

Involving before Evolving: A Vision for Trustworthy Enterprise Digital Twin Engineering

Kérian Fiter, Adil Lagrou, Franck Dervault, Bentley Oakes

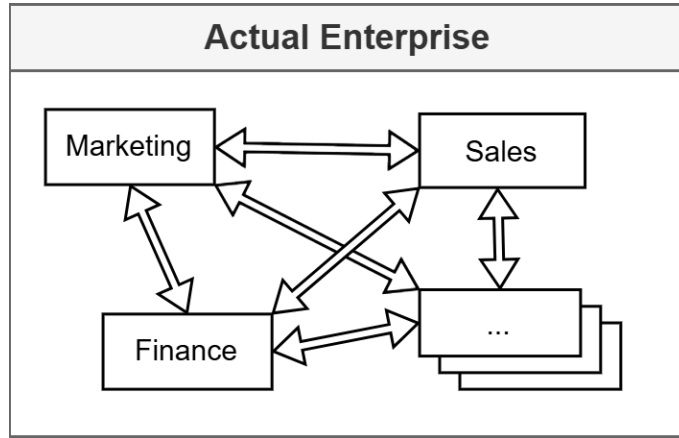


EDTconf
International Conference on
Engineering Digital Twins

Málaga, Spain – October 2026

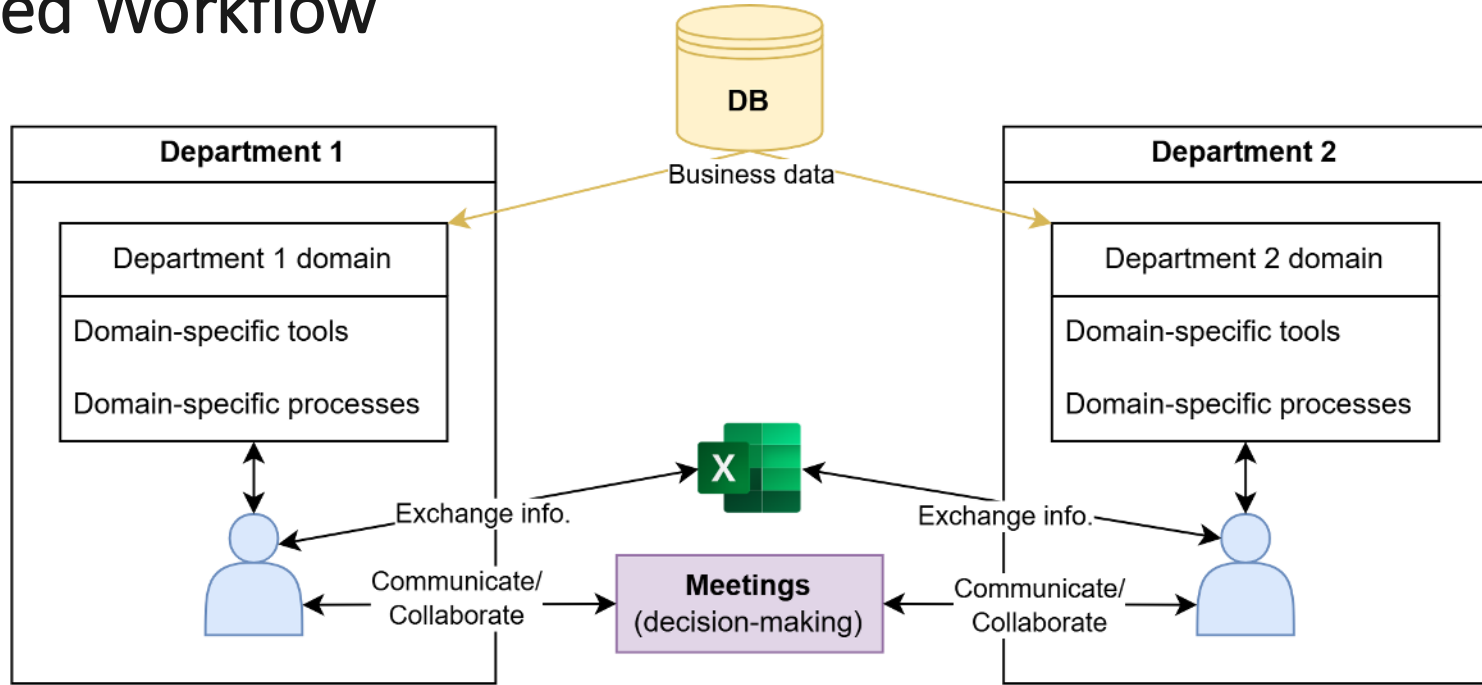
