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DTInsight: A Tool for Explicit, Interactive, and Continuous Digital Twin Reporting

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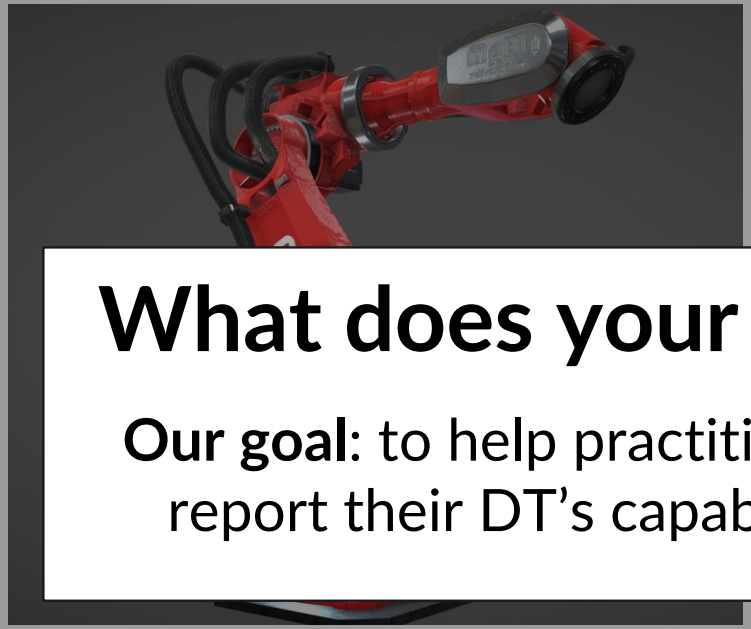
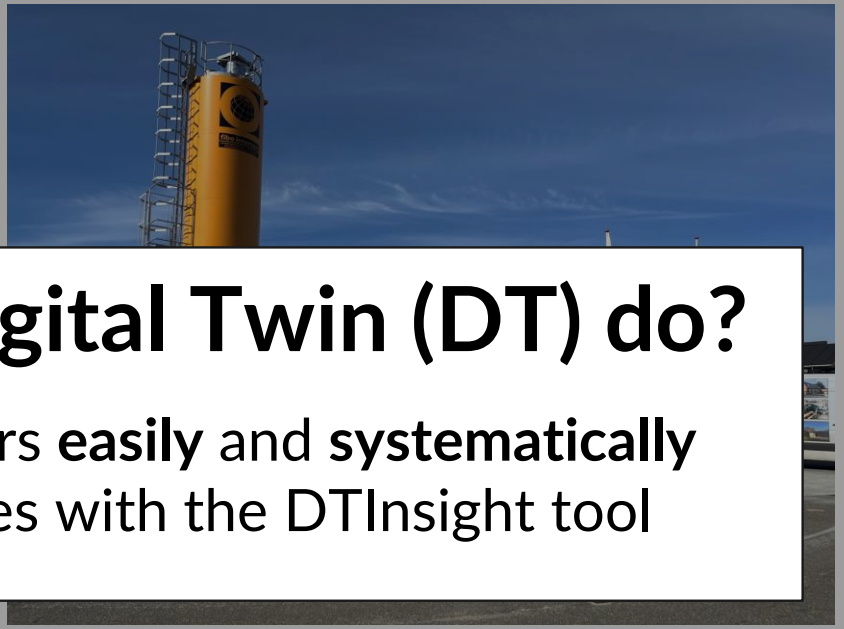




What does your Digital Twin (DT) do?

Our goal: to help practitioners **easily** and **systematically** report their DT's capabilities with the DTInsight tool

Robot arm
A Digital Shadow for Accurate Robot Motion Control: Integrating Data with Friction Models, Heithoff *et al.*

Concrete mixer
Probabilistic Update Scheduling for Digital Twins: A Semi-Markov Approach, Andersen *et al.*

21 DT characteristics from previous work [1]

- **C1.** System under study
- **C2.** Physical acting components
- **C3.** Physical sensing components
- **C4.** Physical-to-virtual interaction
- **C5.** Virtual-to-physical interaction
- **C6.** DT services
- **C7.** Twinning time-scale
- **C8.** Multiplicities
- **C9.** Life-cycle stages
- **C10.** DT models and data
- **C11.** Tooling and enablers
- **C12.** DT constellation
- **C13.** Twinning process and DT evolution
- **C14.** Fidelity and validity considerations
- **C15.** DT technical connection
- **C16.** DT hosting/deployment
- **C17.** Insights and decision making
- **C18.** Horizontal integration
- **C19.** Data ownership and privacy
- **C20.** Standardization
- **C21.** Security and safety considerations

