Cibus Tec 28 October 2026
The TOMATO conference
news

From Computational Fluid Dynamics to Predictive Control: Towards Digital Twins in Industrial Tomato Evaporation

Federico Solari
Department of Engineering for Industrial Systems and Technologies
University of Parma

UNIVERSITÀ DI PARMA

Monitoring and control of industrial processes

Performance (Efficiency) **Quality** **Safety**

REAL PROCESS

Physical sensors:
- Temperature
- Pressure
- Flow rate
- …
- …

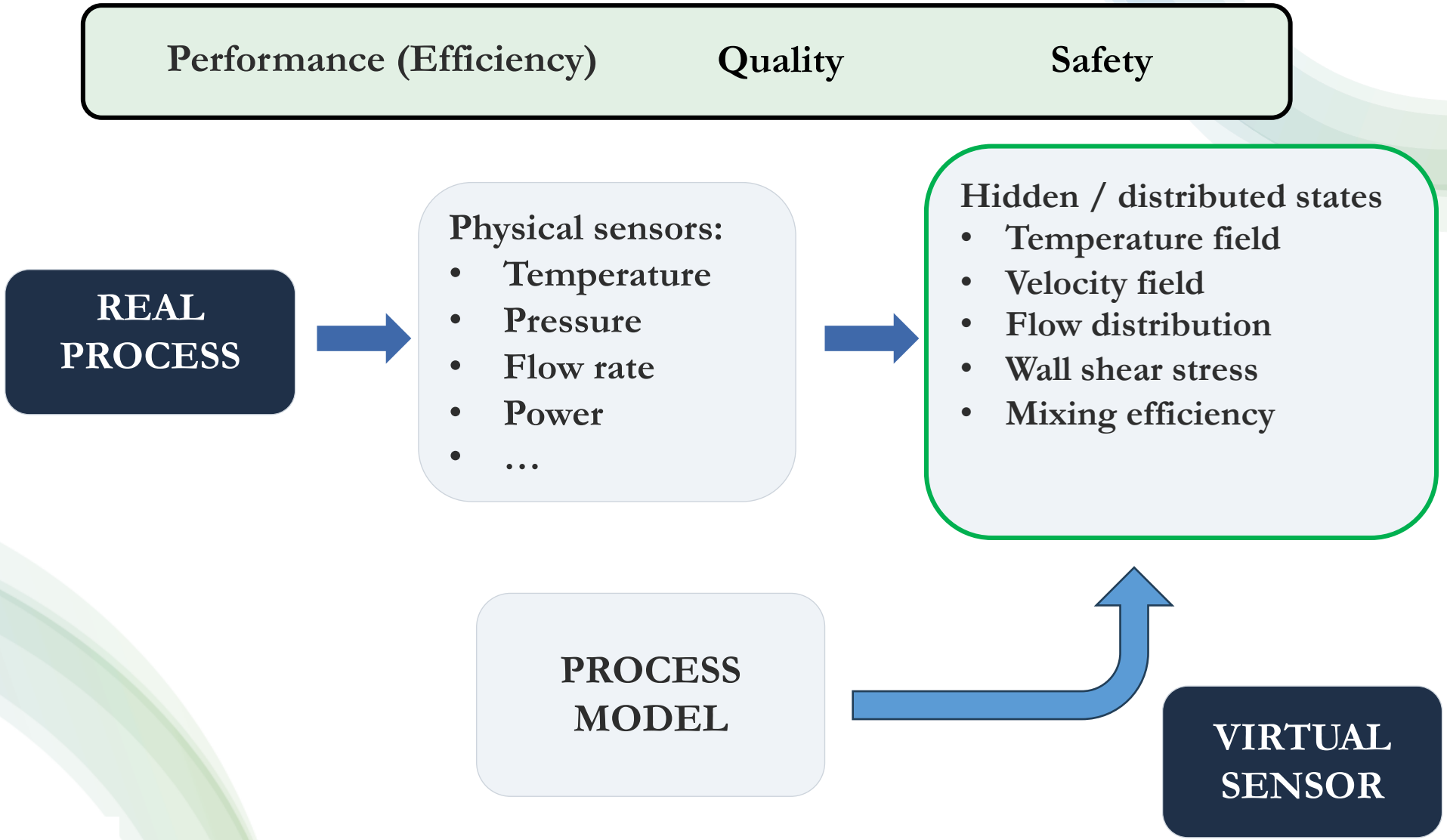
Hidden / distributed states
- Temperature field
- Velocity field
- Flow distribution
- Wall shear stress
- Quality attributes

The variables we need for process characterization and control are often spatially distributed and **not directly measurable**.