Problem and Context

- **Michelin** business unit (€3B revenue)
- Makes **strategic business decisions**
- Involves **marketing, sales, finance, supply chain** departments



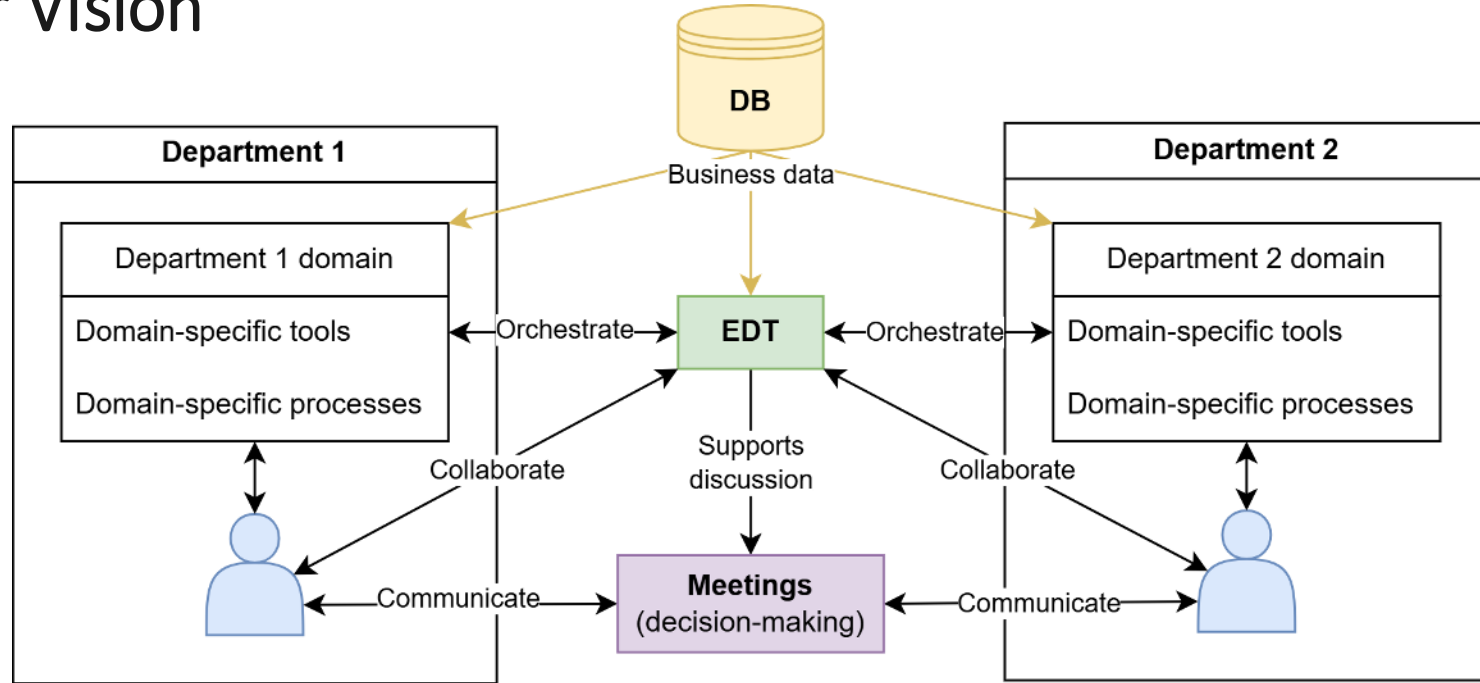
- **Systems-of-systems** with departmental silos
 - Divided responsibilities and goals
 - Own processes and Domain Knowledge (DK)

