

AI in Model-Based Quality Digital Thread

Engineering · Manufacturing · Inspection

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Research Area: AI-integrated Digital Twins



Overview

Abstract:

Standards exist for model-based engineering, quality data exchange, and traceability. What's missing: intelligent systems that can interpret design intent, reason over structured data, and bridge semantic gaps between organizations and systems.

This paper proposes AI as semantic middleware—transforming MBE and QIF from passive data containers into an active, reasoning-capable quality digital thread.

Standards exist:	MBE	Captures design intent in 3D with PMI
	QIF	Structured schema for quality data exchange
	Persistent IDs	End-to-end traceability via UUIDs

The Problem: Semantic Interpretation Gap

Not the absence of standards — the absence of intelligent systems that can interpret design intent, reason over QIF data, and bridge semantic gaps between systems, terminology, and organizational boundaries.

Proposed Approach for AI Architecture: Semantic Middleware

AI as the interpretation & linkage layer that activates standards infrastructure



AI Capabilities

- Interprets design intent into structured Bill of Characteristics
- Validates inspection plan coverage — zero missed characteristics
- Links every measurement result to its specific feature & tolerance
- Enables feature-resolved nonconformance analysis
- Preserves trust and auditability for aerospace compliance

FIVE-PHASE ARCHITECTURE



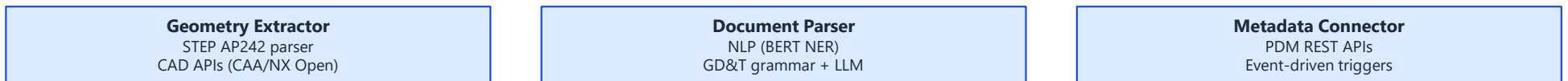
Phase 1: AI Interprets Design Intent -> Bill of Characteristics

Three extraction layers + three AI modules = structured, traceable BoC

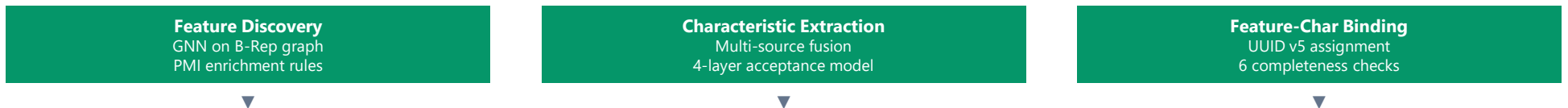
SOURCE SYSTEMS



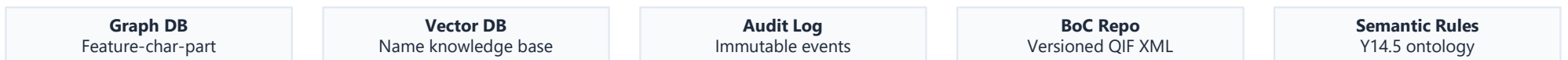
DATA EXTRACTION



AI SEMANTIC ENGINE



DATA STORES



Overall System-of-Systems Technical Architecture

End-to-end tech stack: CAD/PDM → AI Platform → Metrology → MES → SPC → Data Lake → Digital Twin

ENTERPRISE SOURCE SYSTEMS



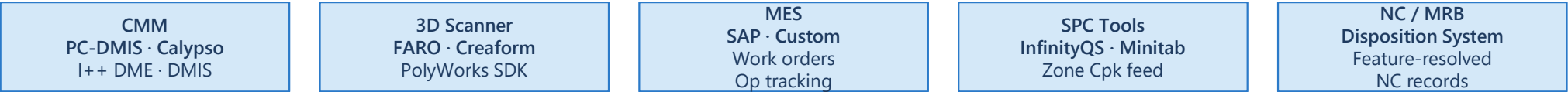
INTEGRATION BUS: Kafka Event Broker · REST / GraphQL API Gateway · File Watchers · PDM Webhooks · OPC-UA Adapters

AI SEMANTIC BRIDGE PLATFORM

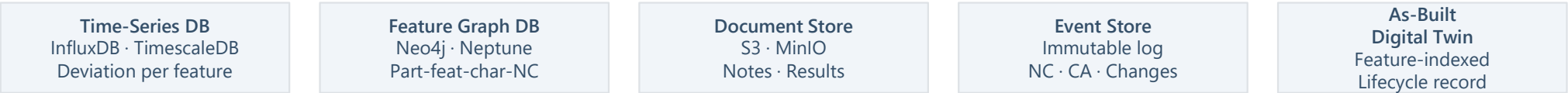


PHASE 5 — TRUST LAYER: Explainability · Audit Trail (Immutable Log) · Model Governance (MLOps) · Regulatory Map · Human Override

METROLOGY & MANUFACTURING SYSTEMS



DATA LAKE & DIGITAL TWIN



UUID-LINKED DIGITAL THREAD: Design Intent (MBE) → BoC → Inspection Plan → Measurement Results → NC Records → As-Built Twin
Every data point: Part UUID → Feature UUID → Characteristic UUID → Zone UUID · Standards: STEP AP242 · QIF 4.0 · MBC 1.0

AI Role Boundaries & Governance

Clear delineation of AI vs Human authority across all phases

AI Role Matrix (All Phases)

Phase 1: AI interprets & structures → Human APPROVES BoC
Phase 2: AI assists (optional) → Human AUTHORS plan
Phase 3: AI validates & flags → Human RESOLVES flags
Phase 4: AI analyzes & forecasts → Human DECIDES actions
Phase 5: AI logs & explains → Human GOVERNS & audits

Failure Handling

- AI degrades: confidence drops → alert
- AI errors: QE catches → feedback loop
- AI unavailable: manual fallback works
- Regulatory query: audit log proves
'AI suggested, human approved'

Model Governance (MLOps)

- Model registry: versioned, tested, approved
- Performance monitoring: confidence tracked
- Drift detection → auto-alert + lockout
- Change control via QMS process
- Rollback capability (instant revert)

Human Oversight Mechanisms

- Mandatory QE sign-off (no auto-approval)
- Random sampling audit of AI outputs
- Escalation: low-conf → mandatory human
- Feedback loop: corrections retrain model
- Kill switch: disable AI at any time

Novelty & Relevance to Practice

What is Novel

- No standard interprets design intent into BoC from fused model/notes/drawings — AI fills this
- BoC becomes the indexing structure making all downstream activities feature-precise
- AI role is interpretation & linkage, not plan generation — preserving QE authority
- Feature-resolved analytics expose insights invisible to part-level aggregation

Practitioner Grounding

This work originates from manufacturing and quality IT practice, informed by MES platform experience, QIF implementation challenges, and MBE adoption experiments.

Thank You

Questions & Discussion

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