UNIVERSITÀ DI PARMA

Cibus Tec 28 October 2026
The TOMATO conference news

Monitoring and control of industrial processes



The modelling dilemma: data-driven or physics-based

	DATA-DRIVEN MODELS	PHYSICS-BASED MODELS
Strenghts	Fast and computationally efficient	Interpretable and physically consistent
	Flexible for complex and nonlinear systems	Good extrapolation capability
	Continuously updatable	Requires fewer experimental data
Weakness	Strong dependence on data quality and domain coverage	Can be complex and time-consuming
	Limited interpretability and extrapolation	High-fidelity models can be computationally expensive

Can we combine their strengths?

Research questions

RQ1 — Observability	How can high-fidelity multiphysics simulations provide access to process states that cannot be measured directly?
RQ2 — Real-time prediction	How can simulation-derived information be transformed into computationally efficient virtual sensors?
RQ3 — Industrial integration	How can virtual sensors be integrated into hybrid Digital Twins to support monitoring and control?

UNIVERSITÀ DI PARMA

State of the art

DATA-DRIVEN

Infer process behaviour from historical data.

- Flexible and computationally efficient
- Adaptable to complex nonlinear behaviour
- Dependent on representative training data
- Limited extrapolation and interpretability

PHYSICS-BASED

Represent process behaviour through governing physical laws.

- Physically consistent and interpretable
- Robust when conditions or geometry vary
- Lumped models simplify spatial behaviour
- High-fidelity multiphysics models are computationally demanding

HYBRID / GREY-BOX

Combine mechanistic knowledge with data-driven techniques.

- Combines robustness and flexibility
- Includes physics-informed approaches (e.g. PINNs, SINDy)
- Can exploit high-fidelity simulation data
- Promising route for industrial virtual sensing

Simulation-derived virtual sensors bridge the gap between physics-rich simulation and real-time process observability.

HIGH-FIDELITY MULTIPHYSICS
CFD / detailed physical fields

→

MODEL REDUCTION
ROM / surrogate model

→

VIRTUAL SENSOR
Near-real-time estimation

→

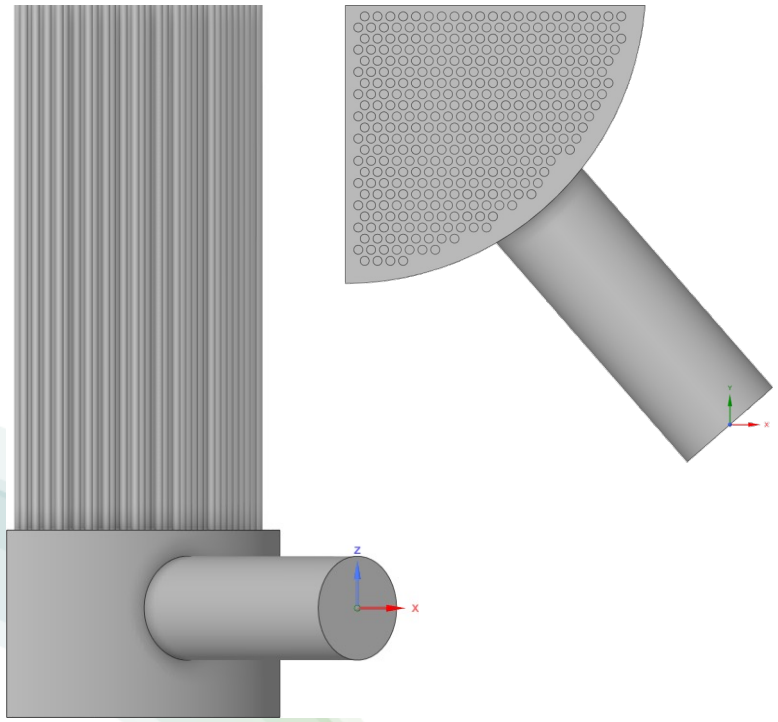
DIGITAL TWIN
Monitoring • control • optimisation

