A Knowledge Graph-Based Digital Twin for Semantic Lifecycle Interoperability

From Semantic Interoperability to AI-Assisted Engineering

Torbjörn Holm
Torbjörn B Holm Konsult AB
TBHK

TBHK
INTO THE FUTURE

Main results developed within the Arrowhead fPVN project

ARROWHEAD fPVN



PLM Road Map™ & PDT EMEA 2026

AI in PLM: A Disruptive Opportunity and Challenge

Turning AI disruption into enterprise value:
Strategic insights for the PLM professional

4-5 November 2026

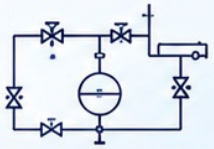
The Industrial Engineering Challenge

Engineering information is distributed across disciplines, systems and lifecycle stages

- Different systems, formats and semantics
- Information owned by different organizations
- Difficult to establish a consistent understanding across the lifecycle
- Limits efficient information reuse and collaboration



Process & Functional Engineering (P&ID)



3D Engineering (CAD / BIM)



Requirements and Specifications



Automation and Control



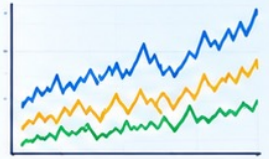
Product and Lifecycle Information (STEP)



Maintenance (EAM / Work Orders)



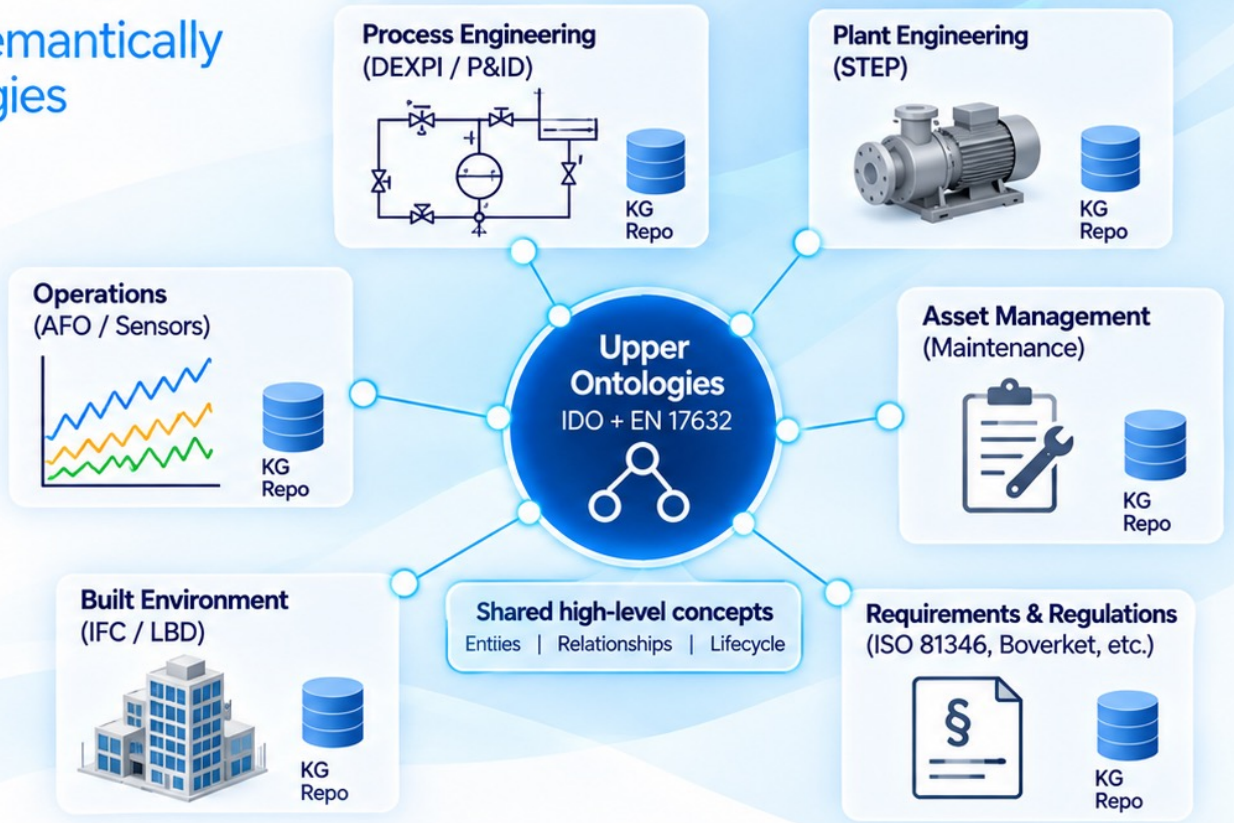
Operational Data (Sensors, Data Histories)



