BENCHMARKING COLLABORATIVE ASSET LIFE CYCLE MANAGEMENT: STRATEGIC INSIGHTS TOWARD A WIN-WIN-WIN MODEL

Lappeenranta–Lahti University of Technology LUT

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Abstract

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This thesis explores how collaborative, data-driven practices in industrial ecosystems can enable fair and sustainable management of asset lifecycle data. The research was conducted within the CoLife project, which develops national-level models for the fair-data economy in Finland. The study aims to identify how lifecycle data can be governed and utilised collectively to create value for companies, regulators, and society.

The research applies a qualitative benchmarking approach, analysing 36 European and Finnish initiatives that represent advanced use of data in industrial lifecycle management. The cases were examined through three analytical dimensions: (1) Asset Lifecycle Management and data continuity (A-claims), (2) Collaborative Governance and trust architectures (C-claims), and (3) Value Co-Creation and fair-data business models (V-claims).

The results show that lifecycle data continuity is emerging as a strategic infrastructure that enables predictive and circular decision-making across design, operation, and end-of-life phases. Collaborative governance practices are moving from relational coordination toward policy-as-code mechanisms that institutionalise trust and transparency. Value co-creation increasingly depends on fair and programmable data architectures that link technical datasets with contractual and quality metadata, turning data into a renewable and tradeable asset.

Building on these findings, the thesis proposes the CoLife Win-Win-Win Collaboration

Model, which integrates lifecycle data infrastructure, hybrid governance, and layered value architecture into a single system. This model defines CoLife as a collaborative infrastructure which is connecting technical efficiency, institutional reliability, and societal benefit. The study concludes that institutionalising lifecycle data governance can strengthen Finland's position as a forerunner in fair-data industrial collaboration and provides actionable guidance for implementing the CoLife Playbook.

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Azin Rafati

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Symbols and abbreviations

Abbreviations

AAIM	Advanced Asset Integrity Management
AAS	Asset Administration Shell
AI	Artificial Intelligence
ALM	Asset Lifecycle Management
API	Application Programming Interface
B2B	Business-to-Business
BIM	Building Information Modelling
BOM	Bill Of Materials
BOP	Bill Of Process
CE	Circular Economy
CEN	European Committee for Standardization; appears in your standards discussion
CORDIS	Community Research and Development Information Service (EU project repository)
CPS	Cyber-Physical Systems (used alongside DT)
CSA	Coordination and Support Action
DCF	Data Collection Framework
DIH	Digital Innovation Hub
DMP	Data Management Plan
DSS	Decision-Support System
DT	Digital Twin
EAL	Expected Annual Loss
ERP	Enterprise Resource Planning
FAIR	Findable, Accessible, Interoperable, Reusable
FIWARE	Open-source context platform by FIWARE Foundation
FPY	First Pass Yield
GAIA-X	European data spaces initiative
GDPR	General Data Protection Regulation
HPC	High-Performance Computing
HPDA	High-Performance Data Analytics
ICT	Information and Communication Technology
IDS	International Data Spaces
IEEE	Institute of Electrical and Electronics Engineers
IFC	Industry Foundation Classes

IMA	Independent Meta Agent
IoT	Internet of Things
IP	Intellectual Property
IPR	Intellectual Property Rights (exploitation/IPR plan)
ISO	International Organization for Standardization
OT	Operational Technology
KPI	Key Performance Indicator
LCA	Life Cycle Assessment
LCC	Life Cycle Cost
MAS	Multi-Agent System
MIDIH	Manufacturing Industry Digital Innovation Hubs
NGSI	Next Generation Service Interfaces (FIWARE data model/API family)
NIS2	EU Network and Information Security Directive (Directive (EU) 2022/2555)
OEE	Overall Equipment Effectiveness
OEM	Original Equipment Manufacturer
OPC UA	Open Platform Communications Unified Architecture
PLM	Product Lifecycle Management
QNH	Quintuple Helix
RCEAF	Regional Circular Economy Assessment Framework
RDF	Resource Description Framework
REST	Representational State Transfer (REST APIs)
ROI	Return On Investment
RRF	Recovery and Resilience Facility
SHM	Structural Health Monitoring
SITs	Smart Inspection Tools
SMEs	Small and Medium-sized Enterprises
TSN	Time-Sensitive Networking
WP	Work Package
ZDMP	Zero Defect Manufacturing Platform
ZDM	Zero Defect Manufacturing

Table of contents

List of Figures

List of Tables

Declarations

Turnitin

The originality of this thesis has been reviewed with the Turnitin similarity checking service.

AI usage

The author of the thesis, Azin Rafati, used the following AI-tools during the preparation of the thesis:

1. AI tool Grammarly
   - Purpose of use: developing the presentation and grammar of textual information
2. NotebookLM
   - Purpose of use: summarising the articles and case documents
   - Explanation of the use of the tool: AI-assisted tools were used to summarise academic articles, project deliverables, and case documents that formed part of the benchmarking dataset. The tool was applied only to support reading comprehension and synthesis by condensing long texts into concise summaries. All analytical interpretations, conceptual frameworks, and written sections of the thesis were prepared independently by the author. AI results were reviewed against original sources and were used to increase efficiency in information processing, without generating the main thesis content.

Responsibility

The author, Azin Rafati, takes full responsibility for the content of this thesis and has reviewed and edited the content generated by the possible use of AI tools

1 Introduction

The opening chapter introduces the overall theme of this study and situates it within the broader academic and industrial discourse on asset lifecycle management and collaborative data ecosystems. It illustrates the motivation for the research, explains the context provided by the CoLife project, and defines the key questions, objectives, scope, and structure of the thesis. So, the introduction establishes both the relevance of the topic and the contribution that this thesis seeks to make.

1.1 Research context and background: The CoLife project

Industrial companies increasingly rely on asset lifecycle data that spans from design and commissioning to operation, maintenance, and end of life. This data has the possibility to improve asset performance, extend lifetimes, support maintenance, and enable the sustainability transitions (ISO 55000, 2024; Kortelainen et al., 2023). However, in practice, data remains fragmented across organisational and technical boundaries, which limits its usability and creates barriers to collaboration. The main challenge is the coordination of lifecycle data in multi-actor ecosystems in a way that maintains semantic integrity and enables shared value creation (Kääriäinen et al., 2025).

This problem is not only a technical issue but also an ecosystem-level coordination challenge. Previous studies have shown that data sharing is often blocked by the lack of trust, unclear governance, and uncertainty about value distribution (Curry et al., 2022; GFMAM, 2024). Companies do not utilise data and lose opportunities for achieving business growth, safety improvement, and Circular Economy benefits (European-Commission, 2020a).

The *CoLife project (Data economy in collaborative asset lifecycle solutions)* responds to this challenge. It is a Business Finland co-research initiative (2024-2026) led by VTT and LUT University, aiming to create a playbook for fair data economy in industrial asset management ecosystems. Its vision is that business partners collaborate equally in lifecycle phases, generating economic, environmental, and social benefits through fair data sharing and new operating practices (CoLife-project-plan, 2024; CoLife-Presentation, 2025). This thesis is embedded within CoLife, and according to systematically *benchmarking international cases* to extract strategic insights for a *win-win-win collaboration model* tailored to the Finnish industry.

1.2 Research objective and questions, and scope of research

The overall objective of this thesis is to benchmark collaborative practices and value co-creation models in data-driven industrial asset lifecycle ecosystems, with the aim of supporting the development of fair and future-oriented collaboration models in Finland and beyond. In other words, the study wants to generate actionable strategic insights for CoLife by evaluating how collaborative ecosystems manage lifecycle data, how value is co-created, and how benefits can be shared fairly.

From this objective arises one main research question and four sub-questions:

Main Research Question:

1. *How do industrial data ecosystems manage asset lifecycle data to enable value co-creation and fair data sharing practices among stakeholders?*

Sub-questions:

1. *What collaborative practices and actor roles are present in existing asset lifecycle data-sharing ecosystems?*
2. *In what ways is data used as a strategic asset, and how does this influence business outcomes and sustainability?*
3. *What types of value co-creation (win-win-win) models are applied, and how do they address the fairness in data use between different actors?*
4. *What strategic insights can be drawn from benchmarking cases to improve industrial data ecosystems for asset lifecycle management models in the Finnish context?*

These questions not only narrow the research area, but also shape the literature review including themes such as asset lifecycle management, collaborative ecosystems, and value co-creation, the research design which includes systematic benchmarking of EU and Finnish cases, and the analysis approach which is cross-case synthesis.