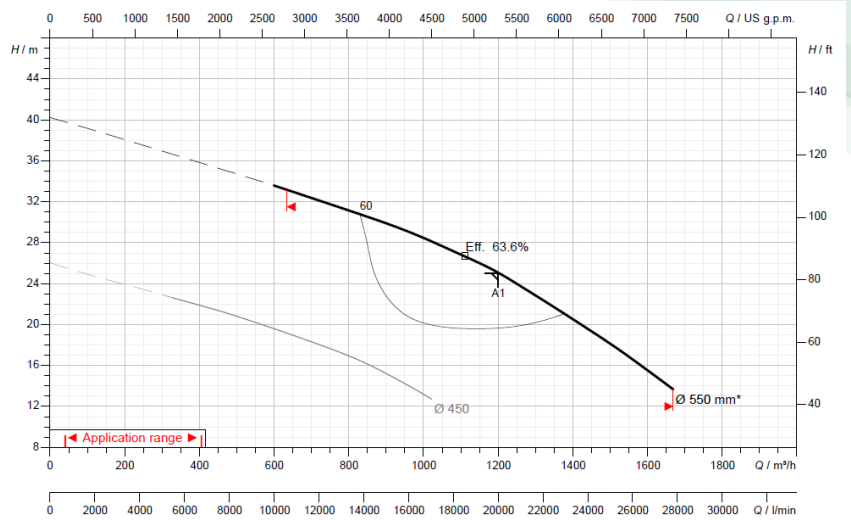
UNIVERSITÀ DI PARMA

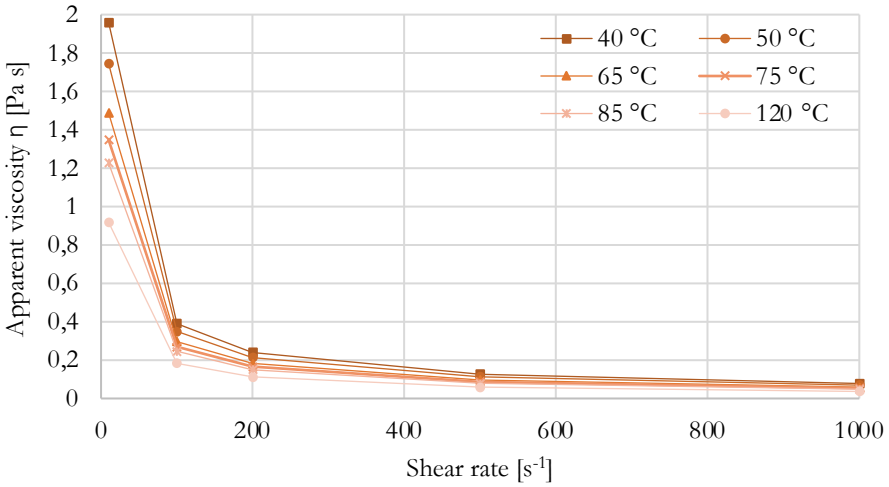
High fidelity models

ACTUAL 3D GEOMETRY

PRECISE COMPONENT AND PRODUCT CHARACTERIZATION





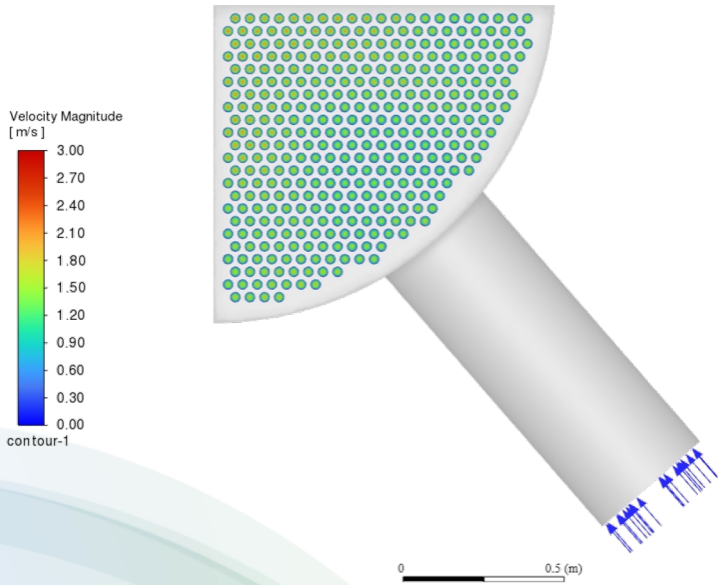


UNIVERSITÀ DI PARMA

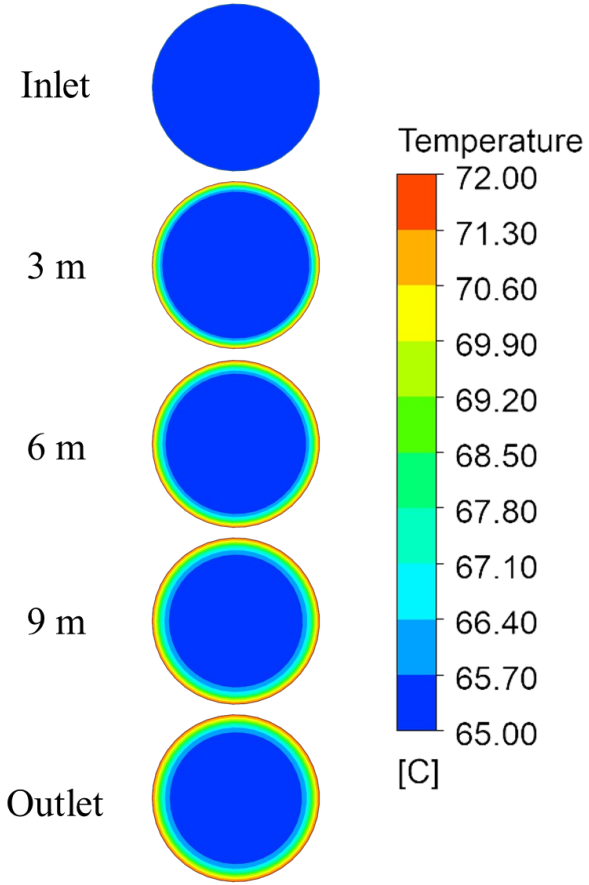
Cibus Tec 28 October 2026
The TOMATO conference
news