The Semantic Foundation: Federated Knowledge Graphs

Domain knowledge graphs are semantically connected through upper ontologies (IDO + EN 17632)

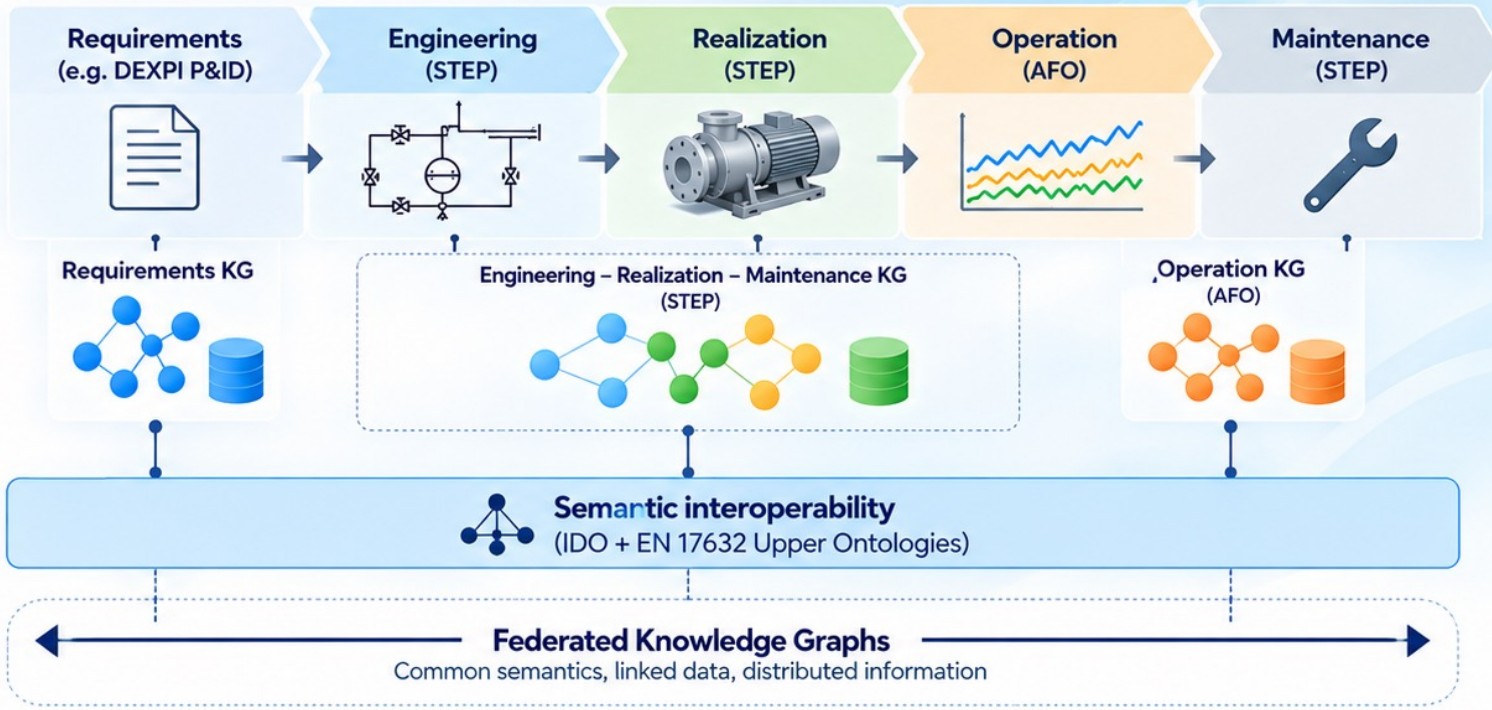
- Domain-specific knowledge graphs remain distributed
- Upper ontologies (IDO + EN 17632) provide shared, high-level semantics
- Semantic bridging enables interoperability across domains, systems and organizations
- No need to consolidate all information in one database