The study concentrates on collaborative ecosystems in which multiple actors such as Original Equipment Manufacturers (OEMs), service providers, operators, regulators, and technology firms engage in lifecycle data sharing. The geographic focus is mainly European, with cases drawn from EU Horizon projects and Business Finland initiatives, where collaboration models are actively tested in line with EU digital and green transition policies (European-Commission, 2020a).

Case selection follows the systematic search process, which is documented in the *CoLife*

Search Tracker (2025) (see Appendix 1), which identified cases with high-, medium-, and low- relevance. The benchmarking analysis focuses on high- and medium-relevance cases to identify strategic alignment with CoLife's goals.

1.3 Structure of thesis

This thesis is structured in six main chapters that progress from defining the research context to deriving strategic insights for the CoLife project. Each chapter builds on the previous one and contributes to answering the research question and sub research questions (RQ, and Sub-Q1-Q4) presented earlier. Table 1 summarises the structure and illustrates how each chapter contributes to the research questions and their sub-questions.

Chapter	Main content	Key contribution/Link to RQ & SRQs
1 Introduction	Presents the study background, motivation, research objectives, and scope within the CoLife project context. Defines the main and sub-research questions guiding the work.	Frames the overall research problem and objectives that the subsequent chapters address.
2 Literature Review	Synthesises theories on asset lifecycle management, collaborative ecosystems, data as a strategic asset, value co-creation, and data-driven business models. From these, three analytical pillars are derived to guide the analysis.	Addresses SRQ 1–2 by establishing the conceptual foundation for benchmarking collaborative practices and data-driven value creation.
3 Methodology	Describes the benchmarking design, including search strategy, selection criteria, data sources, and analysis framework. Ensures methodological transparency and reliability.	Explains how the theoretical pillars are operationalised; supports SRQ 1–4 through systematic data collection and analysis design.
4 Benchmarking Analysis	Presents results from 36 European and Finnish initiatives. Summarises key practices, governance models, and data-use approaches relevant to CoLife.	Provides empirical evidence to answer SRQ 1–3, showing how lifecycle data and collaboration are managed in real projects.
5 Discussion	Interprets benchmarking findings through the A-, C-, V-claims framework. Derives strategic implications for CoLife and proposes the Win-Win-Win Collaboration Model.	Integrates insights to answer SRQ 4 and the Main Research Question concerning how collaborative ecosystems manage and share lifecycle data for value co-creation.
6 Conclusions	Summarises key findings, outlines contributions to the CoLife Playbook, and discusses research limitations and directions for future research. Emphasises how lifecycle data continuity, governance, value creation interconnect.	Consolidates all research questions and highlights the overall contribution of the study to the CoLife concept.

Table 1: Structure of the thesis

2 Literature review

This chapter builds the theoretical scaffolding that guides the study clarifying what core concepts matter, how they relate, and why those relationships should hold, along with who, where, and when boundary conditions. It synthesises five strands, such as *asset lifecycle management*, *collaborative ecosystem practices*, *data as a strategic asset*, *value co-creation* and *win-win-win models*, and *data-driven business model and monetisation strategies*. The literature is integrated into a coherent conceptual frame that later informs case selection, CoLife search tracker (see appendix 1), and interpretation, and it culminates in a summary of the theoretical framework used in analysis.

2.1 Asset lifecycle management

Asset Lifecycle Management (ALM) concerns the coordinated management of physical assets and their information from early design and engineering through production, operation and maintenance, and finally end-of-life, recovery and circular loops. The ISO 55000 family frames asset management as the systematic, risk-based realisation of value across the whole lifecycle, aligning investment, performance and risk with organisational objectives (ISO 55000, 2024; ISO 55002, 2018). In contemporary manufacturing, ALM is inseparable from data continuity. Decisions taken at design and process engineering must remain traceable to behaviours observed in production and in-use, otherwise quality, safety and sustainability claims rest on fragmented evidence (Stark, 2022). When lifecycle data travel with the asset, organisations reduce rework and the cost of proof quality, improve availability and reliability, and enable sustainability outcomes such as lifetime extension, reuse and remanufacturing (Porter & Heppelmann, 2014;Tao et al., 2019).

It is helpful to distinguish Product Lifecycle Management (PLM) from ALM. PLM is the information backbone for product artefacts and engineering change. In this thesis, ALM emphasises the broader industrial lifecycle of assets in operation, including service logs, condition monitoring, work orders and end-of-life decisions. Reliability-Centred Maintenance (RCM) illustrates how lifecycle thinking moves organisations from reactive to proactive regimes by linking failure data to design changes and maintenance plans (Moubray, 1997). In that sense, ALM is not merely a software category but a managerial and governance challenge; who can access to which lifecycle records, with what rights, so that lessons learned at one stage feed improvement in others.

While ALM focuses on optimising the use and performance of physical assets throughout their operational life, it closely interacts with PLM, which governs product-related data and processes from design to manufacturing. In practice, these two domains are increasingly integrated through digital twins, data spaces, and interoperability standards that enable continuity of information from product design to asset operation (ISO 55000, 2024; GFMAM, 2024; Stark, 2022). Subsection 2.1.2 introduces PLM as a complementary framework to ALM, highlighting their convergence in modern data-driven ecosystems.

2.1.1 Lifecycle data continuity and feedback loops

The core challenge for achieving lifecycle data continuity is preserving semantic integrity so that meaning and context survive each handover (design $\rightarrow$ production $\rightarrow$ operations $\rightarrow$ service). Practically, this means binding "as-designed" product structures (BOM (Bill Of Materials)), "as-planned" process (BOP (Bill of Process)), and "as-built/as-maintained" states into a coherent (Stark, 2022). With that thread in place, closed-loop learning becomes routine: defects seen at inspection trigger parameter changes in the process plan; recurrent field failures motivate a design modification and new work instructions. Such loops are credible only when provenance, versioning and change control are robust, and when cross-firm agreements make reuse of shared data legitimate and worthwhile (ISO 55002, 2018; Tao et al., 2019). Without such foundations, lifecycle analytics produce false certainty and organisational learning stalls.

2.1.2 Digital enablers for asset lifecycle management

Digital enablers such as PLM and digital twins (DTs) play a crucial role in achieving lifecycle data continuity and collaborative value creation. Together, they support integration, real-time insights, and secure data sharing across ecosystems (Stark, 2022;Firdausy et al., 2022). PLM platforms provide structured repositories and workflows for lifecycle artefacts, ensuring that engineering changes, approvals, and releases are governed and auditable. Digital twins synchronise virtual models with live operational data to support predictive maintenance, quality management, and "what-if" analysis; they become powerful when linked to upstream design intent and downstream service outcomes (Tao et al., 2019). Emerging industrial data spaces expand these capabilities across organisations by ensuring data sovereignty, usage control, and interoperable semantics are crucial when lifecycle actors span OEMs, suppliers, service providers, and recyclers (Otto, Teuscher & Lohmann, 2019). Standards such as ISO 23247 established a reference framework for digital twins in manufacturing, helping organisations operationalise twins as part of lifecycle governance (ISO 23247-1, 2021). These technologies create value only when embedded in clear ecosystem governance and a viable value logic topics developed in sections 2.2, 2.4, and 2.5.

2.2 Ecosystem collaboration practices

Industrial value creation increasingly takes place in ecosystem, not in isolated firms or simple dyadic supply contracts. An ecosystem is a set of interdependent actors such as OEMs, Small and Medium-sized Enterprises (SMEs), technology vendors, research organisations and public bodies, whose offerings combine to deliver a large solution to end users (Adner, 2017). Unlike a traditional supply chain that is orchestrated mainly by price and bilateral contracts, ecosystems performance depends on orchestration (who convenes and sets direction), the role structure such as owner, integrators, complementors, and trust mechanisms that reduce the cost of collaboration at scale (Tiwana, 2014). Governance choices include decision rights, admission and certification, liability rules, and conflict resolution process; they make collaboration predictable and reduce transaction costs (Jacobides, Cennamo & Gawer, 2018).

In this thesis, the term *collaborative ecosystem* refers to an industrial data ecosystem in which multiple independent organisations intentionally coordinate technical, organisational, and governance activities to enable shared value creation. While all ecosystems involve interdependence, the qualifier collaborative highlights that data sharing, joint governance, and co-creation mechanisms are explicit, structured, and necessary for lifecycle data continuity.