Siloed Workflow



- **Tacit knowledge** stored in **spreadsheets** -> **limited explainability and data grounding**
- Collaborate on strategic forecasts (**5+ years** horizon) during **meetings**

Our Vision



- **Not fully replacing spreadsheets**
- Visual and uncertainty management tool to **support discussions** during **meetings**
- The **Enterprise Digital Twin (EDT)** does not take decisions automatically

Approach

Enterprise DTs against Other DTs

Enterprise Digital Twin (EDT): "purposive analyzable and simulatable model representing the enterprise" supporting "what-if scenario[s] playing in virtual space" [1]

How far is this from other DTs?

Lots of overlap with cyber-physical systems and systems engineering:

- Interoperability and data silos concerns, uncertainty, data quality, rich semantic domains

But:

- **Long loop DT:** human-made decisions with high impact **days, months, years later**
- Non-technical stakeholders with **busy schedules and tight deadlines**
 - Need to **show value fast**

[1] Kulkarni, Barat, & Clark (2019, December). Towards adaptive enterprises using digital twins. In *2019 winter simulation conference (WSC)* (pp. 60-74). IEEE.

Developing an EDT

- **Resistance** to new workflows
- **Disinterest** without recognition of **immediate value and potential**
- Vague/complicated **requirements** -> requires **multiple iterations**

Decision support

Explore business strategies

What-if simulation

Forecast multiple financial scenarios

Easy modeling

Non-technical stakeholders

Interoperability

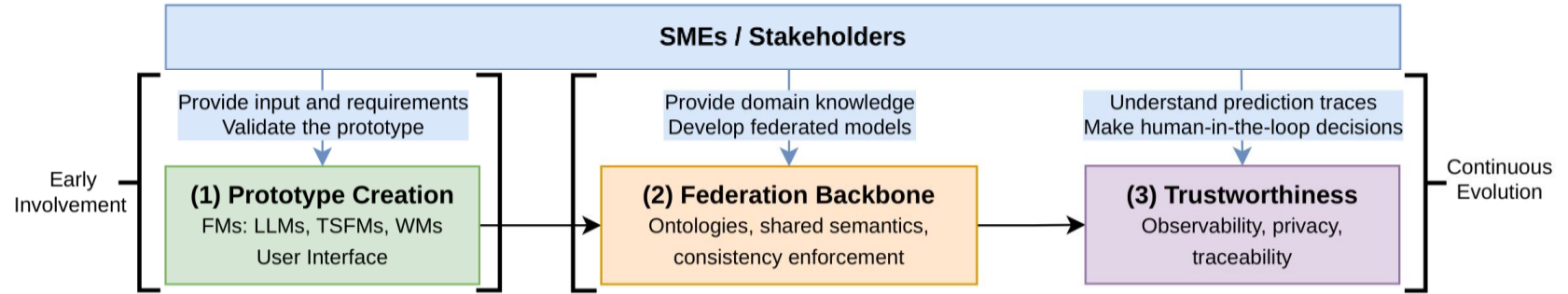
Works across systems-of-systems

Observability

Compare solution and scenarios

➡ **Involving** before **Evolving** Secure **organizational buy-in** with working prototype **first**, **evolve** EDT toward federation and higher maturity **then**.

Approach Summary



(1) Prototype Creation: Gather requirements, pick formalisms, fast low-maturity prototype

- **Large Language Models (LLMs):** Build models, tools and User Interfaces
- **Time-Series-Foundation Models (TSFMs):** Forecast time-series data
- **World Models (WMs):** Action-conditioned compact predictions of future states

(2) Federation: Owned ontology by each department, **interoperable** through shared contracts.