A Digital Twin Across the Engineering Lifecycle

Domain knowledge graphs are federated and semantically connected using upper ontologies (IDO + EN 17632)

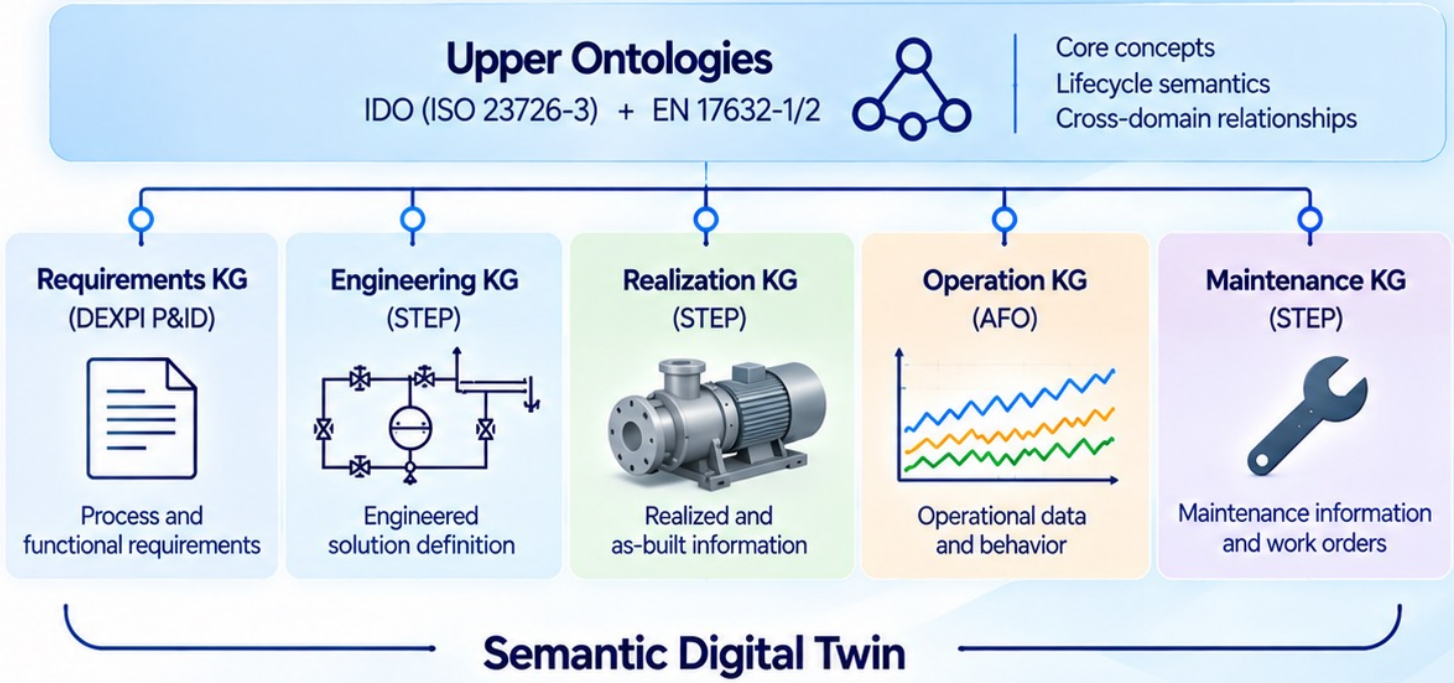
- Different lifecycle stages contribute domain knowledge graphs
- The graphs are semantically connected using upper ontologies (IDO + EN 17632)
- In Skoghall, requirements in DEXPI, engineering–realization–maintenance in STEP, and operation in AFO
- Other implementations may use different graphs with the same architectural principle