In practice, effective collaboration hinges on how the ecosystem is orchestrated and how participants are enabled to contribute. Orchestration may follow a keystone-led model, where a dominant platform owner sets the direction; a consortium-led model, where several anchors share control; or a neutral-intermediated model, coordinated by an independent third party with light assets. Each mode implies different decision rights, funding flows and accountability, and thus different barriers to entry for participating firms (Gawer & Cusumano, 2014; Dhanaraj & Parkhe, 2006). Role clarity is reinforced by boundary resources, Application Programming Interfaces (APIs), data schemas, Software Development Kits (SDKs), testbeds and clarification kits that lower integration costs and make complementor behaviour predictable at scale (Tiwana, 2014; Parker, Alstyne & Choudary, 2016). When boundary resources are stable and well-documented, partners can invest in complements without fear of holdup or sudden rule changes (Adner, 2017).

Governance translates the rules of the game into working routines. The participation rules define who can join and under what conditions. Interface and versioning policies specify how data models and APIs evolve without breaking installed integrations. Intellectual Property (IP) and data-usage policies determine what can be shared and on what terms. Liability and dispute resolution allocate risk when things go wrong, while compliance processes make behaviour observable and enforceable (Jacobides et al., 2018). These routines reduce transaction costs that would otherwise multiply across one-off bilateral deals, and they encourage participants to contribute higher-quality data because rights and responsibilities are unambiguous.

Sustained collaboration also requires a track of trust organisational, social, and technical. Organisational trust is created by contracts, accreditation, and credible enforcement (Khatri & Brown, 2010; Otto et al., 2019); social trust grows through reputation and repeated interaction (Dhanaraj & Parkhe, 2006; Jacobides et al., 2018); and technical trust comes from identity and access management, policy-enforced usage control (who may use which data, for what purpose, under which licence), and auditability, so contributions and use can be verified after the fact (Curry et al., 2022). Modern data space approaches such as the International Data Spaces (IDS) reference architecture and European data spaces initiative (GAIA-X) combine these controls with governance patterns, so firms can share lifecycle data while retaining sovereignty over how their data are used (Otto et al., 2019;Firdausy et al., 2022). In asset-intensive settings, this trust stack is what allows *as-designed* and *as-planned* data to meet *as-built/as-maintained* records across firm boundaries without losing context or breaching obligations (GFMAM, 2024; Kääriäinen et al., 2025).

Collaboration is only sustainable when benefits are perceived as fair, ecosystems typically embed incentive alignment. Mechanisms include contribution-based access tiers, revenue-sharing for data-enabled services, shared-saving contracts for quality or uptime improvements, and recognition schemas that reward high-value data providers. These mechanisms link contribution to appropriation, preventing free-riding and keeping SMEs engaged alongside large orchestrators (Parker et al., 2016). Where environmental or societal outcomes matter, multi-dimensional Key Performance Indicators (KPIs) keep the *win-win-win* principle which is creating shared value for industry, the environment, and society, promise visible and auditable across partners.

In ALM, collaborative practices determine whether the *digital thread* which is the continuous flow of data linking design, production, operation, and end-of-life, can truly cross organisational boundaries. The concept refers to maintaining a continuous chain of digital information that links as-designed, as-built, as-used, and as-maintained records, thereby enabling end-to-end traceability can across organisational boundaries (Tao et al., 2019; Singh & Willcox, 2018). A well-coordinated ecosystem mandates shared identifiers and schemas, certifies data producers and consumers, and enforces usage policies so suppliers can publish quality and process capability data, service partners can append maintenance and condition histories, and OEMs can feed lessons back into design. The result is closed-loop learning that improves quality, resilience and circularity at the system level (Adner, 2017; Tiwana, 2014). Where orchestration is weak or rules are ambiguous, data either do not flow or arrive stripped of provenance and permission, undermining their value for ALM decision making.

2.3 Data as a strategic asset

In this thesis, treating data as a strategic asset means managing data with the same discipline as any asset that creates value over time. It must be identified, governed, protected, maintained, combined with complementary resources, and measured for impact. Unlike physical assets, data are non-rival, durable, and scalable. These properties make data uniquely powerful for cross-firm collaboration, provided quality, rights, and trust are in place (Laney, 2017). The following subsections show how economic, organisational, and technical elements must work together for data to function as a strategic resource.

2.3.1 Value creation mechanisms with data

Scholars generally agree that *data contribute to value creation* through multiple interrelated pathways when they are effectively combined with organisational capabilities and ecosystem arrangements. Building on the literature, three broad pathways can be distinguished that are particularly relevant to collaborative asset lifecycle management.

First is: *efficiency gains and risk reduction*. It means that by connecting design, manufacturing, and service data, organisations can reduce defects, downtime, and rework. Data-driven coordination improves asset reliability, reduces maintenance costs, and decrease operational risks with finding early faults and more efficient use of resources (Porter & Heppelmann, 2014; P. Hartmann et al., 2016; Wamba et al., 2017). The second pathway is: *data enhances services and decision-making*. Lifecycle data becomes a base for new analytics-based services, ranging from predictive maintenance and quality forecasting to improved production planning. So, data acts as a strategic asset that not only informs internal decision-making but also enables new value propositions for customers and partners (Tao et al., 2019; Bharadwaj et al., 2013; Loebbecke & Picot, 2015). And the third pathway is: *collaborative data sharing generates ecosystem and network effects*. When multiple actors contribute interoperable datasets, the value of the system increased with each additional participant. Such data network effects create opportunities for richer insights, but their realisation depends on clear rules for contribution, access and appropriation of value. Without proper management, data may be withheld and the collective interest undermined (Parker et al., 2016; Jacobides et al., 2018). In other words, *data alone are not inherently valuable*. They become a source of sustained advantage only when combined with organisational capabilities in governance, analytics, and change management, alongside effective participation of ecosystem partners (P. Hartmann et al., 2016; Wamba et al., 2017).

2.3.2 Data governance operation model

A strategic stance on data governance requires a governance operation model that makes day-to-day decisions predictable and repeatable across participants (Khatri & Brown, 2010). In practical terms, this model specifies decision rights and roles, who owns which datasets, who serves as data owner, steward or custodian, and who approves sharing or retention, together with the policies and controls that govern access and usage such as licences and permitted purposes, classification, retention, security and end-to-end lineage so it is always clear who changed what and when. It also institutionalised data quality management by defining explicit dimensions and themes like accuracy, completeness, consistency, timeliness, and validity, setting thresholds and monitoring routines, and establishing remediation paths when quality drifts (R. Wang & Strong, 1996). To make assets discoverable and usable beyond a single team or firm, the operating model mandates catalogues and metadata, for example, entries that record each dataset's owner, schema, licence and quality score, and it encourages treating curated data products such as stable, documented, versioned datasets or APIs, as reusable building blocks that downstream teams and partners can rely on. In combination, these elements translate strategy into operational practice: partners know what they can obtain, under what conditions, and who is accountable, essential prerequisites for collaboration at scale (Khatri & Brown, 2010).

2.3.3 Interoperability and sovereignty

Cross-firm lifecycle sharing only works when two conditions are met: (1) interoperability and (2) data sovereignty. Interoperability must exist simultaneously at three level; the *syntactic level* which is common formats and APIs so system can exchange payloads without manual rework; the s*emantic level* which is shared data models and ontologies so exchanged terms mean the same thing to all parties; and the *organisational level* which is aligned processes and responsibilities, so data are produced, curated, and consumed in predictable way. FAIR principles are Findable, Accessible, Interoperable, and Reusable to provide a practical test of whether data sets are *asset ready* beyond a single enterprise (Wilkinson et al., 2016). To protect contributors while still enabling reuse, many industrial ecosystems adopt data space architectures (e.g., International Data Spaces, GAIA-X) that combine strong identity, policy enforced usage control and auditability, allowing companies to share data with conditions instead of relinquishing copies (Firdausy et al., 2022). In manufacturing specifically, patterns such as the Asset Administration Shell (AAS) and Open Platform Communications Unified Architecture (OPC UA) interfaces, together with ISO's digital-twin framework, reduce ambiguity when linking design, process and maintenance information across actors, and they make provenance, versioning and permissions travel with the data along the entire digital thread (ISO 23247-1, 2021).

2.3.4 Regulatory context

The regulatory frame defines what is permissible and how rights are allocated. The General Data Protection Regulation (GDPR) governs personal data relevant at the shop-floor or field service boundary where worker or end-user information appears (Regulation (EU), 2016). The Data Governance Act encourages trustworthy data intermediation and altruism in the EU, while the Data Act clarifies who may access data generated by connected products and related services, sets neutrality duties for data intermediaries, and facilitates Business-to-Business (B2B) access under fair terms, directly impacting industrial ecosystems (European Commission, 2023). For critical infrastructure and suppliers, EU Network and Information Security Directive (NIS2) elevates cybersecurity obligations important when cross-firm data flows become operationally essential. These rules do not prevent sharing; they shape viable governance and contracting designs.