[1] Gil *et al.*. Toward a systematic reporting framework for Digital Twins: a cooperative robotics case study. *SIMULATION*. 2024

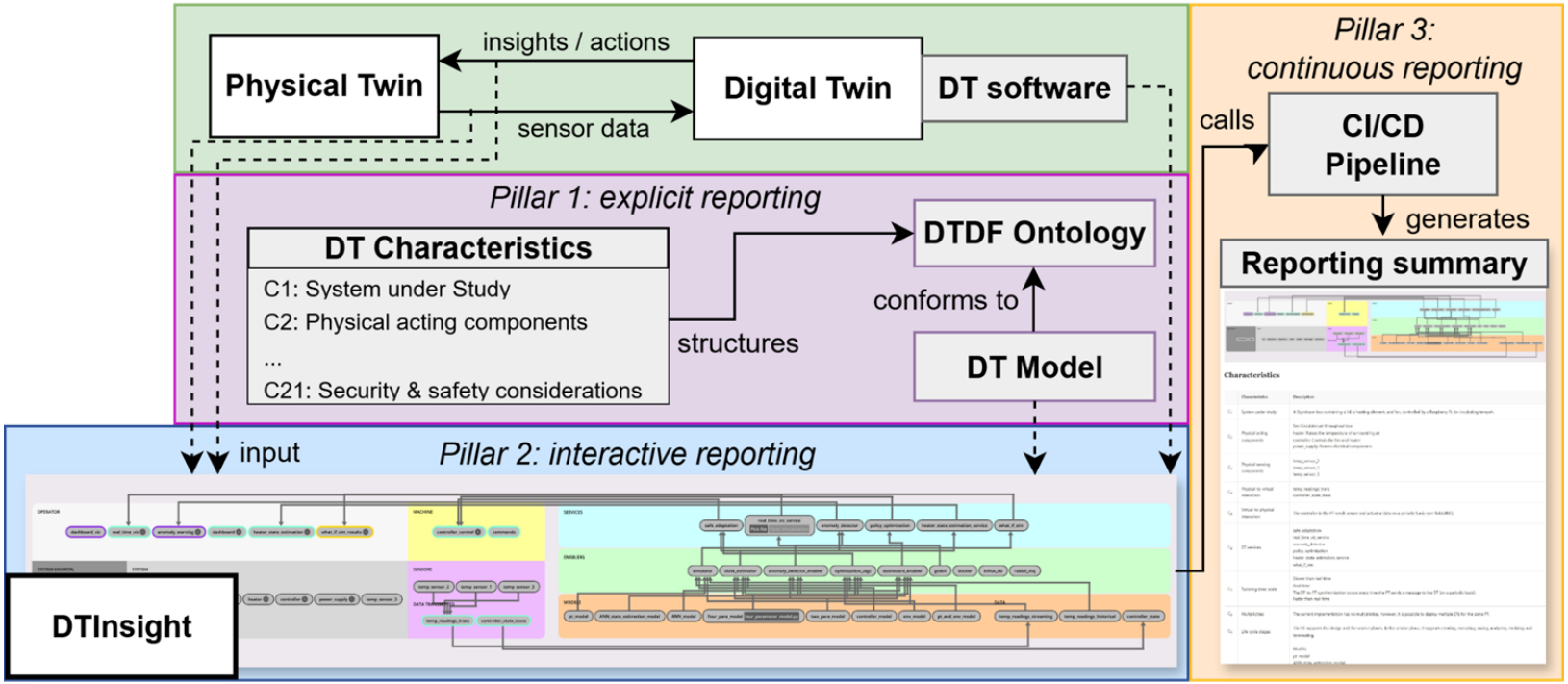
Research Questions

(1) How to make DT reporting **more formal & systematic**?

(2) How to easily explain a DT to **different stakeholders**?

(3) How to provide **continuous reports** of evolving DTs?

