QAI for Industrial Engineering — Master Architecture Proposal

# Hosting Layer — how QAI-Industrial fits your frameworks

A1. Org Framework (governance layer)  
- Modules: Roles & RACI, Ethics & AI Board, Program/Portfolio Mgmt, Vendor Mgmt, Licensing & IP.  
- Functions: Policy, approvals, audits, stakeholder alignment, risk acceptance.  
- I/O: Inputs—Standards, contracts, risk registers; Outputs—policy packs, decision logs.  
- Tech stack: Policy engines, GRC tools, contract repositories.  
- Merit: Clear accountability + faster approvals.  
- Use cases: Regulated plants; vendor multi-ecosystems; export-compliance lines.  
  
A2. 16 Ops Framework (execution layer)  
- Modules: CloudOps, DevOps, MLOps, DataOps, SecOps, ResearchOps, Site Reliability, FedOps, FinOps, ModelOps, RoboOps, EdgeOps, ITSM/ESM, Change/Release/Config (ITIL), ComplianceOps, SustainOps.  
- Functions: CI/CD for apps & models, drift detection, patch & rollout, PQC crypto rollout, incident mgmt.  
- I/O: Inputs—code, models, infra as code; Outputs—versions, deployments, telemetry.  
- Tech stack: QAI OS, QAI Hub, QAI Datacenter; Kubernetes, IaC, model registries.  
- Merit: Industrial-grade reliability & repeatability.  
- Use cases: Multi-plant rollouts; safe hotfixes; blue/green model swaps.  
  
A3. Business Transformation Framework (BTF) — Configurable Maps  
- Maps (dynamic & composable): Capability, Process (BPMN/VSM), Technology, Compliance, Data (ontology/taxonomy), Transformation (baseline→target), Sustainability.  
- Functions: Domain dictionary ingestion → traceability → solution synthesis.  
- I/O: Inputs—domain taxonomies, standards (ISO/IEC/NIST/ASTM/DoD/IEEE), client KPIs; Outputs—target architectures, migration plans, compliance matrices.  
- Tech stack: QAI reasoning (GenAI + rules + optimization), ontology stores, model-based SysEng.  
- Merit: One framework, many industries (automotive, pharma, aerospace, heavy mech).  
- Use cases: Rapid proposal generation; multi-standard alignment; audit-ready designs.

# QAI Industrial Engineering — domain framework (modules)

1) Retrofitting & Edge Instrumentation  
- Functions: Sensorization, gateway installs, motor/drive upgrades, transducers, machine vision.  
- I/O: In—legacy machine signals, PLC tags; Out—normalized telemetry (time-series, events).  
- Tech stack: Edge nodes (QAI OS Edge), OPC-UA/Modbus/Profibus/CAN; vision kits; safety relays.  
- Merit: Unlocks data from legacy assets; minimal downtime.  
- Use cases: Brownfield plants; long-life heavy equipment.  
  
2) IT/OT Gateway & Protocol Migration  
- Functions: Translate OT protocols → IIoT (OPC-UA, MQTT, DDS, AMQP); deterministic routing; buffering.  
- I/O: In—fieldbus frames; Out—secure, structured topics/OPC nodes.  
- Tech stack: QAI Hub adapters; uC/SoC gateways; time-sensitive networking (TSN).  
- Merit: Safe IT+OT convergence; vendor lock-in escape.  
- Use cases: Mixed-vendor lines, SCADA to cloud analytics, multi-plant overlays.  
  
3) Data Fabric & Digital Twin (DT)  
- Functions: Unified data model, historian, feature store, DT/MBSE sync, context graphs.  
- I/O: In—sensor streams, MES/ERP events, CAD/BOM; Out—DT states, feature vectors, simulation alerts.  
- Tech stack: Graph DB, time-series DB, DT runtime, model registry, ASTM E3012-inspired schemas.  
- Merit: Single source of truth; simulation-backed decisions.  
- Use cases: Virtual commissioning; what-if energy/cycle-time tradeoffs.  
  
4) QAI Cognition & Optimization  
- Functions: Predictive maintenance, anomaly detection, quality prediction, scheduling/OR, energy optimization, sustainability scoring.  
- I/O: In—DT state, constraints, KPIs; Out—setpoints, schedules, advisories, maintenance tickets.  
- Tech stack: QAI Processor, QAI OS, OR solvers, RL, Bayesian, graph, quantum annealing APIs.  
- Merit: Throughput ↑, scrap ↓, energy ↓, OEE ↑.  
- Use cases: Job-shop scheduling, bottleneck relief, carbon-aware production sequencing.  
  
5) Orchestration & Execution  
- Functions: Policy-based actuation, closed/open loop control, rollout canaries, fallback to manual/safe states.  
- I/O: In—optimized plans; Out—PLC/DCS setpoints, work orders, HMI prompts.  
- Tech stack: QAI Orchestrator, Kubernetes, OPC-UA write-backs, IEC 61131 bridges.  
- Merit: Safe autonomy with human override; progressive automation.  
- Use cases: Line balancing; adaptive takt; recipe optimization.  
  