High fidelity models

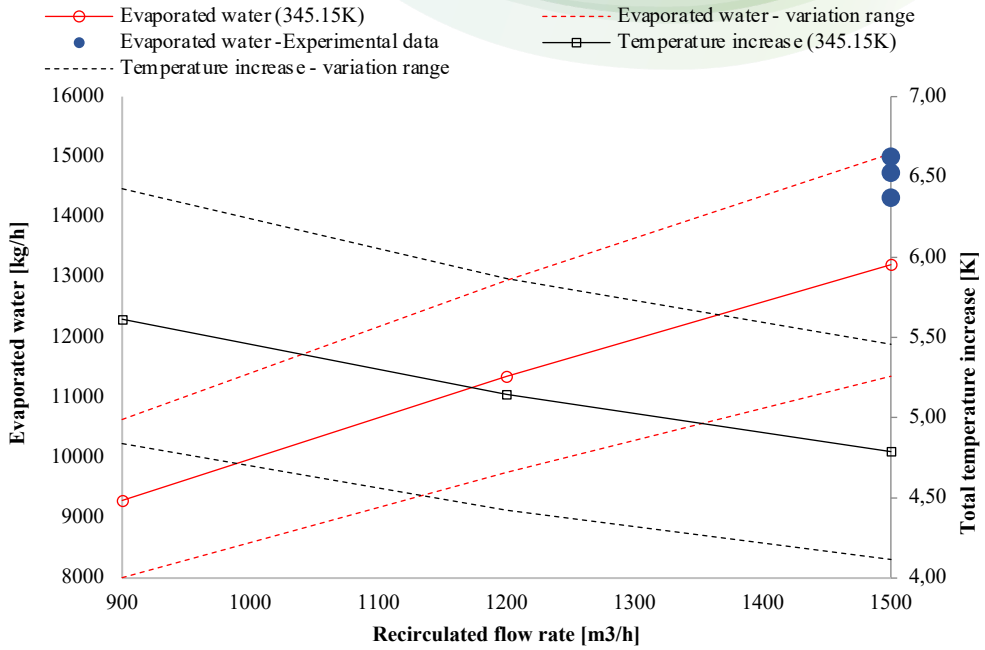
VELOCITY FIELD



TEMPERATURE FIELD



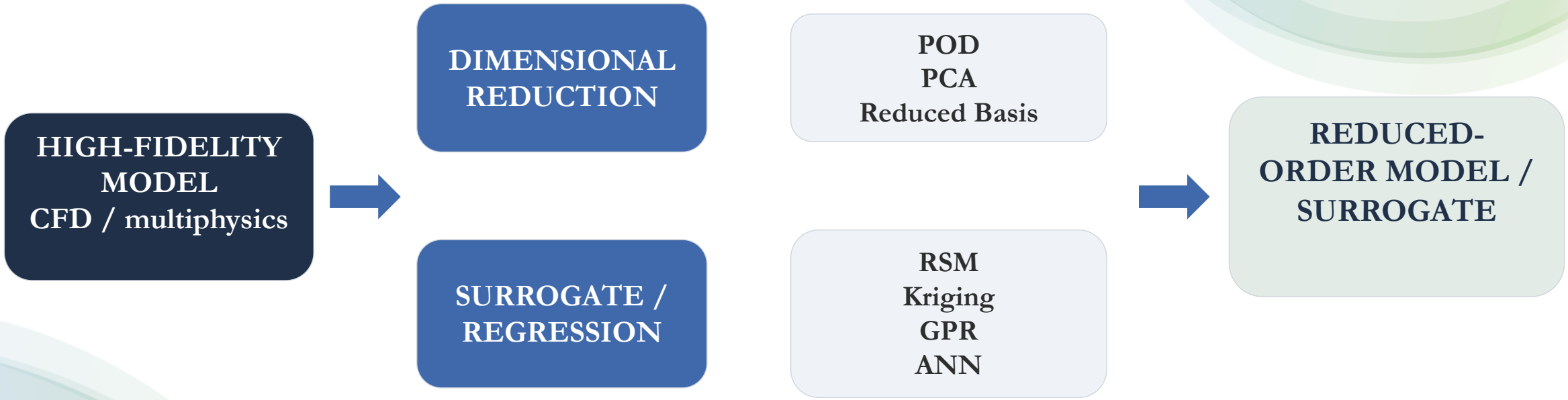