(1) Explicit (2) Interactive (3) Continuous



21 characteristics to describe a DT

- **C1.** System under study
- **C2.** Physical acting components
- ...
- **C21.** Security and safety considerations

(1) Explicit representation in **O**ntology **M**odeling **L**anguage

```
// C10: Models/Data
aspect Input
concept Model < DTComponent, Input
concept Data < DTComponent, Input

relation entity InputTo [
    from Input
    to Enabler
    forward inputTo
    reverse hasInput
]
```

OML vocabulary (concepts)

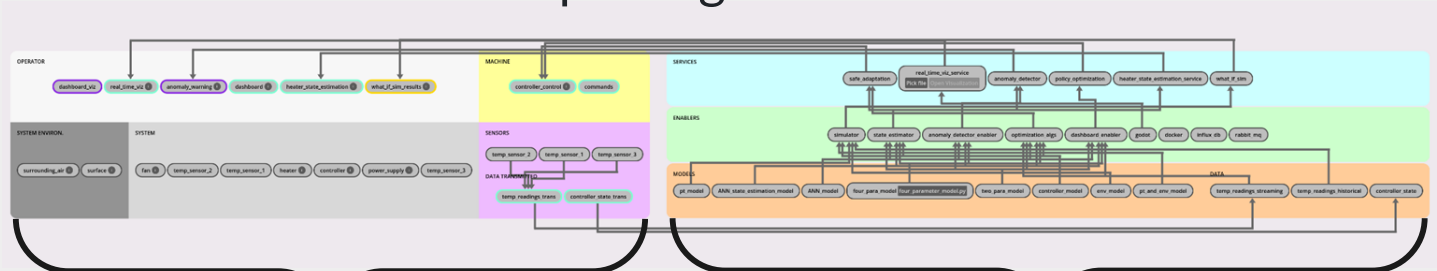
```
// MODELS / DATA
instance controller_model : DTDFVocab:Model [
    DTDFVocab:inputTo simulator
]
instance sensor_data_historical : DTDFVocab:Data
 [
    DTDFVocab:inputTo simulator, data_processing, data_fusion
    DTDFVocab:fromData aeroboat_pt:sensor_data
]

// C16: DT hosting/deployment
instance deployment : DTDFVocab:Deployment [
    base:desc "The Incubator DT is deployed locally on a LAN."
]
```

OML description (instances)

(2) **Interactive** DT Conceptual Architecture Visualization

DT constellation for reporting both **structure** and **behaviour**

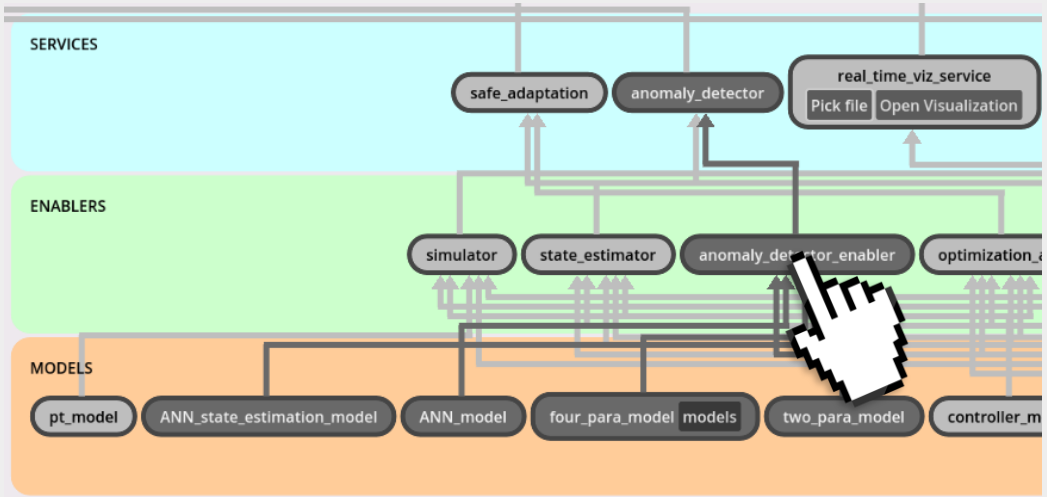


Physical Twin (left part):
Operator, Machine, System Environment, System, and Sensors/Data Transmission

Digital Twin (right part):
Models/Data, Enablers, and Services

(2) Interactive DT Conceptual Architecture Visualization

- Viz built in **open-source game engine** (Godot)
- Uses **SPARQL queries** to fetch the DT characteristics
- Example constellation is of the **incubator DT**