2.3.5 Enabling conditions for data-driven value creation

Because *you cannot manage what you do not measure*, a strategic stance includes valuation and performance metrics (Laney, 2017). Internally, you can track use, reuse, and time-to-insight for key data products, assign owner/stewards, and report quality KPIs. Economically, firms may estimate data's economic value of information and, in collaborative settings, use shared-savings, access-tier or revenue-share mechanisms that link contribution to appropriation (P. Hartmann et al., 2016; Teece, 2010). The point is not to put data on a balance sheet, but to make investment and sharing decisions transparent, repeatable, and defensible.

In the literature, treating data as a strategic asset is often described as a bridge between technical feasibility and sustainable participation in the ecosystem. Several conditions have been highlighted as significant for enabling data-driven value creation. First, it is essential to have explicit governance mechanisms to define roles, responsibilities, and decision-making rights among actors (Khatri & Brown, 2010; Otto et al., 2019). Second, providing FAIR data, and provided with clear quality criteria and licensing arrangements, supports trust and comparability (Wilkinson et al., 2016). Third, governance controls over data sharing, as advanced in international data spaces and related architectures, allow companies to maintain control while participating in collaborative value creation (Otto et al., 2019; Curry et al., 2022). Finally, measuring value outcomes, which are productivity improvements, resilience benefits, or Circular Economy gains, creates incentives for partners to engage beyond pilot projects and help transform one-off initiatives into reusable and multi-agent capabilities (P. Hartmann et al., 2016).

2.4 Value co-creation and win-win-win models

In this thesis, value co-creation means that outcomes emerge from the joint activities and resources of multiple stakeholders rather than being delivered unilaterally by a single firm. In industrial settings, those interactions span design, manufacturing, service and end-of-life loops; When actors bring complementary data, capabilities and context to these touchpoints, the result can be fewer defects, shorter downtimes, better planning and extended asset life (Grönroos & Voima, 2013; Porter & Heppelmann, 2014). Importantly, co-creation is a process, not a slogan: It requires repeated exchanges in which data and insights flow both ways, learning accumulates, and practices are adjusted (Payne, Storbacka & Frow, 2008).

Operationally, ecosystems co-create value when they lower the cost of coordinating many partners and make shared data reliably usable. Boundary resources such as stable APIs, schemas, and testbeds, partner enablement such as documentation and certification, and clear participation rules reduce integration friction so complementors can contribute without bespoke negotiations each time (Tiwana, 2014; Jacobides et al., 2018). In asset-lifecycle context, these enablers allow suppliers to publish process and quality data, OEMs to supply engineering context, and service partners to attach condition and repair histories. The joint outcomes are a richer digital thread that supports, for example, predictive maintenance, quality prediction, and circular decisions, benefits that no single firm could create alone (Porter & Heppelmann, 2014; Tao et al., 2019).

As benefits and costs are distributed, durable co-creation depends on fairness in how contributions are recognised and rewards are allocated. Without credible mechanisms, large players may dominate and SMEs under-invest. Fairness can be designed through contribution-aware access (greater data contribution unlocks richer services), transparent usage licences, shared-savings or outcome-based contracts, and revenue-sharing for data-enabled services (Parker et al., 2016). These mechanisms connect contribution like granular, high-quality process data, and domain apps to appropriation such as preferential access, fees, revenue share, reducing free-riding and aligning incentives over time. Governance then makes fairness enforceable: decision rights, admission/certification, dispute resolution and audit trails provide the institutional scaffolding so partners can trust that agreed splits will hold (Jacobides et al., 2018).

A win-win-win framing extends co-creation more than bilateral firm-to-firm gains to include societal and environmental value. This broader lens reflects the triple bottom line economic, environmental, and social performance and legitimises investments whose private return is coupled to system-level benefits such as reduced scrap, energy efficiency, and safer operations (Porter & Heppelmann, 2014; Lozano, 2012). In practice, this widens the incentive space: firms can justify participation not only private Return On Investment (ROI), but also on compliance, licence-to-operate, and reputation (Prahalad & Ramaswamy, 2004; Vargo & Lusch, 2008).

To keep the third win visible and credible, ecosystems need multi-dimensional KPIs that combine efficiency/quality metrics like FPY (First Pass Yield), MTBF (Mean Time Between Failures), and rework, risk/resilience indicators and environmental measures. Publishing these indicators at agreed cadences, and linking parts of remuneration or access tiers to them, helps sustain contribution that create public or system value (Kaplan & Norton, 2004; Schaltegger et al., 2006; Rajala, Westerlund & Lampikoski, 2016).

Tensions in value co-creation with lifecycle data are inevitable when multiple actors with different incentives collaborate. For instance, short-term data protection concerns can conflict with the goal of long-term system learning and innovation. Similarly, local optimisation at the enterprise level, such as not providing specific performance data, can undermine system-level efficiency across the ecosystem. Finally, asymmetric data ownership and control may distort bargaining power, enabling dominant players to capture disproportionate value at the expense of smaller partners (Jacobides et al., 2018; Kohtamäki et al., 2019).

Researchers emphasise that co-creation only survives when such trade-offs are explicitly managed. Data space approaches that combine usage-controlled sharing with auditability allow partners to contribute data under defined conditions rather than relinquishing full control, while contractual arrangements establish liability rules and protect intellectual property rights (Curry et al., 2022; Otto et al., 2019). Seen from this perspective, sustainable value co-creation requires repeatable governance patterns that convert heterogeneous contribution into joint outcomes and distribute gains credibly across firms and society (Ramaswamy & Ozcan, 2018; Ritter & Pedersen, 2019).

2.5 Data-driven business models and monetisation strategies

In this thesis, a data-driven business model is the coherent logic by which organisations create, deliver and capture value from data embedded in products, processes and services. Data reshape both what is offered (from one-off artefacts to ongoing outcomes) and how value is divided among ecosystem actors. Crucially, monetisation is not the same as *selling data*. It encompasses efficiency gains that reduce cost and risk, new service revenues enabled by continuous telemetry, multi-sided platform income from brokering interaction, and packaged data products with explicit service levels, each demanding distinct choices about governance, pricing and risk allocation. The questions are: who pays? for what and why?, and the answers show how these models attach credible cashflows or verified savings to the flows of lifecycle data.

Scholars of digitalisation and data-driven business models have identified several distinct monetisation logics through which firms and ecosystems capture value from data (P. Hartmann et al., 2016; Ritter & Pedersen, 2019; Wirtz et al., 2016). Synthesising these insights, four logics can be distinguished as particularly relevant for collaborative asset lifecycle management.

The first logic is *efficiency-anchored value capture*, where better lifecycle data close the loop between design, manufacturing, and service. When a robust digital thread exists, firms cut rework and scrap, reduce downtime and inventories, and stabilise quality; the value is realised as cost avoidance and yield improvements, even if no data are sold outright (Porter & Heppelmann, 2014; Wamba et al., 2017). In inter-firm settings this logic scales via shared-savings contracts: verified improvements (e.g., scrap reduction, higher Overall Equipment Effectiveness (OEE)) are split between contributors, effectively pricing the right to use cross-firm datasets through the savings allocation. This makes participation economically rational for supplier and service partners whose high-quality data are essential to the outcome.

The second logic is *service/servitization*, where revenue shifts from product sales to pay-per-use or outcome-based contracts that depend on continuous condition and usage data (Baines et al., 2009; Porter & Heppelmann, 2015). Predictive maintenance and performance guarantees rely on telemetry to pick risk, schedule interventions and documents delivered outcomes (Baines et al., 2009; Porter & Heppelmann, 2015; Kohtamäki et al., 2019). Here data are strategic because they reduce uncertainty for both parties: providers price more accurately and intervene earlier; customers buy availability, energy efficiency or quality rather than inputs. Monetisation sits in the contract fees indexed to KPIs such as uptime or energy intensity, while governance must settle liability, IP and data-rights so the requisite datasets keep flowing across the asset's life.

The third logic is *platform/data-space intermediation*, where a neutral or keystone actor brokers data and services among many participants and enables complementors (Eisenmann, Parker & Alstyne, 2006; Parker et al., 2016). Revenues arise from access tiers, brokerage, certification, analytics services or revenue sharing (Eisenmann et al., 2006; Parker et al., 2016). In industrial contexts data-space patterns such as IDS and GAIA-X, matter because they support usage-controlled sharing: participants contribute data with conditions and retain sovereignty, which expands the pool of willing contributors. Monetisation therefore couples governance themes like policies, certification, auditability, with pricing which tiers for access quality, fees for verified usage, turning trust into an economic asset that attracts both SMEs and large firms (Firdausy et al., 2022; Otto et al., 2019; Curry et al., 2022).