KPI EVALUATION



UNIVERSITÀ DI PARMA

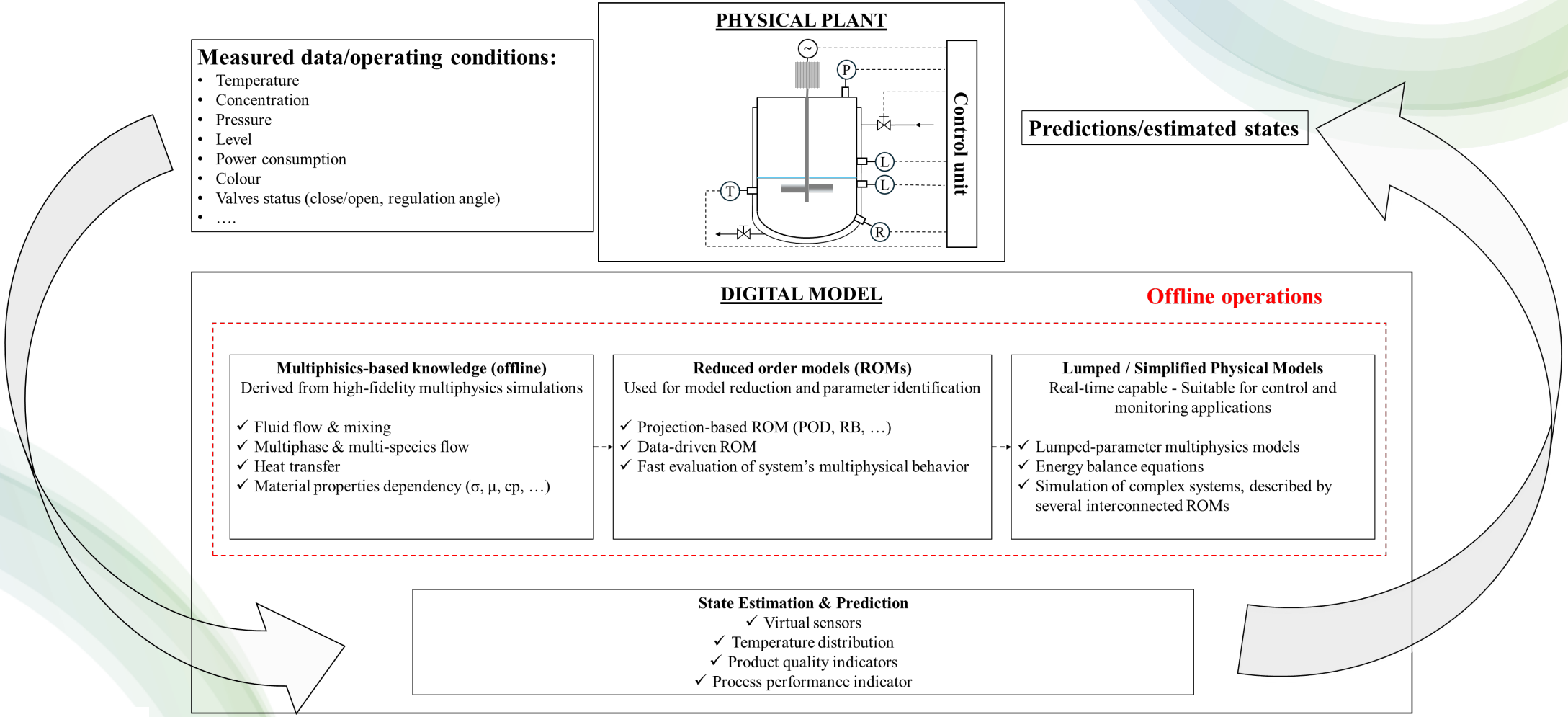
Cibus Tec 28 October 2026
The TOMATO conference
news