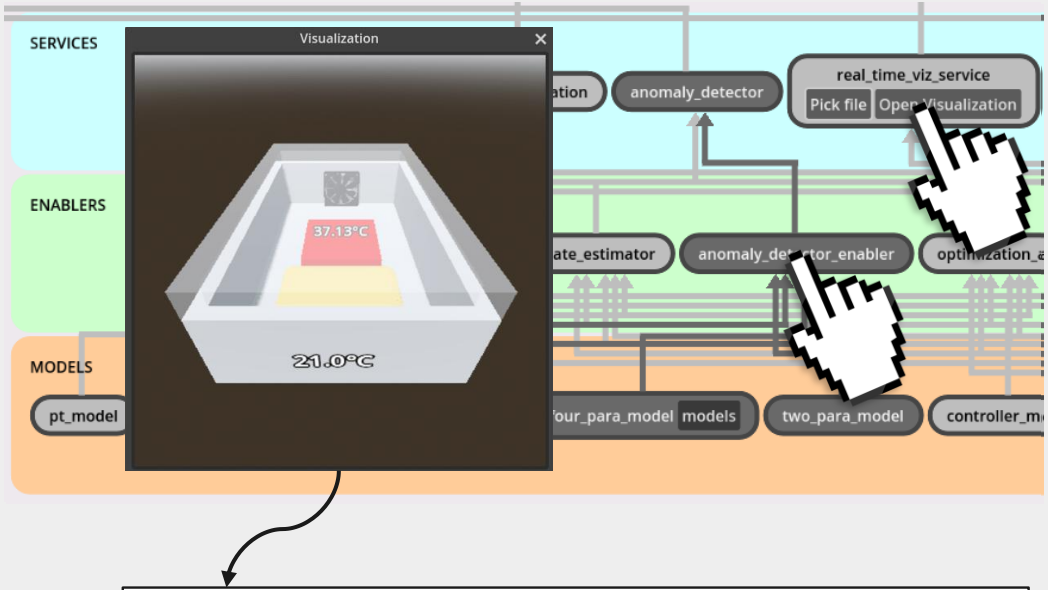


GODOT

Feng H *et al.* "The incubator case study for digital twin engineering", arXiv:2102.10390

(2) Interactive DT Conceptual Architecture Visualization

- Three main capabilities:
  - Hover to **explore data flows** between DT components
  - View DT component **scripts**
  - Visualize **real-time sensor data** (graphs or 3D)



Goal: Relating DT **structure** and **behaviour**

Interactive monitoring with RabbitMQ message broker

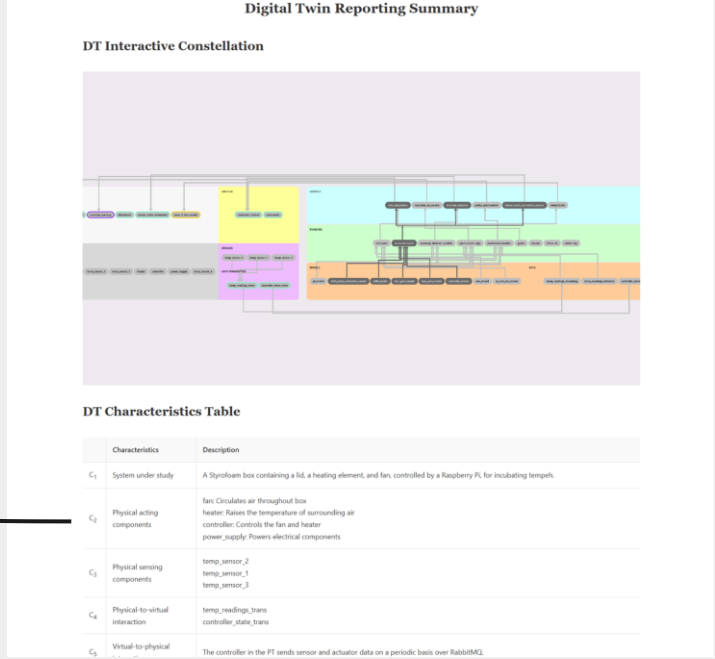
(3) Continuous Integration into a live reporting page

- **Continually** generated by a CI/CD pipeline to generate a reporting page website
- When the ontology representing the system changes, the **reporting page is re-generated**

