

Module 14: Digital Transformation and Innovation for Enabling Reconfigurable Production Systems

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Reconfigurable Manufacturing System (RMS)

An RMS should be capable to (Kim et al., 2020):

- (1) Swiftly adapting to customer demands,
- (2) Effectively retooling machinery, modifying operational parameters to address unexpected system failures and maintain product quality, and
- (3) Upgrading older systems to integrate new technologies

RMS place a strong emphasis on **modularity** (the system is made up of independent, interchangeable modules), **convertibility** (the system can be readily changed or reconfigured), **integrability** (the modules can function together efficiently) and **interoperability** (the system can work with other systems) (Kim et al., 2020).

Modularity is a crucial design approach for RMS

SWOT Analysis – MODAPTO as an RMS

Strengths	<i>Adaptability to Market Changes: RMS enables quick adjustments to consumer demand and supply chain shifts.</i>
Strengths	<i>Cost-Efficiency: Modular setups reduce capital expenditures and extend equipment life.</i>
Strengths	<i>Technological Advancements: Integration of digital twins, AI, and IoT enhances efficiency and reduces downtime.</i>
Strengths	<i>Sustainability: Optimized production reduces waste and supports regulatory environmental goals.</i>
Weaknesses	<i>High Initial Costs: Implementation requires significant upfront investment, challenging for smaller companies.</i>
Weaknesses	<i>Complex Integration: Customization needs can lead to long setup times and demand specialized skills.</i>
Weaknesses	<i>Dependency on Skilled Workforce: Requires a technically skilled workforce, creating potential resource constraints.</i>
Weaknesses	<i>Interoperability Issues: Compatibility challenges with legacy equipment and modular systems.</i>