(3) Trustworthiness: Observability through traceability + data sovereignty for **long-term adoption**

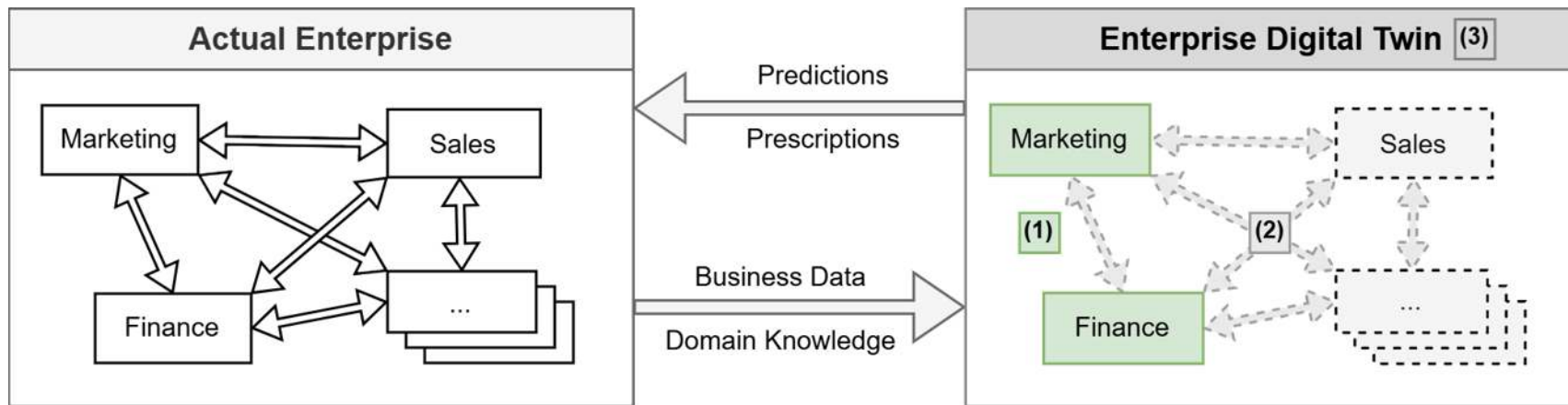
(1) Prototype Creation

MVP for Early Validation

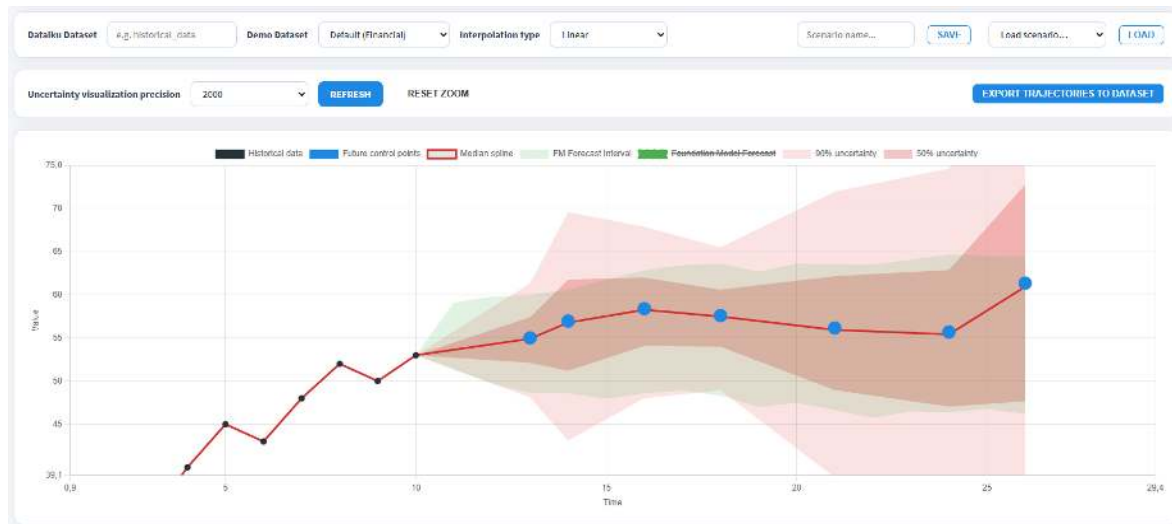
- **Foundation Models** as rapid forecasting/simulation placeholders
- Create a MVP for **early validation**
- Invest in verification/formalization later