6) Human-in-the-Loop (HITL) & Robot-in-the-Loop (RITL)  
- Functions: Approval gates, AR/VR assisted tasks, cobot collaboration, ergonomic monitoring, skill capture.  
- I/O: In—operator feedback, pose/ergonomic data; Out—work instructions, teach-by-demonstration trajectories.  
- Tech stack: Cobots, AR headsets, vision pose estimation, RLHF for robots.  
- Merit: Human-centric Industry 5.0; safety & acceptance.  
- Use cases: Precision assembly, changeovers, inspection with assisted vision.  
  
7) Governance, Security & Compliance  
- Functions: AI risk controls, PQC crypto, SBOM/MBOM traceability, audit trails, sovereignty.  
- I/O: In—policies, standards; Out—attestations, compliance reports.  
- Tech stack: NIST AI RMF, ISO 9001/14001/42001, PQC key mgmt, SIEM/XDR.  
- Merit: Trust-by-design; certification-ready ops.  
- Use cases: Pharma GMP lines; aerospace traceability; critical infra.  
  
8) Sustainability & KPI Layer  
- Functions: ASTM E3012-style characterization, LCA hooks, energy/carbon accounting, circularity metrics.  
- I/O: In—process maps, meter data; Out—dashboards, sustainability scores, ESG reports.  
- Tech stack: Meter gateways, LCA databases, KPI engine, digital MRV connectors.  
- Merit: Measurable Industry 5.0 outcomes.  
- Use cases: Carbon-aware scheduling; heat-recovery projects; waste minimization.  
  
9) PLM/ALM Integration  
- Functions: Closed-loop DFX, change impact, OTA updates for robots/edge.  
- I/O: In—CAD/BOM/MBSE models, field faults; Out—ECO/ECR, new configs, tuned models.  
- Tech stack: QAI PLM, MBSE tools, Req/Trace tools, model registries.  
- Merit: Learning enterprise—each cycle gets smarter.  
- Use cases: Rapid SKU ramps; post-market improvements; supplier collaboration.

# End-to-End Flow

1. Sense: Legacy assets emit OT signals → Gateways normalize & secure.   
2. Model: Data Fabric contextualizes; Digital Twins simulate & predict.   
3. Decide: QAI optimizes schedules, energy, quality; computes risk-aware actions.   
4. Act: Orchestrator writes setpoints; Humans/Cobots co-execute where needed.   
5. Assure: Security, compliance, KPI & sustainability continuously verified.   
6. Learn: PLM/ALM close the loop; Ops automates rollouts; BTF maps update.

# Technology Stack

- Compute: QAI Processor, CPU/GPU/NPU at edge & DC.   
- OS/Platform: QAI OS, QAI Hub, QAI Datacenter.   
- Data Layer: Time-series DB, Graph/Ontology store, Feature store, Historian.   
- Integration: OPC-UA, MQTT, DDS, AMQP, TSN, IEC 61131 bridges.   
- AI/QAI: OR solvers, RL, Bayesian, GNNs, quantum annealing/gate APIs.   
- Security: PQC, PKI, SIEM/XDR, Zero Trust for OT.   
- SE/PLM: MBSE, PLM/ALM toolchain, SBOM/MBOM.   
- Ops: GitOps, IaC, MLOps/ModelOps, SRE.

# Merits

- Throughput↑ & OEE↑ via scheduling & bottleneck relief.   
- Scrap↓, Energy↓, Carbon↓ with optimization and predictive quality.   
- Safety↑ & Ergonomics↑ through HITL/RITL & AR-guided ops.   
- Compliance-ready with audit trails & standards mapping.   
- Brownfield-friendly with progressive retrofits.   
- Scalable multi-plant, multi-vendor, multi-standard via BTF maps.

# Representative Use Cases

1. Brownfield line upgrade → downtime ↓ 20%.   
2. Energy-aware scheduling → 8–15% energy cost reduction.   
3. Quality prediction & inspection → scrap ↓ 10–30%.   
4. Cobotics for high-mix/low-volume → changeover ↓, safety ↑.   
5. Regulated traceability → audit time ↓, compliance ↑.

# Roadmap (Industry 4.0 → 5.0 → 6.0)

Phase 1: Discover & Map — baseline KPIs using BTF maps.   
Phase 2: Retrofit & Converge — sensors + gateways; DTs.   
Phase 3: Optimize & Orchestrate — QAI cognition, HITL guardrails.   
Phase 4: Human-Centric & Sustainable — RITL cobots, carbon-aware ops.   
Phase 5: Autonomy & Ecosystems — Industry 6.0 readiness.

# Standards & Compliance Anchors

- Systems Eng.: INCOSE SE, NASA/DoD SE.   
- AI & Risk: ISO/IEC 42001, NIST AI RMF.   
- Quality/Env.: ISO 9001, ISO 14001, ASTM E3012.   
- OT/Interoperability: IEC 61131/61499, OPC-UA, ISA/IEC 62443.   
- Crypto: NIST PQC candidates.