SWOT Analysis – MODAPTO as an RMS

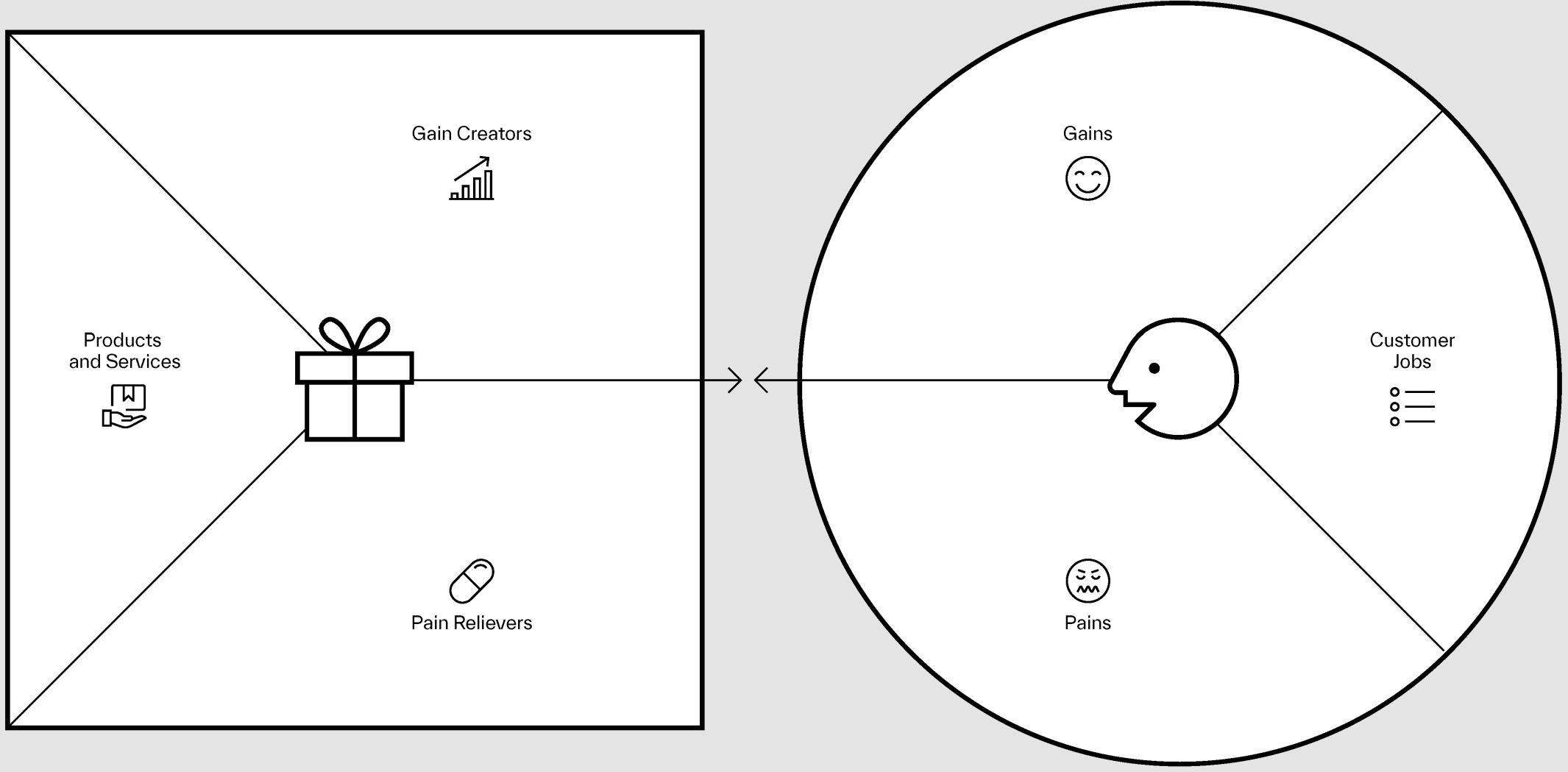
Opportunities	<i>Growing Demand for Customization: RMS enables efficient customization to meet consumer demand shifts.</i>
Opportunities	<i>Emerging Markets: RMS can support localized production models in rapidly industrializing economies.</i>
Opportunities	<i>Advances in Digital Twin and AI Technology: Evolving tech may reduce RMS costs and expand predictive capabilities.</i>
Opportunities	<i>Expansion to New Industries: Industries like food, pharma, and construction are exploring RMS solutions.</i>
Threats	<i>Economic Uncertainty: Economic downturns may reduce manufacturers' investment capacity in RMS.</i>
Threats	<i>Rapid Technological Change: Fast-paced innovation could make current RMS solutions quickly obsolete.</i>
Threats	<i>Cybersecurity Risks: Increased cyber-attack vulnerability due to interconnected RMS systems.</i>
Threats	<i>Competitive Pressure: Smaller companies may struggle to keep pace with large firms investing in proprietary tech.</i>

Value Proposition Canvas

The Value Proposition Canvas

Value Proposition:

Customer Segment:



Turn ideas into revenue with Strategyzer's innovation programs

Copyright Strategyzer AG. The makers of Business Model Generation and Strategyzer.



Source: [Strategyzer](https://www.strategyzer.com)

Industrial Cases of Modular Manufacturing Value Proposition Canvas Tool

MO  APTO

Case A

FAF

Case B

**SEW
USOCOME**

Case C

 **CENTRO
RICERCHE
FIAT**

 **ILTAR
ITALBOX**

FFT (Pilot 1)

Customer Jobs	1. Developing robotic systems for industrial applications.
	2. Integrating tools like welding guns or roller hemming tools with robots.
	3. Optimizing robotic movements for energy efficiency.
	4. Conducting simulations and programming of robots.
	5. Performing virtual commissioning and physical testing.
Customer Pains	1. Complexity in integrating new robotic systems.
	2. High energy costs and environmental impact of manufacturing.
	3. Technical challenges in optimizing robot movements.
	4. Time-consuming testing before deployment, affecting time to market.
Customer Gains	1. Enhanced efficiency and precision in production.
	2. Reduction in energy consumption and carbon emissions.
	3. Advanced modeling for better production planning.
	4. Improved product quality through precise robotic operations.