In Practice

- Met ~30 practitioners across 4 departments
- Day-to-day tools, processes, interactions



Showcasing the Working Prototype



1. Forecast

Locally-hosted TSFM forecasts **uncertainty trajectory** from **historical data**

2. Edit

Drag **spline/control points**, sets **uncertainty range** to embed DK

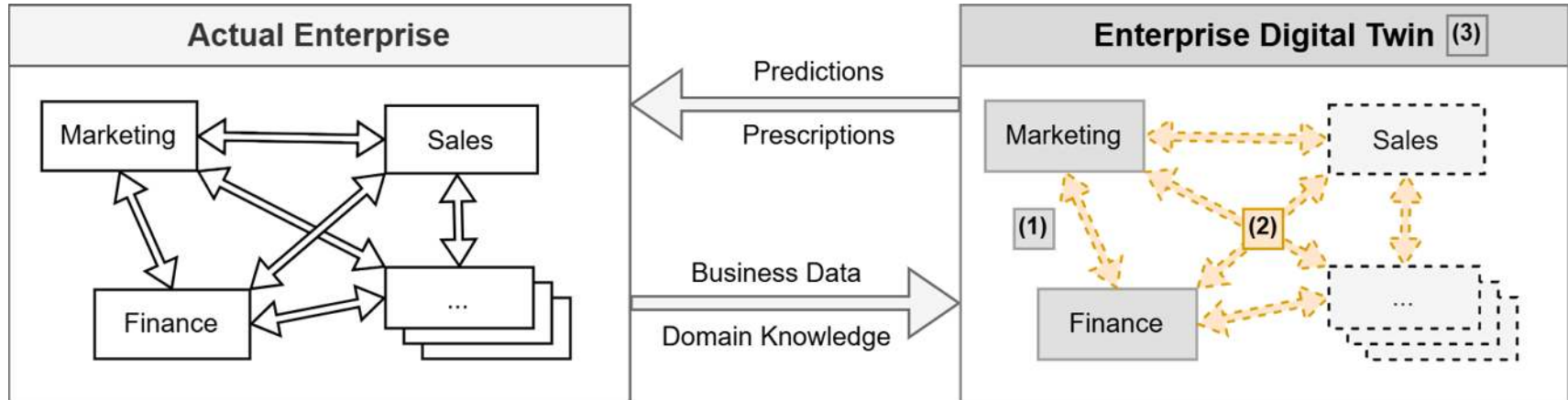
3. Propagate

Monte Carlo simulation pushes uncertainty in expert-built models to support discussions

(2) Federation

Federation

- **Architectural isomorphism:** Mirroring organization's **social structure** as silos (distinct agendas, tools and DK)
- Have to balance **interoperability** + **ownership** of data, models and services
- Needs semantic alignment-> **ontologies**



Ontological Modeling Language



- **Domain Specific Language** over OWL to define concepts, relations, constraints and rules [2]
- Allows vocabulary owners to **author and understand** vocabularies
- Designed to bridge MBSE and semantic web [3]
 - Offer more familiar MBSE concepts/tooling

[2] Elaasar, Rouquette, Wagner, Oakes, Hamou-Lhadj, & Hamdaqa (2023, October). openCAESAR: Balancing agility and rigor in model-based systems engineering. In MODELS-C (pp. 221-230). IEEE.