From Federated Knowledge Graphs to a Semantic Digital Twin

A coherent view across the lifecycle – without centralizing data

- Domain knowledge graphs are semantically connected through upper ontologies (IDO + EN 17632)
- Each domain keeps its information in the systems where it is owned
- Semantic linking enables a coherent Digital Twin across the lifecycle
- The same architectural pattern can be used in different implementations with different graphs



What a Semantic Digital Twin Enables

From data islands to integrated, trusted and actionable knowledge

- Connects people, processes and information across the lifecycle
- Enables traceability from requirements to operation
- Supports automation, analysis and better decisions
- Keeps information with the owner and works across organizational and system boundaries



Better Engineering
Consistent requirements, solutions and specifications

- Fewer errors
- Higher quality
- Shorter lead times

Efficient Realization
Traceable installation and as-built information

- Smoother delivery
- Evidence-based acceptance
- Reduced rework

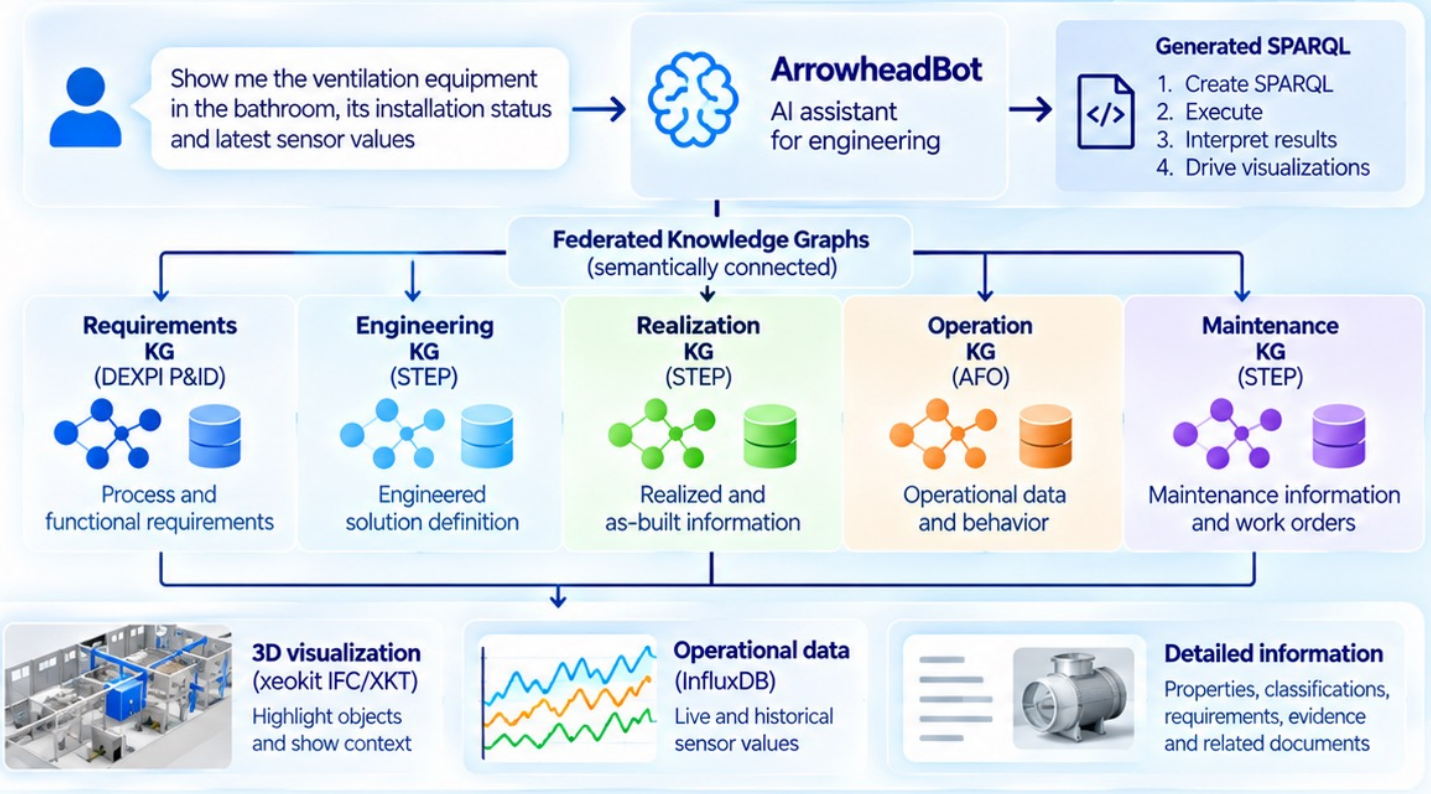
Reliable Operation and Maintenance
Live operational data, structured maintenance