SEW (Pilot 2)

Customer Jobs	1. Developing robotic systems for industrial applications.
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	3. Advanced modeling for better production planning.
	4. Improved product quality through precise robotic operations.

(Farmakis et al, 2024C)

ILTAR & CRF(Pilot 3)

Customer Jobs	- Design and production of a modular, reconfigurable "smart" Kit-Holder (KH) by ILTAR.
	- Utilization of KH in warehousing and production operations by CRF.
	- Customization of KH to fit various production environments.
	- Integration of KH with Kitting Robot Systems (KRSs) for optimized picking.
	- Monitoring and improving warehouse and production line processes.
Customer Pains	- Complexity in designing a versatile and modular KH.
	- Challenges in integrating KH with existing warehousing and production systems.
	- Ensuring seamless communication between KH and KRSs.
	- Identifying and resolving bottlenecks in production and warehousing.
Customer Gains	- Enhanced automation and efficiency in warehousing and production.
	- Improved flexibility and reconfigurability in production processes.
	- Better monitoring and decision-making through self-aware KH.
	- Optimized picking sequence, improving cycle time and overall efficiency.
	- Strengthened collaboration between supply chain partners.



Products and Services

- **Simulation Services:** Enables risk-free testing and improvement of production processes through (co-)simulation, utilizing data from multiple manufacturing modules and information systems.
- **Optimization Services:** Utilizes input from various modules and data sources to enhance manufacturing processes, improving efficiency and output through (co-)optimization strategies.
- **Advanced Analytics & Monitoring:** Analytical tools for process signal interpretation and state monitoring of production modules.
- **Predictive Maintenance:** Services for tracking the health of production modules, including predictive maintenance scheduling.
- **Support & Decision-Making Tools:** Notification services, virtual commissioning tools, and decision support services for comprehensive production management.
- **Modular Production Units:** Flexible and reconfigurable production units that can adapt easily to changing manufacturing needs.
- **Integrated Digital Twins:** Combines production modules with their Digital Twins for real-time monitoring and optimization.
- **User Experience Platform:** User Interface (UI) for managing production modules, including visualization, dashboards, and interaction elements.
- **Comprehensive APIs & Interfaces:** Unified APIs for interaction with MODAPTO modules, including data exchange and operation management.
- **Communication & Coordination Framework:** Includes Message Bus for real-time communication and Service Composition for orchestrating complex workflows.
- **Security & Access Management:** Access Control Service for secure user authentication and authorization management.



The “Module” concept — in a nutshell

What it is:

A *Module* = **production module (physical or logical asset) + its Digital Twin (DT)** bundled together as one managed entity.

Production module part:

Any asset that performs a manufacturing task—e.g., a single machine, a robot cell, or even an entire line. Modules can be nested (a line made of smaller modules).

Digital-Twin part:

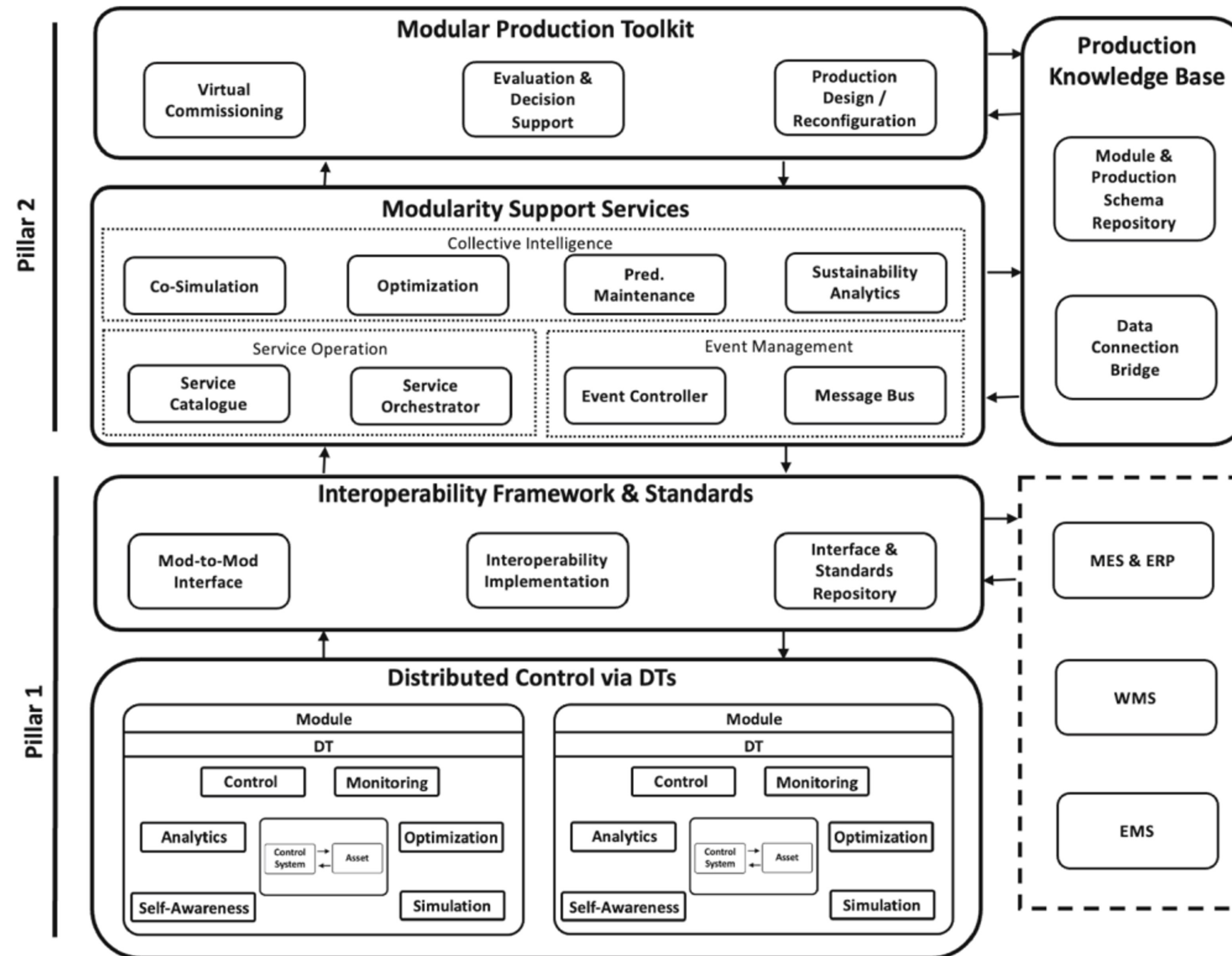
A real-time virtual replica that taps sensor data to monitor, predict, simulate and optimise that asset. It injects extra “brains”: self-awareness, analytics, co-simulation, optimisation, predictive maintenance.

Why it matters:

By fusing asset + DT, each Module becomes a *plug-and-play building block* you can insert, remove or rearrange within a production schema. Modules talk to each other via standardised interfaces, so the whole factory can be reconfigured quickly, simulated before changes, and steered by distributed intelligence rather than one central controller. The Module concept turns traditional equipment into smart, interoperable, micro-service-like blocks—laying the groundwork for truly modular, reconfigurable manufacturing systems (RMS).

(Plitsos et al., 2025)

Modapto conceptual Architecture



(Plitsos et al., 2025)



Pillar 1 – Distributed control on the shop-floor

The proposed architecture is built around two cooperating “pillars,” each implemented as sets of micro-services.