The fourth logic is the *data-product approach*, where specified datasets, APIs or analytical outputs are packaged as products with clear semantics, documentation, quality scores and versioning. Successful data products are discoverable and dependable enough for downstream planning or automation, which justifies subscriptions, consumption-based API pricing, or embedded monetisation when data products are bundled into higher margin service (Laney, 2017; P. Hartmann et al., 2016). Because multiple parties often hold rights in the underlying data, governance must address licensing, provenance and revenue allocation; ecosystems typically rely on contributor agreements and telemetry-based usage logs to apportion value fairly (P. Hartmann et al., 2016)

These choices do not happen in a vacuum, regulation shapes what is viable. The EU Data Act clarifies who may access data generated by connected products and related services, promotes fair B2B access, and sets neutrality duties for certain intermediaries (European Commission, 2023). The practical effect is to make exclusivity strategies harder to sustain and to push platform owners toward neutral governance that treats participants even-handedly while still allowing value capture via certification, analytics or premium features. Conversely, in safety-critical or IP-sensitive sectors, sovereign sharing with strong usage control and certification remains justified, showing that regulation channel model design rather than forbids it.

Across all models, two design principles determine whether value is merely created or actually captured. First, there must be a credible appropriation mechanism that links contribution to reward shared savings, tiered access, revenue share or outcome indexed fees otherwise contributors (especially SMEs) under-invest (Teece, 2010). Second, governance must make that link enforceable: decision rights, licensing, audit trails and dispute resolution transform promises into predictable cashflows and sustained participation.

Finally, measurement anchors credibility and supports pricing. Firms should track not only revenue but also quality/efficiency KPIs, risk/resilience indicators, and where relevant sustainability metrics (Kaplan & Norton, 2004; Schaltegger et al., 2006; Rajala et al., 2016). These indicators validate shared-savings splits, justify service fees and make environmental value visible an essential part of the win-win-win logic that keep ecosystems stable in the long run (Porter & Kramer, 2011; Baines et al., 2009).

2.6 Summary of theoretical framework

The integrated framework, illustrated in Figure 1, positions ALM as the process spine that defines *"what"* data must flow and *"when"*. Collaborative ecosystem practices and data as a strategic asset provide the coordination and governance context that makes cross-firm data sharing feasible, representing the capability to govern, secure, and combine data across organisational boundaries, so they answer to *"how"*. Value co-creation and data-driven business models capture the intended pattern of shared benefits, including environmental and societal outcomes, and define the monetisation and appropriation mechanisms that sustain participation in the ecosystem, so they answer to *"why"*.

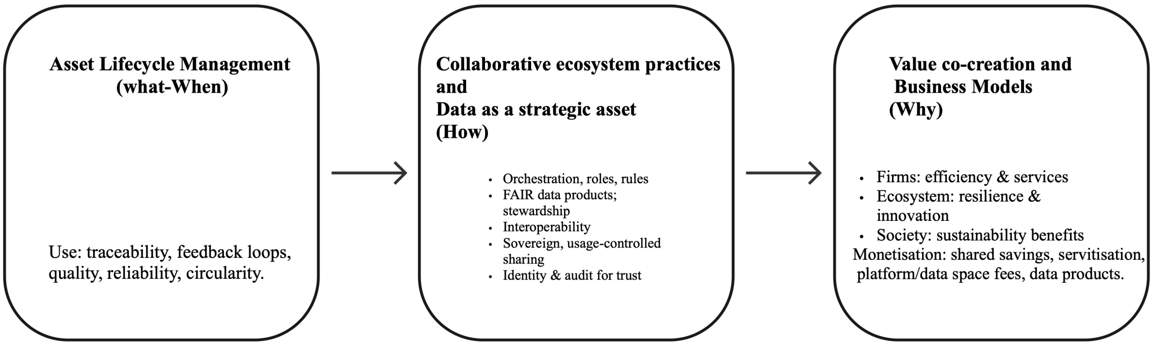

Figure 1: Theory to design map

The integrated framework is further operationalised through the pillars and associated clusters, which serve as the conceptual bridge between theory and benchmarking practice. These clusters translate the three pillars into observable domains, industrial data ecosystems and marketplaces, governance and trust, Circular Economy, Zero-Defect Manufacturing (ZDM), and supply chain collaboration. The relationship between the pillars and clusters is illustrated in Figure 2. Together, these lenses explain what must be shared across the asset lifecycle, how ecosystem structures enable that sharing, and why actors participate under explicit boundary conditions. This theoretical synthesis maps directly to the benchmarking variables and evaluation criteria used in the empirical chapters: lifecycle coverage, collaboration and governance, data assets and infrastructures, and value logic. Therefore, it provides a coherent basis for case selection, coding, and cross-case interpretation in the CoLife context.

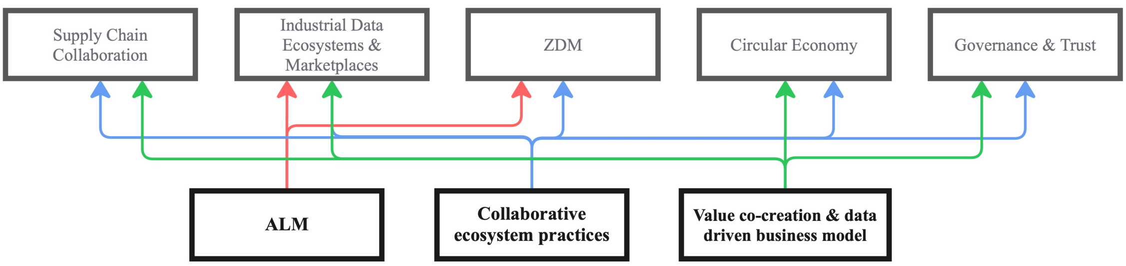

Figure 2: Theoretical pillars and search clusters

To anchor terminology and ensure consistent coding across cases, Table 2 consolidates concise definitions of the core constructs used in this thesis; Asset lifecycle management, collaborative ecosystems, data as a strategic asset, value co-creation, win-win-win model, and data-driven business models, clarify the specific role each construct plays in this study. This shared vocabulary reduces ambiguity in later chapters and links the theoretical discourse to the operational framework applied in the benchmarking.

Term	Definition	How it's used in the thesis
Asset lifecycle management (ALM)	Coordinated management of an asset and its information from design and process planning through production, operation/maintenance, and end-of-life/circular loops. Practically, ALM depends on a governed digital thread that ties "as-designed" (BOM), "as-planned" (BOP/routings) and "as-built/as-maintained" states so evidence can flow forward to execution and back to design.	ALM is the process spine: it specifies what data must flow, when and why. This study benchmarks cases based on lifecycle coverage and the strength of feedback loops.
Collaborative ecosystem	A coordinated set of interdependent actors (e.g., OEMs, SMEs, technology vendors, research bodies, public agencies) that create value together via shared interfaces, standards and governance. Effective ecosystems have explicit orchestration, roles, rules and trust mechanisms that lower coordination costs.	Provides the "how we collaborate" context. The study looks for orchestration, roles, rules, and trust/sovereignty controls that let lifecycle data cross firm boundaries predictably.
Data as a strategic asset	Treating data like any value-creating asset: identified, governed, protected, quality-managed, interoperable and measured for impact. Asset-readiness is shown by stewardship, quality/lineage controls, FAIR principles and packaging data as reusable "data products".	Supplies the capability layer that turns raw signals into dependable assets. The study checks for governance, quality, metadata/-catalogues, interoperability and sovereign sharing.
Value co-creation	Value emerges from interactions among multiple stakeholders rather than being delivered by one firm alone. In industry, co-creation occurs when actors contribute complementary data and capabilities across design–production–service, producing fewer defects, shorter downtimes, better planning and circularity gains.	Defines the outcomes that are expected from sharing lifecycle data. The study assesses whether cases evidence joint outcomes and whether fairness mechanisms recognise contributors.
Win-win-win model	Collaboration that creates value simultaneously for firms (cost/quality/service), for the ecosystem (resilience, shared learning, innovation) and for society/environment (less waste, lower emissions, safer operations). It remains credible when contribution→reward links and multi-dimensional KPIs are transparent.	Sets evaluation lens for benefits and fairness. The study looks for firm/network/societal KPIs and mechanisms such as shared savings, revenue-share or access tiers.
Data-driven business model	The logic by which organisations create, deliver and capture value from data embedded in products, processes and services. Common logics include efficiency/shared-savings, servitization (pay-per-use/outcome-based), platform/data space intermediation, and packaged data products.	Provides the appropriation logic that sustains participation. The study identifies which model a case uses and how contribution is linked to reward under regulation (e.g., EU Data Act).