[3] Elaasar, Oakes, Kamburjan, Hamdaqa, & Hamou-Lhadj (2026, October). Bridging the Semantic Web and Model-Based Systems Engineering with the Ontological Modeling Language. In ISWC.

Using Ontologies as a Semantic Backbone

Structural/Semantic typing

Ontologically-typed data
exchanged between
departments

-> **Alignment on what that
signal represents**

Traceability

Ontologies capture decision
traces for different scenarios

-> **Creating a decision-
making thread**

Encoding fidelity levels

Domain-based scenario input
tagging with fidelity levels

-> **Automatically flag
scenarios with low-fidelity
inputs**

[2] Elaasar, Rouquette, Wagner, Oakes, Hamou-Lhadj, & Hamdaqa (2023, October). openCAESAR: Balancing agility and rigor in model-based systems engineering. In MODELS-C (pp. 221-230). IEEE.

(3) Trustworthiness

Stage 3: Observability for Promoting Trust

Trustworthiness: ability to inspect, understand, trace and challenge EDT outputs while preserving data sovereignty and organizational accountability

What it means in practice

- Compare **current scenarios** and store them
- Compare **past scenario** decisions and predictions with current data
- Ensure **historical data** used for forecasts is the same between departments
- **Import and export** between local and familiar tools
- Preserve **confidentiality** of business data

Stage 3: Promoting Trust in Our Approach

Probability-based formalism

Explainable Monte Carlo simulation

Curve-editing for inputs

Stakeholders stay in control

Accountable and traceable

Knowing **who** and **what** generated a prediction

Maintain familiar tooling

Users will be able to use familiar tooling (internal dataflow tool, Excel)

Integrating MBSE Practices

Versioning of ontology models

Private and sovereign

Agentic LLMs on company infrastructure + **local TSFM instance** for sensitive time-series forecasts

Next Steps

Expected Gains

- **Rapid and increased buy-in** -> early involvement with a prototype
- **Fewer errors, better collaboration** -> ontologies
- **Increased agility** -> federated departments own data and models
- **Trusted probabilistic what-if simulations** -> observable, traceable, privacy-respecting
- **Increased resilience** -> data-driven decision-making support

Where the Project Is and What's Next

Current

- 2 supervisors, 2 PhD + 1 MSc students
- **Webapp** hosted on company infrastructure
- Hierarchical **scenario creation**
- **Early prototype validation**, getting it to users



Future work

- Setting up **tooling** for this (difficult within enterprise constraints)
- Reducing ontological **modelling burden** for users (LLMs)
- Enhancing **ontological constraints**
- Additional meetings and getting **buy-in from multiple departments**

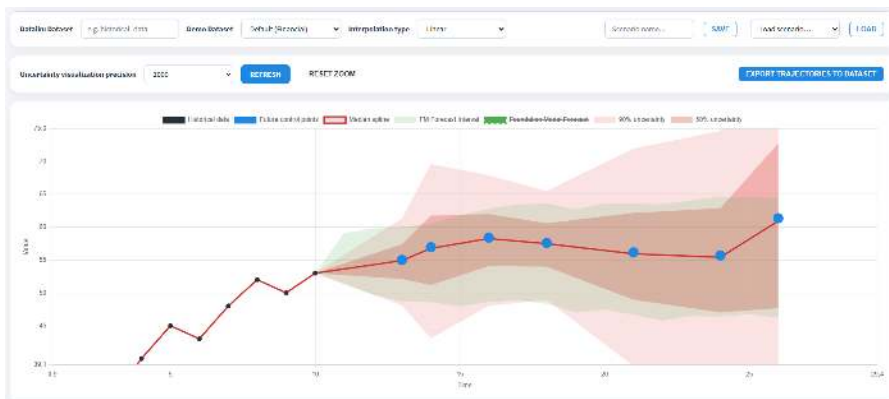
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(2) Federation

(3) Trustworthiness



Let's connect!

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