Pillar 1 sits on the shop-floor: every production module has its own Digital Twin (DT) that runs as a micro-service. Through open, standards-based interfaces, these DTs expose the module’s control functions, local analytics and simulation tools, so they can talk directly to one another and to higher-level IT systems. This distributed, peer-to-peer setup makes each module self-aware and able to coordinate with its neighbours without relying on a central Programmable Logic Controller

- Interoperable DTs embed local control logic, analytics & decision support.
- Interoperability Framework & Standards
 - Open, standards-based interfaces to physical modules & IT systems.
 - *Module-to-Module Interface* lets any two modules talk directly, even with proprietary protocols.
 - Repository keeps all interface definitions & mappings.
- Result: modules become self-aware, self-optimising and can coordinate without a central PLC.



Pillar 2 – Plant-level design & optimisation

Pillar 2 provides plant-level decision support. A “Modular Production Toolkit” lets engineers design or reconfigure single modules or entire lines, run simulations, optimise KPIs and perform virtual commissioning before any hardware changes. Under the hood, a common Knowledge Base stores live and historical production data, while a set of “Modularity Support Services” orchestrates all micro-services, handles real-time events and runs cross-module intelligence such as global optimisation, predictive maintenance and sustainability analytics.

- **Modular Production Toolkit**
 - Design or reconfigure single modules or entire lines.
 - Evaluate alternatives via dashboards, optimisation & simulation.
 - Virtual commissioning to test new modules before purchase.
- **Production Knowledge Base**
 - Stores current & candidate production schemas plus data feeds.
 - One gateway (Data Connection Bridge) to all machines/IT systems.
- **Modularity Support Services** (system “brain”)
 - *Service Operation* – Service Catalogue & Orchestrator deploy/manage micro-services.
 - *Event Management* – Message Bus + Event Controller for real-time, asynchronous events.
 - *Collective Intelligence* – cross-module Co-Simulation, Optimisation, Predictive Maintenance, Sustainability Analytics.

Why this matters

Transformation	MODAPTO enablers	What they unlock
Customer Experience (CE)	<ul style="list-style-type: none"> • Rapid re-configuration of modules (Pillar 1) • Virtual commissioning + simulation (Toolkit) 	<ul style="list-style-type: none"> • Shorter lead time & on-time delivery • Greater product personalisation • More reliable order-status information for customers
Business Processes (BP)	<ul style="list-style-type: none"> • Distributed control via interoperable DTs • Collective-Intelligence services (optimisation, predictive maintenance, sustainability analytics) 	<ul style="list-style-type: none"> • End-to-end process digitalisation & real-time visibility • Higher OEE, lower energy and reconfiguration time • Data-driven business performance management
Business Model (BM)	<ul style="list-style-type: none"> • DTs exposed as micro-services → “capabilities-as-a-service” • Open interfaces that let partners plug new modules/lines quickly 	<ul style="list-style-type: none"> • New digital revenue streams (e.g., remote optimisation, Predictive-Maintenance-as-a-Service) • Fast roll-out of supplementary digital channels & lines of business • Scalable international roll-outs without replicating heavy MES/PLC stacks
Organisational (OT)	<ul style="list-style-type: none"> • Knowledge Base = single source of truth 	<ul style="list-style-type: none"> • Integrated, data-centred strategy across IT & OT • Cross-functional “module teams” replace siloed hierarchy • Upskilled workforce: analytics, simulation, AI



How MODAPTO lifts the Customer-Experience (CE) pillar

Rapid re-configuration of modules)

- Because each machine + DT is a self-contained “Module”, you can insert, remove or rearrange stations through plug-and-play interfaces.
- Change-overs that once took days drop to minutes / hours → you can adapt the line to a new product variant almost immediately.