How can a high-fidelity model be reduced?

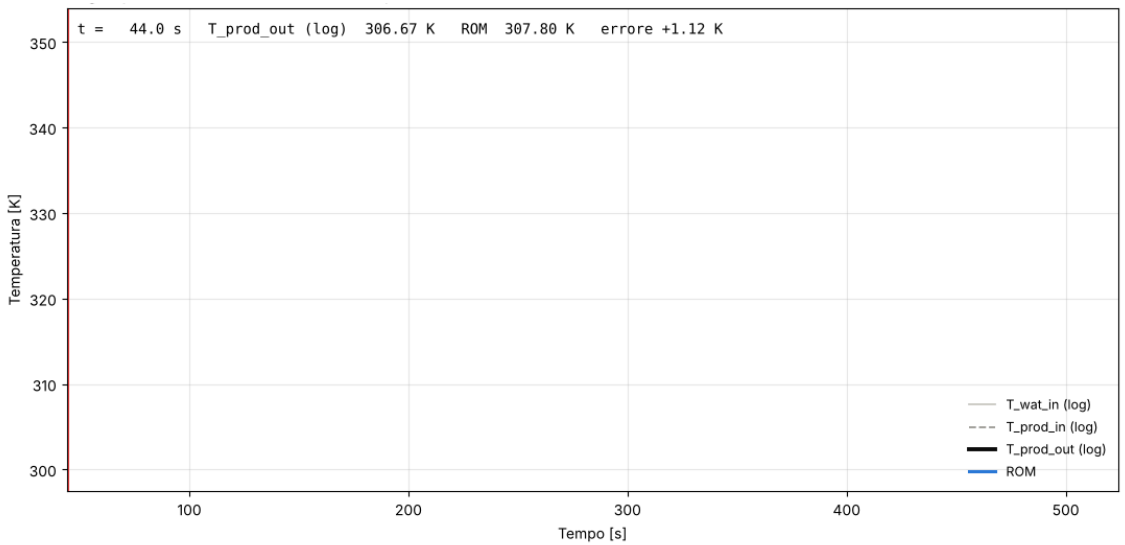


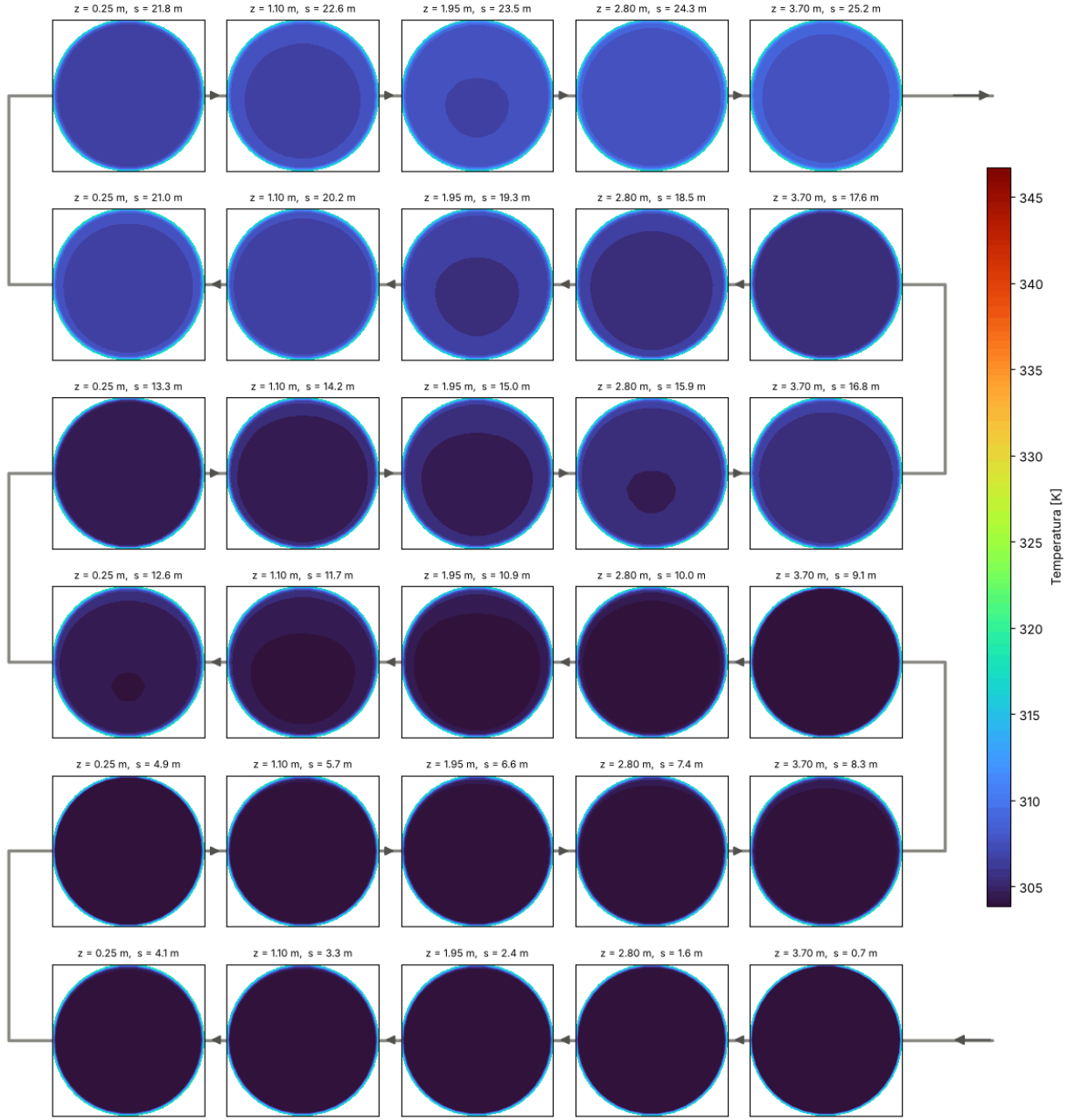
- preserve dominant process behaviour
- reduce online computational cost
- enable near-real-time prediction

From high fidelity models to virtual sensors and hybrid digital twins



From high fidelity models to virtual sensors and hybrid digital twins





Conclusions

- The integration of high-fidelity multiphysics simulations with reduced-order models (ROMs) and AI-based data analysis combines the **interpretability** and **physical consistency** of mechanistic models with the **efficiency** and **adaptability** of data-driven approaches.
- **Physics-based modelling will remain central to future DT architectures**.
- **Rather than replacing mechanistic models**, AI is expected to **enhance parameter estimation, uncertainty management, and computational efficiency**.
- The integration of **high-fidelity simulations**, **ROMs**, and **lumped-parameter system-level models**, enables scalable DTs development capable of **representing both individual process units and their interactions** across entire production systems.
- **Simulation-based digital twin** have the potential to **become key enabling technologies for next-generation cyber-physical production systems**, supporting **predictive control**, **process optimisation**, and **predictive maintenance**.

Future directions

ROM IMPROVEMENT

Can a more detailed numerical model or other Reduced Order methodologies outperform the presented approach in strongly non-linear context?

IN FIELD VALIDATION

Does the virtual sensor reproduce reality?

UNCERTAINTY

How confident are we in the prediction?

ADAPTABILITY

Can it remain valid when the process changes?

INTEROPERABILITY

Can it communicate with industrial automation systems?

Thank you for your attention!

federico.solari@unipr.it

UNIVERSITÀ
DI PARMA