Table 2: Definitions and roles

2.7 Implications for the CoLife Project

The literature reviewed in this chapter highlights several challenges and influencing factors that are directly relevant to the CoLife project's ambition of designing a fair data economy for industrial asset management ecosystems.

First, research on *Asset Lifecycle Management* emphasises that the core challenge lies in preserving the semantic integrity of lifecycle data across organisational and system boundaries (ISO 55000, 2024; Kortelainen et al., 2023). This reinforces CoLife's focus on creating collaboration models that allow lifecycle data to be used jointly, rather than being lost or fragmented at organisational interfaces.

Second, studies on *digital enablers such as PLM, Digital Twins, and Data Spaces* demonstrate that technical tools alone are insufficient; they must be embedded within shared governance mechanisms and trust-building arrangements to enable cross-actor participation (Curry et al., 2022). This resonates with CoLife's interest in combining technical feasibility with organisational models that ensure participation from multiple stakeholders, including SMEs.

Third, the literature on *collaborative ecosystems and value co-creation* shows that data-driven value is realised not only through bilateral contracts but also through multi-actor orchestration, which requires alignment of incentives and benefit-sharing mechanisms (Jacobides, Cennamo & Gawer, 2018; Kohtamäki et al., 2019). This aligns with CoLife's ambition to design a win-win-win model where companies, society, and the environment benefit simultaneously.

Finally, research on *data-driven business models and monetisation logics* underlines that sustainable collaboration depends on both credible appropriation mechanisms and enforceable governance structures (Teece, 2010; Ritter & Pedersen, 2019). This supports CoLife's goal of moving beyond isolated pilots toward repeatable, scalable practices that make participation economically rational for all actors.

The theoretical review confirms that CoLife's core design challenge is not technological but institutional and organisational: finding credible ways to coordinate lifecycle data across diverse actors, while ensuring fair distribution of risks and rewards. The benchmarking analysis in subsequent chapters will operationalise these insights by examining how international cases have addressed these issues, and what lessons can be drawn for developing a fair and future-oriented collaboration model for Finland.

3 Research methodology

The methodology of this thesis explains how this research was designed and implemented to respond to the questions introduced in Chapter 1. This methodology shows the steps from transforming the theoretical framework into search clusters, with case identification and screening to the systematic extraction and analysis of data. By following this structured approach, this study ensures transparency, comparability, and validity in benchmarking participatory practices.

3.1 Research process overview

The research process followed in this study is structured in sequential stages, summarised in Figure 3. This staged design reflects best practices in systematic benchmarking and case study research (Miles, Huberman & Saldaña, 2014; Saunders, Lewis & Thornhill, 2019). While the list provides a simplified overview, Figure 3 provides a more detailed picture of the process and specific activities in each phase to guide iteration. The stages are: (1) translating the theoretical pillars into search clusters, (2) developing keywords, (3) executing searches in trusted sources, (4) applying inclusion and exclusion criteria, (5) extracting data into a structured benchmarking sheet, and (6) applying a framework and relevance rubric to prepare the material for cross-case analysis. The following subsections present each stage in turn, ensuring a transparent and replicable research design (Tranfield, Denyer & Smart, 2003).

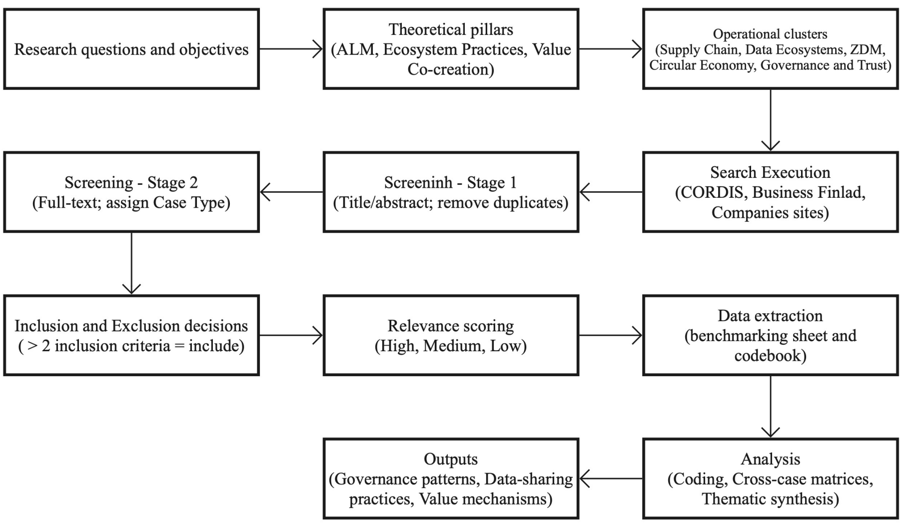

Figure 3: Summary of the research process

3.2 From pillars to search clusters

The research design builds directly on the theoretical framework presented in Section 2.6. The three pillars; ALM, Collaborative Ecosystem Practices, and Value Co-Creation and Data-driven Business Models were selected because they capture the main theoretical perspectives necessary to understand how lifecycle data can be governed, shared, and monetised in industrial ecosystems. These perspectives emerged from the literature review (Chapter 2), which identified ALM as the process backbone of industrial value creation (Stark, 2022; ISO 55000, 2024; GFMAM, 2024), collaborative ecosystem practices as the coordination context that structures interactions between diverse actors (Dhanaraj & Parkhe, 2006; Jacobides et al., 2018), and value co-creation/business models as the incentive and appropriation structures that sustain collaboration (P. Hartmann et al., 2016; Porter & Heppelmann, 2014; Ritter & Pedersen, 2019).

To operationalise these pillars into a practical search strategy, they were transformed into five thematic search clusters; *Supply Chain Collaboration*, *Industrial Data Ecosystems & Marketplaces*, *ZDM*, *Circular Economy*, and *Governance & Trust*. These clusters illustrate distinct but complementary areas of industrial performance. Supply chain collaboration and industrial data ecosystems that represent inter-company integration and data sharing (Simatupang & Sridharan, 2005). ZDM emphasises data-driven quality improvement and feedback loops (Colledani et al., 2014; Lee, Bagheri & Kao, 2015). The Circular Economy cluster links lifecycle data to sustainability and resource efficiency (Geissdoerfer et al., 2017; Kirchherr, Reike & Hekkert, 2017). Finally, Governance & Trust addresses the frameworks, roles, and mechanisms that enable secure, fair, and reliable data exchange among ecosystem participants (Otto et al.,2019; Khatri & Brown, 2010).

By using these clusters to structure a search strategy which is aligned with recommendations for managing complex, multidisciplinary reviews and ensuring theoretical and empirical relevance (Boell & Cecez-Kecmanovic, 2015; Snyder, 2019; Tranfield et al., (2003)).

3.3 Keyword derivation

To populate the search clusters with relevant cases, a systematic keyword derivation process was applied. Keywords were generated with a combination of deductive and inductive approaches. The deductive approach drew directly from the theoretical framework developed in Section 2.6 and its associated clusters, resulting in terms such as *manufacturing data space*, *digital twin and quality*, and *industrial data marketplace*. The inductive approach complemented this by scanning project descriptions and scoping materials to capture emergent terminology, for example *predictive quality and manufacturing*, *industrial sym-*

biosis and circularity, or *sovereign data sharing*. Using both deductive and inductive key wording reflects a recognised practice in systematic reviews, as it ensures theory-driven focus while remaining open to emerging language in practice domains (Snyder, 2019; Booth et al., 2022). These approaches are particularly relevant when combining academic literature with grey literature such as databases from EU projects, where terminology rather than peer-reviewed publications evolves more rapidly (Adams, Smart & Huff, 2017).

The process was managed with a living keyword log, which documented the exact search strings, sources consulted, number of results retrieved, and reasons for inclusion or exclusion. Such explicit logging aligns with best practices for ensuring transparency, reproducibility, and rigour in systematic review and benchmarking studies (Tranfield et al., 2003). With maintaining a traceable record of search decisions, the keyword extraction process supported both methodological robustness and accountability, ensuring that case identification remained consistent with the aims of this study.