Virtual commissioning & simulation (Modular Production Toolkit)

- Before touching the shop-floor, engineers clone the line in the Toolkit, run a virtual try-out and iron out bottlenecks.
- That slashes ramp-up errors and unplanned downtime, so promised delivery dates stay intact.

Impact on the end customer

- **Shorter lead time & higher on-time-delivery (OTD)** – quick change-overs + fewer start-up glitches remove waiting days from the order cycle.
- **Greater personalisation / lot-size** – with modules reconfiguring on demand, you can fulfil small, custom batches profitably instead of batching them into big runs.
- **Reliable, real-time order status** – DTs stream progress and quality data into the Knowledge Base; the ERP/portal pulls that feed, so customers see up-to-the-minute status instead of generic “in production” flags.



How MODAPTO boosts the Business-Processes (BP) pillar

Distributed control through interoperable Digital Twins (DTs)

- Every machine, cell or line runs its own DT as a micro-service.
- DTs talk directly over a standards-based “module-to-module” bus, so scheduling, routing and quality rules are negotiated locally instead of funnelled through a central MES/PLC.
- Result ⇒ bottlenecks resolved in real time; the line keeps moving even if one controller or module goes offline.

Collective-Intelligence services

- Pillar 2 hosts shared engines for **optimisation**, **predictive maintenance**, and **sustainability analytics**.
- These services pull live data from all DTs, run global algorithms (e.g., energy-aware job sequencing, remaining-useful-life predictions) and push back set-points or alerts.
- The plant therefore acts as one self-optimising organism rather than isolated islands of automation.

End-to-end digitalisation & real-time visibility

- From raw-material receipt to finished-goods pallet, every step is mirrored in the Knowledge Base with timestamped events, KPIs and context.
- Operators and managers open a single dashboard to see cycle time, quality, energy, WIP, emissions—updated every few seconds.

Operational gains

- **Higher Overall Equipment Effectiveness** – predictive maintenance cuts unplanned stops; local optimisation trims small losses.
- **Lower energy use** – sustainability analytics suggest off-peak runs, idle-state strategies and eco-optimal process parameters.
- **Shorter reconfiguration time** – plug-and-play modules + digital templates shrink change-over from days to hours or minutes.

Data-driven business performance management

- Teams no longer hunt for data; they query the Knowledge Base, replay past runs in simulation, and deploy tweaks via the Service Orchestrator.
- Each improvement is version-controlled as a micro-service update, making PDCA cycles faster and evidence-based.



How MODAPTO reshapes the Business-Model (BM) pillar

Digital Twins offered as micro-services → “capabilities-as-a-service”

- Every DT exposes its algorithms (simulation, optimisation, health prediction, energy analytics) through APIs.
- You can sell these cloud-hosted capabilities to customers or sister plants on a pay-per-use or subscription basis—no need to install full-blown software at each site.

Open interfaces for partners to plug in new modules or complete production lines

- Standardised “module-to-module” and “module-to-system” contracts let companies ship pre-digital-twinning equipment that the plant can recognise instantly.
- This shortens time-to-market for joint ventures and enables marketplace models where third-party vendors list certified modules.

New digital revenue streams

- **Remote optimisation-as-a-Service:** sell scheduling or energy-minimisation runs performed by your Collective-Intelligence engine to external plants.
- **Predictive-Maintenance-as-a-Service:** monitor customers’ machines remotely and charge per asset or per avoided failure.
- **Sustainability dashboards:** monetise emissions reporting for supply-chain partners

Rapid launch of supplementary digital channels & lines of business

- Because the toolkit and orchestrator manage micro-service life-cycles, spinning up a customer portal or data-sharing channel is essentially a code deploy, not a plant-wide IT project.
- Enables agile experimentation with freemium features or pilot services without disrupting operations.

Scalable international roll-outs without heavy MES/PLC replication

- A green-field plant abroad only needs the lightweight message-bus, service-orchestrator, and the DT images; it does **not** need a monolithic MES build.
- Corporate HQ can push updates centrally while allowing local “think-global-act-local” customisations.