- Higher availability
- Optimized maintenance
- Longer lifetime

From Semantic Digital Twins to AI-Assisted Engineering

Natural language access to federated knowledge graphs

- AI assistant that understands the domain and repository context
- Generates and executes SPARQL queries across federated knowledge graphs
- Combines information from engineering, realization, operation and maintenance
- Links results to 3D models, sensor data and related documents
- Helps engineers explore, validate and act on trusted information



AI as an Active Engineering Interface

From natural language to knowledge, visualization and insight

- Understand natural language requests in engineering context
- Generate and execute SPARQL queries across federated knowledge graphs
- Combine and interpret results from multiple sources (knowledge graphs, 3D, sensors, documents)
- Iteratively refine queries and take follow-up actions
- Provide traceable results with links to source data
- Support engineers in exploration, validation and decision making



AI Engineering Copilot in Action

One question – integrated results across knowledge graphs, 3D and operational data

1 Natural language question

"Show me the ventilation equipment in the bathroom, its installation status and latest sensor values."

2 AI interprets and executes

Generates and runs SPARQL queries across federated knowledge graphs

3 Integrates results

Combines information from engineering, 3D model, operational data and documents

4 Supports engineering decisions

Provides a coherent, traceable view with links to source data



One Architecture, Multiple Application Domains

The same semantic foundation – applied to different engineering domains

Skoghall
Process industry



- Process and functional requirements
- Engineering and realization
- Operation and maintenance

Cottage
Building Digital Twin



- BIM and 3D model (IFC / LBD)
- Sensor data (operational)
- Building log book and documentation

Building Permit
Planning and compliance



- Planning requirements (Boverket)
- BIM and spatial analysis
- Compliance assessment

Federated Knowledge Graphs
Semantically connected – different ontologies and data sources

- Requirements KG (DEXPI P&ID)
- Engineering KG (STEP)
- Realization KG (STEP)
- Operation KG (AFO)
- Maintenance KG (STEP)

AI-Assisted Interaction
Common interface across domains

→ Natural language questions → Semantic search and SPARQL → Integrated visualization → Analysis and insights

POC 07 – AI-Supported Solution Development

From engineering intent to verified and selected solution

1 Engineering Intent

Requirements, context and constraints



EI-BATH-VENT-001

- Ventilation for bathroom
- Year-round operation (Luleå)
- Geometric and installation constraints
- Indoor climate and energy requirements
- Maintenance accessibility