3.4 Data sources and search execution

The primary data sources were CORDIS, the European Commission's repository for FP7 (Seventh Framework Programme for Research and Technological Development), Horizon 2020 and Horizon Europe projects, and Business Finland databases, which include Veturi programmes and national flagship initiatives. These repositories were selected due to they are both authoritative and comprehensive, covering the most relevant European and Finnish collaborative projects in the industrial digitalisation and sustainability field (Business-Finland, 2025a; European-Commission-CORDIS, 2025). CORDIS provides structured access to funded research and innovation projects, while Business Finland's programme portfolios capture large-scale public–private partnerships, making them complementary sources.

Searches were conducted systematically within these repositories, using the deductively and inductively derived keywords described in Section 3.3. In addition, project websites, deliverables, and programme pages were consulted where needed to obtain richer descriptions of governance arrangements, technical outcomes, and sustainability impacts. This layered search approach is recommended in management and innovation studies to capture both peer-reviewed and grey literature outputs, ensuring that the review reflects the latest state of practice as well as academic insights (Adams et al., 2017; Garousi, Felderer & Mäntylä, 2019).

To increase transparency and replicability, all search queries, results, and exclusion notes were systematically documented in the CoLife Search Tracker (see Appendix 1). Maintaining this audit trail is consistent with methodological guidance for systematic and evidence-based reviews (Tranfield et al., 2003; Booth et al., 2022). This approach ensured that project selection followed clear criteria and used documented evidence. As a result, the research process was both valid and reliable.

3.5 Screening: inclusion and exclusion criteria

The raw search results were systematically filtered using predefined inclusion and exclusion criteria which are summarised in Table 3. The inclusion and exclusion criteria were selected to reflect both the theoretical pillars developed in Chapter 2 and the applied objectives of the CoLife project. Criteria 1 and 2 arise from the pillars of asset lifecycle management and data as a strategic asset, which emphasise that lifecycle coverage and data use are central to understanding collaborative data practices (Stark, 2022; ISO 55000, 2024). Criterion 3 represents the ecosystem's participatory practices pillar and ensures that only multilateral initiatives that illustrate cross-border collaboration are maintained (Dhanaraj & Parkhe, 2006; Jacobides et al., 2018). Criterion 4, which requires documented outputs such as platforms, standards, or governance models, is included to ensure that evidence can be systematically compared across cases, which is a main principle in benchmarking research (Tranfield et al., 2003; Booth et al., 2022). Finally, criterion 5 demonstrates the alignment of the CoLife project with the EU and Finnish digitalisation and industrial sustainability strategies, which emphasise digital platforms, ecosystems, and fair use of data for competitiveness and circularity (European-Commission-CORDIS, 2025; Business-Finland, 2025a). Together, these criteria ensured that selected cases were both theoretically grounded and partically relevant for informing CoLife's benchmarking.

A project was included if it satisfied at least two of the following conditions: (1) it addressed asset lifecycle management across design, production, use, maintenance, or end-of-life phases; (2) it explicitly treated data as a strategic asset, for example through interoperability, or analytics; (3) it operated within a collaborative ecosystem involving multiple stakeholders or sectors; (4) it provided documented outputs, such as platforms, standards, or governance models; or (5) it demonstrated relevance to EU or Finnish industrial digitalisation and sustainability goals. Projects that did not meet at least two of these inclusion criteria were excluded.

Inclusion criteria	Exclusion criteria
Covers more than one asset-lifecycle phase.	Narrow, single-tool pilots with no ecosystem relevance.
Uses data as a strategic asset	Lacks evidence of data governance/sharing or unverifiable claims.
Operates within a collaborative ecosystem	Purely conceptual pieces without an industrial context.
Produces documented outputs	Insufficient public documentation to support benchmarking
Aligns with EU industrial digitalisation and/or circularity priorities.	Duplicates or superseded items

Table 3: Inclusion and exclusion criteria

This approach reflects best practice in systematic review methodology, where transparent review methodology, where transparent inclusion and exclusion criteria are used to avoid bias and make case selection replicable (Tranfield et al., 2003; Booth et al., 2022). Applying rules is significant when reviews cover grey literature and projects, as the quality and detail of documentation can vaty significantly (Adams et al., 2017; Garousi et al., 2019). Using multiple criteria, the process ensured that projects were not included based on a single dimension, but rather reflected the multifaceted scope of asset lifecycle management, ecosystem collaboration, and data-driven value creation.

Screening decisions were recorded in the CoLife Search Tracker (see Appendix 1), which records for each case the criteria applied, reasons for exclusion, and links to sources. This type of audit trail enhances methodological transparency and strengthens the reliability of the selection process (Nowell et al., 2017; Snyder, 2019). The projects that passed screening were then extracted into structured benchmarking sheet (see Appendix 2), which served as the foundation for coding and analysis.

3.6 Benchmarking framework and evaluation criteria

The projects that passed screening were systematically captured and evaluated using a structured benchmarking framework. At the core of this framework is the benchmarking sheet, which ensured that comparable information was collected across different cases. The sheet includes fields for *contextual details* such as programme, funding, duration, partners, and sector focus; *actors and collaboration* such as ecosystem composition, roles, and governance structures; *lifecycle and data coverage* included which phases are addressed, what types of data are shared, and how interoperability is ensured; *data governance and trust* such as decision rights, responsibility and data governance mechanisms; and *value logic* such as efficiency, services, platforms, data products, and co-creation benefits. In addition, the sheet contains *control fields* such as relevance category, analysis status, and references. The full benchmarking sheet is reproduced in Appendix 2 to provide transparency and enable replication.

To describe the collected data explicitly, CoLife search tracker (see Appendix 1) was developed to guide the coding of six key variables: (1) actors and roles, (2) lifecycle coverage, (3) data assets, (4) data governance and trust, (5) collaboration form, and (6) value logic. Each variable was clearly defined and supported with examples, which reduced ambiguity and ensured that similar evidence was coded between cases. The variables were directly extracted from the theoretical pillars, which are introduced in Chapter 2 and operationalised to capture the observable characteristics of collaborative asset lifecycle ecosystems. This alignment between theory and data ensures that the analysis remains comparable conceptually and empirically (Miles et al., 2014; Yin, 2018).

Alongside the framework, a relevance criterion was applied to classify cases as high, medium, or low relevance. The rubric drew on four evaluation criteria: (1) the presence of lifecycle architecture and governance structures; (2) evidence of cross-actor data sharing; (3) robustness of collaboration mechanisms; and (4) the availability of documented outputs, such as platforms, governance models, or standards. Projects classified as high and medium relevance provided rich evidence across these dimensions and were selected for deeper qualitative analysis in Chapter 4. Using decision rules in this way strengthens reliability by making the assessment process replicable and by providing transparent justification for why certain cases were prioritised over others (Nowell et al., 2017).

The benchmarking framework combines structured data extraction with transparent coding rules and clear relevance criteria. This approach reflects best practice in systematic reviews and benchmarking research, where the aim is to move between case summaries toward systematic comparison and synthesis across cases (Tranfield et al., 2003; Booth et al., 2022; Snyder, 2019). By linking the framework directly to the theoretical pillars, the study ensures that benchmarking not only organises empirical information but also contributes to answering the research questions and supporting the CoLife project's ambition to design win–win–win collaboration models for asset lifecycle management.

3.7 Ensuring research Validity and Reliability

Ensuring validity and reliability is essential in benchmarking studies where evidence is drawn from heterogeneous sources. In this thesis, several steps were taken to increase trustworthiness in the research process. First, calibration sessions with supervisors were conducted to align interpretations of inclusion criteria, coding practices, and related classifications. This reduced researcher bias and ensured a consistent understanding of how projects should be assessed. Second, triangulation was applied by consulting multiple forms of evidence for each case, including project deliverables, academic publications, press releases, and programme documentation. This strategy helps validate findings by confirming patterns with data sources (Denzin, 2009). Third, an audit trail, including keyword reports, screening notes, and benchmarking sheet entries, was maintained to document each step of the process. This traceability improves transparency and allows for methodological replication (Denzin, 2009; Nowell et al., 2017).

Despite these efforts, this study faces limitations. Furthermore, the evaluation of projects required a balance between breadth and depth: while systematic benchmarking allows for cross-case comparisons, it does not capture the full richness of the individual projects' dynamics. These trade-offs are common in benchmarking and systematic review approaches (Tranfield et al., 2003; Snyder, 2019). Furthermore, the rapidly evolving nature of industry data ecosystems means that project results may continue to evolve beyond the time frame of this study, introducing an element of time constraint.

Overall, the criteria used in calibration, triangulation, and clear documentation enhance the validity and reliability of the findings, while recognising limitations demonstrates flexibility in the research process (Miles et al., 2014). While acknowledging its strengths and limitations, this study provides a balanced account of its methodological validity and reliability that is consistent with the standards of management and innovation research.