Digital Transformation Lens

Customer Experience (CE)	Business Processes (BP)	Business Model (BM)
<ul style="list-style-type: none">•Products/services (PS) lead to better product quality and faster delivery times, enhancing the customer experience.•PS also ensure consistent quality to customers.•Simulation services allow for the testing and development of more customer-tailored products and services.•Enhanced Digital Twins allow businesses to offer superior products by closely monitoring and adjusting production processes in real-time, ensuring high quality and customisation.	<ul style="list-style-type: none">•PS enhances business process efficiency through optimised scheduling and decision support tools.•PS also aims to optimise and innovate internal processes through simulation and experimentation.•PS streamlining maintenance planning, optimising asset performance, and minimising downtime.•Implementing precise measurement and storage of energy and carbon data at the module level enables businesses to make informed operational efficiency and sustainability decisions.•Reconfiguring modules streamline internal processes, making them more adaptable and efficient.•PS supports employees' daily tasks, centralising essential production knowledge and offering intelligent services.	<ul style="list-style-type: none">•Virtual commissioning enables pilots to adapt to customer requirements, leading to mass customization and personalization.•Indirectly applicable as access to detailed energy and carbon metrics facilitates the transformation of business models to include sustainability as a value proposition for environmentally conscious consumers.•New digital services/products/business models

Business KPIs can be improved using Modapto (1)

KPI	Details	Literature
Supply chain costs	Total costs in managing the supply chain (logistics, warehousing, transportation). Importance: Optimises supply-chain operations and reduces related costs.	Choy et al. (2007); Narimissa et al. (2020); Uysal (2012); Varsei et al. (2014)
Lead time	Time from order receipt to product delivery. Importance: Affects customer satisfaction and inventory management.	Cagno et al. (2019); Mittal & Jain (2014); Narimissa et al. (2020); Peruzzini & Pellicciari (2018); Shuaib et al. (2014)
Manufacturing costs	Total costs in producing goods (materials, labour, energy, overhead). Importance: Direct impact on pricing & profitability.	García-Muiña et al. (2018); Huang & Badurdeen (2018); Trianni et al. (2019)
Productivity	Output relative to input in production. Importance: Key for optimising resource use and efficiency.	Ahmad & Dhafr (2002); Mittal & Jain (2014); Schweitzer & Seidmann (1991); Sharma et al. (2018)
Production time	Time from start to completion of one unit. Importance: Critical for scheduling and on-time delivery.	Han et al. (2013); Khan & Bilal (2019); Zhu et al. (2017)
Reconfigurability characteristics	Indicators such as integrability, convertibility, customisation. Importance: Measure reconfiguration potential.	Farid (2017); Maganha et al. (2018)