(C6) DT services: *safe_adaptation, real_time_viz_service, anomaly_detector, policy_optimization, heater_state_estimation_service, what_if_sim*

(C20) Standardization: *Communication is carried out using AMQP standard via RabbitMQ. Behavioral models have been produced following the FMI standard version 2.*

GitHub Actions


Digital Twin Reporting Summary

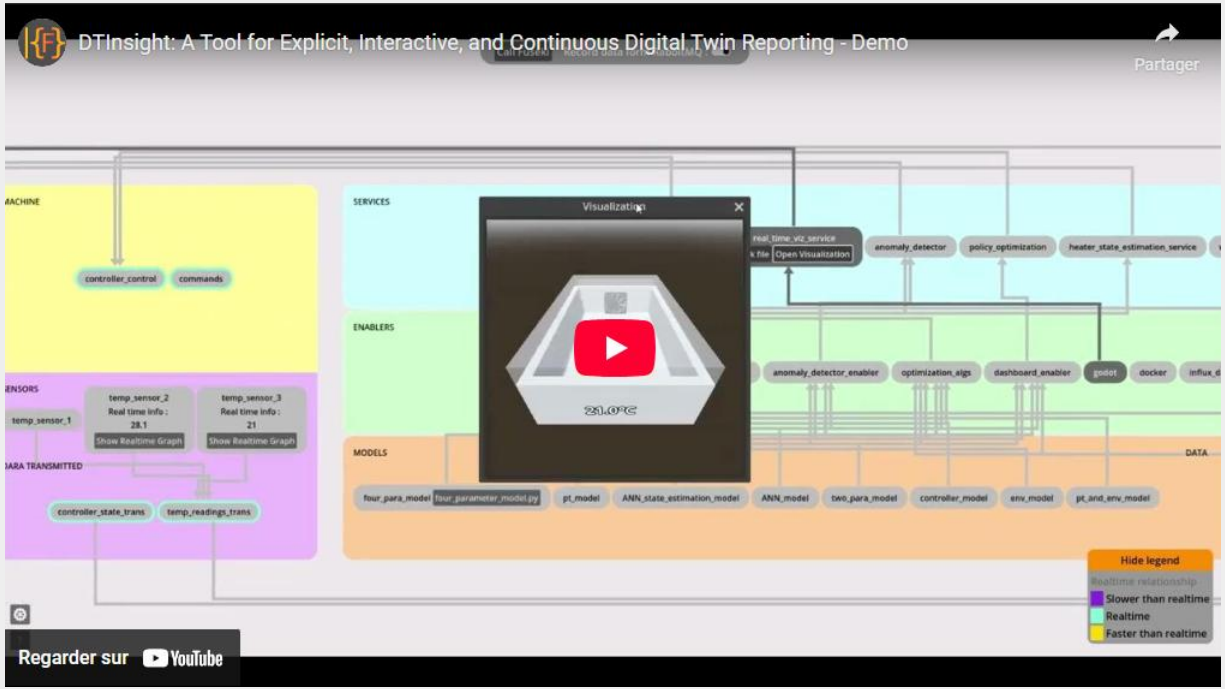
DT Interactive Constellation

DT Characteristics Table

	Characteristics	Description
C_1	System under study	A Styrofoam box containing a lid, a heating element, and fan, controlled by a Raspberry Pi, for incubating tempeh.
C_2	Physical acting components	fan: Circulates air throughout box heater: Raises the temperature of surrounding air controller: Controls the fan and heater power_supply: Powers electrical components
C_3	Physical sensing components	temp_sensor_2 temp_sensor_1 temp_sensor_3
C_4	Physical-to-virtual interaction	temp_readings_trans controller_state_trans
C_5	Virtual-to-physical	The controller in the PT sends sensor and actuator data on a periodic basis over RabbitMQ.

https://oakeslabmtl.github.io/DTDF/

Demo



https://www.youtube.com/watch?v=CD0pdK-eGXY

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Conclusion & Future Work

DTInsight improves stakeholder communication by making DT reporting:

1. **Explicit**: ontology-based modeling
2. **Interactive**: structural + behavioral architecture viz
3. **Continuous**: automated reporting page generation

Paper: https://arxiv.org/abs/2508.18431
Tool: https://github.com/oakeslabmtl/DTInsight

Future work:

- LLMs for ontology modeling
- Drag-and-drop reporting
- Expose further DT behaviour

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Any questions?