2 AI-Generated Solution Alternatives

Different concepts based on requirements and context



A – Ducted ventilation

- Conventional solution
- Reliable and proven
- Requires duct routing



B – Decentralized ventilation

- Local solution
- Minimal ductwork
- Simple installation



C – Local ventilation with heat recovery

- Energy efficient
- Better indoor climate
- Higher complexity and cost

3 Verification and Validation

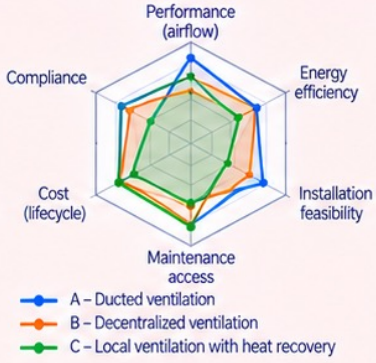
Automatic and rule-based evaluation using governed requirements and evidence

Criteria / Requirement	A	B	C
Airflow capacity	✓	–	✓
Energy efficiency	–	–	✓
Installation feasibility	–	✓	–
Maintenance access	✓	✓	–
Noise level	✓	✓	✓
Cost (lifecycle)	✓	✓	–
Regulatory compliance	✓	✓	✓

✓ Meets requirement
– Partly meets
✗ Does not meet

4 Trade-off Analysis and Recommendation

Multi-criteria evaluation with transparent rationale



Overall assessment (example)

Alternative	Score	Key strengths	Key weaknesses
A	0.72	Proven, high performance	Duct routing, higher cost
B	0.68	Simple, low cost	Lower energy efficiency
C	0.83	Energy efficient, best indoor climate	Higher complexity, higher initial cost

5 Selected Solution

Authorized and established engineering knowledge



Alternative C selected

- Meets requirements and constraints
- Best overall trade-off
- Rationale and evidence documented
- Authorized by engineer
- Established as engineering knowledge in EKS

Governance and Separation of Responsibilities

AI generates candidates
Proposes and explains engineering alternatives based on requirements and context

Rules evaluate
Deterministic validation against requirements, constraints and available evidence

Humans authorize
Engineering decision with explicit approval and rationale

EKS preserves knowledge
Traceable, governed and reusable across lifecycle steps

Key Takeaways

- AI can support engineering solution development, not only information access.
- Verification and validation are essential to ensure requirement compliance.
- Trade-off analysis provides transparent and traceable selection rationale.
- Clear governance keeps AI-generated proposals separate from established engineering knowledge.
- The same semantic infrastructure supports further development, realization, operation and maintenance.

Conclusions and Next Steps

From proven building blocks to broader impact and continued development

Key Takeaways

1. **Semantic foundation is essential**
   Federated knowledge graphs enable common understanding across domains, systems and lifecycle stages.
2. **AI adds real value**
   Natural language interaction and AI-supported solution development improve engineering efficiency and information usage.
3. **Governance is critical**
   Clear separation between proposals, evaluation, evidence and authorized engineering knowledge maintains trust and traceability.
4. **One architecture – multiple domains**
   The same semantic infrastructure supports process industry, buildings and planning compliance.
5. **From information access to automated engineering**
   We have demonstrated both AI-assisted interaction and AI-supported solution development under governance.

Proven Value in Our PoCs



Skoghall – Process Industry
Engineering lifecycle and maintenance with AI-assisted interaction



Cottage – Building Digital Twin
From engineering intent to AI-generated and evaluated solutions (POC 07)



Building Permit
Planning requirements and compliance analysis



Federated Knowledge Graphs
Semantic interoperability across domains and lifecycle stages

Next Steps

1. **Continue POC 07**
   Further develop AI-supported solution development, verification, validation, trade-off analysis and selection.
2. **Strengthen governance**
   Formalize rules, evaluation processes and authorization workflows.
3. **Extend domain coverage**
   Apply the same approach to additional industrial and built environment use cases (e.g. PEAB, OPR).
4. **Integrate with enterprise systems**
   Connect to SAP, time-series data and other relevant systems via federated services.
5. **Move towards operational use**
   From PoCs to reusable components and deployment in real projects.

A scalable foundation for semantic lifecycle engineering

Trusted knowledge. AI-augmented engineering. Real impact.

More efficient engineering | Sustainable solutions | Compliance and traceability | Higher value across the lifecycle

Rate My Presentation