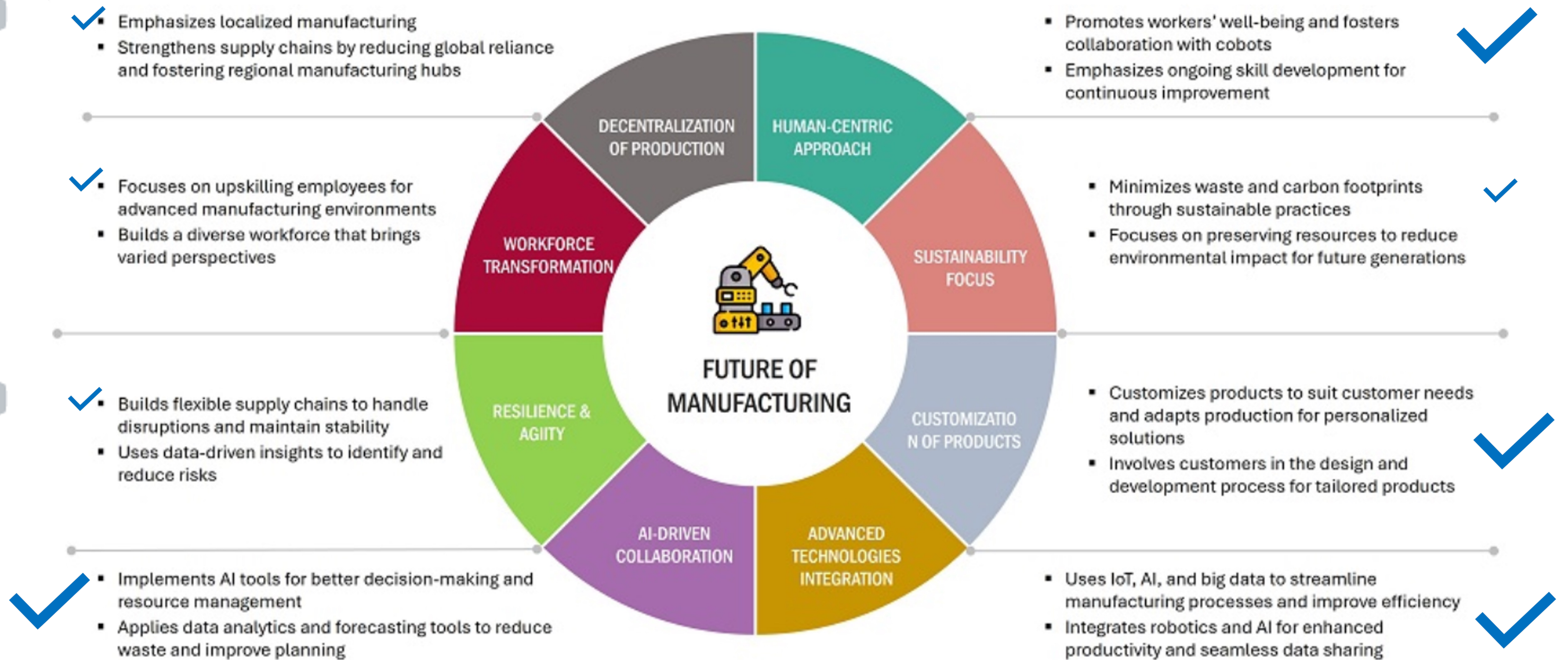
(Plitsos et al., 2025)

Business KPIs can be improved using Modapto (2)

KPI	Details	Literature
Production capacity	Total production capability vs. actual output. Importance: Reveals under/over-utilisation.	Ahmad & Dhafr (2002); Mittal & Jain (2014)
Assembly stability	Uniformity of production rate over time. Importance: Keeps steady pacing for timely delivery.	Zheng et al. (2008)
Due-date performance	System's ability to meet promised delivery deadlines. Importance: Core performance indicator.	Prasad & Jayswal (2018)
Reconfiguration time	Time required to reconfigure the manufacturing system. Importance: Shows adaptability to new needs.	Papazoglou et al. (2015); Prasad & Jayswal (2018)
Ramp-up time	Time to reach full capacity after changes. Importance: RMS must ramp-up fast to meet demand.	Koren et al. (1999); Mittal & Jain (2014)
Energy consumption	Amount of energy used in manufacturing. Importance: Identifies savings opportunities and cost reduction.	Abubakr et al. (2020);Ahi & Searcy (2015); Hristov & Chirico (2019); Shuaib et al. (2014)
Emissions	Pollutants released to air during production. Importance: Compliance with air-quality standards & sustainability.	Cagno et al. (2019); Piotrowicz & Cuthbertson (2015); Qorri et al. (2018); Visentin et al. (2020)

(Plitsos et al., 2025)

Key Drivers Shaping Future of Manufacturing Market – MODAPTO Addressing...



Sources: [MarketsandMarkets Report Future of Manufacturing Market](#)