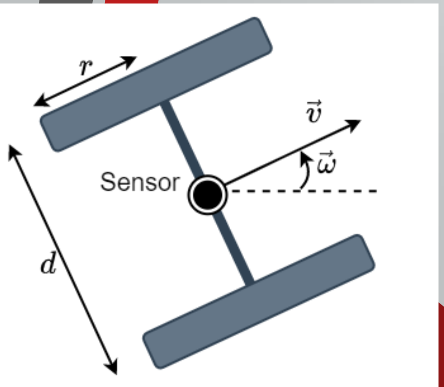
Twinning in the Wild

AGV/LFR Digital Shadow



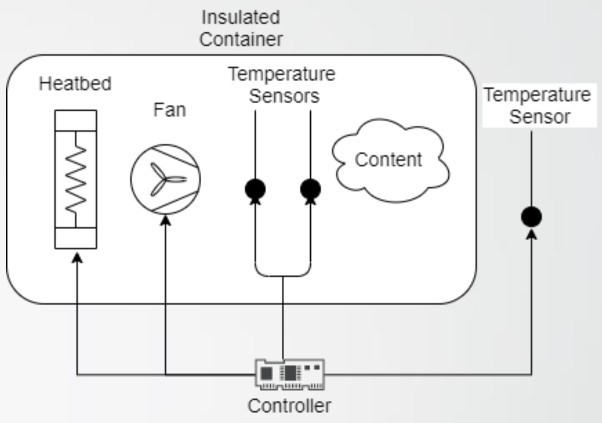


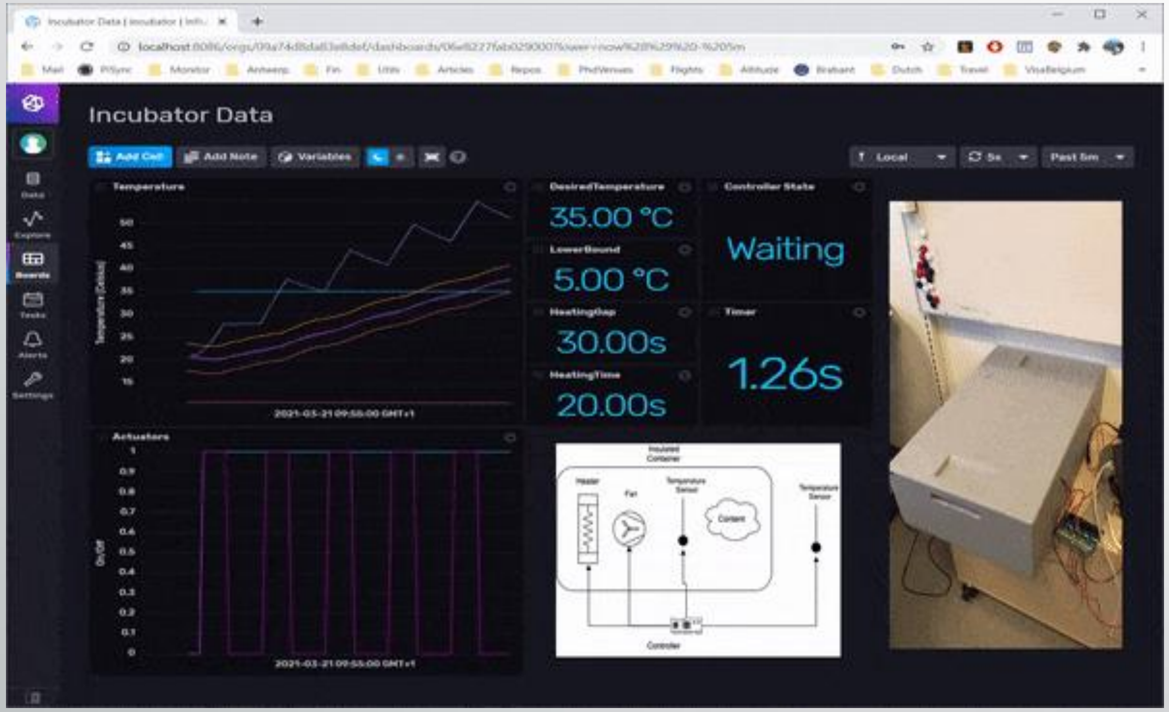


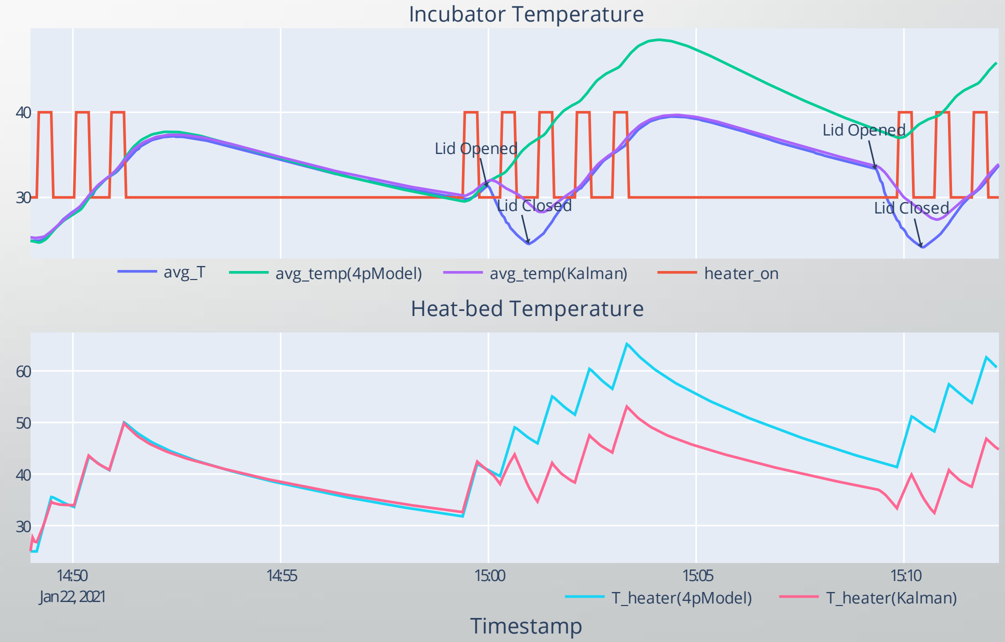


Paredis, R. and H. Vangheluwe. 2021. "*Exploring A Digital Shadow Design Workflow By Means Of A Line Following Robot Use-Case*". In *2021 Annual Modeling and Simulation Conference (ANNSIM)*.

Incubator Digital Twin







Feng, H., Gomes, C. a., Thule, C., Lausdahl, K., Iosifidis, A., and P. G. Larsen. 2021. "*Introduction To Digital Twin Engineering*". In *2021 Annual Modeling and Simulation Conference (ANNSIM)*.