The methodological choices outlined in this chapter, from deriving search clusters and keywords, through systematic screening and data extraction, to coding and evaluation, establish a coherent framework for benchmarking collaborative practices in asset lifecycle ecosystems. Having defined the data sources, instruments, and evaluation criteria, the next chapter applies this framework to the selected cases.

4 Benchmarking analysis

This chapter applied the concepts and methods established in Chapters 2 and 3 to empirical evidence. It presents a systematic benchmarking analysis of 40 cases drawn from European framework programmes (FP7/H2020/Horizon Europe), Business Finland Veturi ecosystems, and selected vendor and company platforms. All cases meet the inclusion criteria defined in Section 3.5. The purpose is to examine, in a comparable way, how different initiatives organise collaboration, manage and share asset lifecycle data, and translate these practices into measurable value for firms, ecosystems, and society thereby operationalising the win-win-win logic guiding CoLife.

The analysis follows the CoLife search tracker (see Appendix 1) and relevance rubric specified in the research methodology and operationalised in Benchmarking sheet (see Appendix 2). Each case was examined in full using public source, including CORDIS entries, official deliverables, programme pages, and technical papers, and coded along common dimensions: actor roles and collaborative practices, lifecycle scope and digital thread strength, data asset readiness, trust and sovereignty controls for cross-firm sharing, and the value logic linking outcomes to benefit-sharing or monetisation. Using identical coding lenses across all 40 cases ensures that subsequent comparisons rest on like-for-like evidence rather than ad hoc impressions.

To keep the narrative coherent and practically useful, the chapter proceeds in four steps. First, it provides an overview of the selected cases, situating them by sector, programme type, and cluster coverage. Second, it analyses collaborative practices and actor roles, showing how orchestration, participation rules, and trust mechanisms shape who contributes what and under which conditions. Third, it evaluates the strategic use of data in asset lifecycle management, inclusing digital thread realisation, adoption of digital twins and analytics, and the operationalisation of interoperability and usage-controlled sharing. Fourth, it synthesises value co-creation models and outcomes, highlighting demonstrated benefits such as improved FPY, Overall Equipment Effectiveness, reduced time-to-recover, and circularity indicators, together with the benefit-sharing mechanisms that sustain participation.

The chapter closes with a cross-case summary that clusters recurring practices and design choices into transferable insights for CoLife. Throughout, claims are tied to traceable artefacts in the source materials, while limitations are flagged where documentation is thin. In short, this chapter systematically benchmarks 36 cases which have High-, and Medium-relevance using a single, transparent rubric, ensuring that the resulting insights are comparable, defensible, and directly actionable for the CoLife.

4.1 Overview of selected benchmarking cases

4.1.1 BEinCPPS

First case is *BEinCPPS* project (Horizon 2020, Ref 680633, 2015-2018) (European-Commission-CORDIS, 2025). Table 4 summarises the core characteristics of the BEinCPPS project, including its funding, actor roles, data use, and assessed relevance for CoLife.

Case Name	Source	Country / Region	Project Type	Data Use	Type of Collaboration	Funding	Value Co-Creation Elements	Relevance
BEinCPPS	CORDIS-id680633	EU	EU H2020 I4MS	Real-time data from CPS for production performance and digital services	Regional pilot lines, DIHs, SME open calls	H2020-EU.2.1.1. (ICT), I4MS	Open calls for SMEs, regional cluster governance, platform co-development	High

Table 4: Key characteristics of the BEinCPPS project

BEinCPPS advanced the adoption of *Cyber-Physical Production Systems* (CPPS) by European SMEs. Its main achievement was the design of a *federated architecture* that combined Internet of Things (IoT), FIWARE, and OpenIoT components in two integration paths: (1) A FAST path for low-latency data exchange and (2) a SMART path for semantically enriched interoperability. This was supported by a Common Cloud Environment (CCE), where containerised services such as identity management, context brokering, and visualisation were deployed, enabling SMEs and competence centres to replicate and extend solutions (Coscia, Ferrandis, et al., 2016; INNO et al., 2017).

The architecture was validated with regional innovation ecosystems in five Vanguard regions (e.g., Lombardy, Euskadi, Rhône-Alpes), where SMEs and industrial champions piloted applications ranging from predictive maintenance in footwear to zero-defect manufacturing in tooling. These pilots reported measurable Business Performance Indicators (BPIs) such as energy savings, improved test flexibility, and reduced downtime. To extend reach, BEinCPPS launched open calls, funding over a dozen SME experiments on lifecycle,logistics, and predictive analytics, and feeding results into standardisation bodies such as ETSI, IEEE, and AIOTI (Coscia, Albertario, et al., 2017; Isaja et al., 2017).

A complementary set of design-time and experimentation tools (e.g., Papyrus, Modelio, 4DIAC, Activiti) supported modelling, orchestration, and virtual testing, while value-added cloud services enhanced data analytics and visualisation (Polcaro, Jara, et al., 2018). Together, these elements lowered entry barriers for SMEs by coupling technical platforms with training, competence centres, and governance structures.

For CoLife, the relevance of BEinCPPS lies less in its technical detail than in its demonstration of how *platform architectures*, *regional ecosystems*, and *open innovation mechanisms* can work together to foster trust, interoperability, and SME inclusion in lifecycle data ecosystems. The project demonstrates that scalable testing environments, combined with governance and training, are key enablers for *fair participation* and for extending collaborative data sharing beyond large firms.

4.1.2 MIDIH

The second case is *MIDIH* project (Manufacturing Industry Digital Innovation Hubs) (Horizon 2020, Ref 767498, 2017-2020) (European-Commission-CORDIS, 2025). Table 5 summarises the core characteristics of the MIDIH project, including its funding, actor roles, data use, and assessed relevance for CoLife.

Case Name	Source	Country / Region	Project Type	Data Use	Type of Collaboration	Funding	Value Co-Creation Elements	Relevance
MIDIH	CORDIS-id767498	EU	EU H2020 I4MS	Supports scale-up of digital manufacturing data services	EU-wide cluster for SMEs, DIHs, and competence centers	H2020-EU.2.1.1. (ICT), I4MS	Multi-actor governance, SME capacity building, ecosystem expansion	High

Table 5: Key characteristics of the MIDIH project

MIDIH was launched to strength Europe's network of *Digital Innovation Hubs* (DIHs) supporting the digital transformation of manufacturing SMEs. The programme did not focus on developing new technical platforms, but rather on capacity-building, improving mentoring, business support, and cross-border collaboration mechanisms across DIHs (European-Commission-CORDIS, 2025; Benedicto, Gusmeroli, et al., 2018; Benedicto, Luca, et al., 2020). It shows how ecosystem orchestration and scaling practices enable smaller actors to access advanced digital capabilities without prohibitive costs. From a collaboration perspective, MIDIH fostered structured brokerage between DIHs, technology providers, and SMEs. Rather than one-off pilots, the project emphasised *replication* and *sustainability mechanisms*, such as training programmes, dissemination of success stories, and open calls for SMEs to test IoT, Cyber-Physical Systems (CPS), and AI technologies (Echebarria & Herrera, 2020; Echebarria & Herrera, 2020; Marguglio & Kuehrer, 2020). This highlights the importance of *governance models* and *shared support structures* for sustaining participation beyond initial funding cycles.

Regarding data use, MIDIH showed that although DIHs rarely generate or own large-scale asset lifecycle data, they act as intermediaries by enabling SMEs to access testbeds, simulation environments, and cloud-based analytics. Trust and sovereignty controls were handled more institutionally than technically: DIHs provided neutral ground and EU-level legitimacy for data sharing. Although the initiative did not produce strong evidence of advanced digital thread practices, it underlined the role of ecosystem enablers in lowering entry barriers and shaping preconditions for future cross-firm data collaboration (Angioletti, Kuherer & Gusmeroli, 2018; Gusmeroli et al., 2019; Benedicto & Luca, 2019). In terms of *value co-creation*, the programme's outcomes were measured less by productivity indicators and more by *ecosystem maturity*: the number of DIHs strengthened, SMEs reached and services sustained (European-Commission-CORDIS, 2025; Marguglio & Kuehrer, 2018). For CoLife, the key lesson is that *collaboration models need both technical and institutional scaffolding*. Where BEinCPPS showed how to build technical enablers, MIDIH illustrates how coordination and capacity building are equally significant for durable win-win-win collaboration.

4.1.3 C2NET

The *C2NET (Cloud Collaborative Manufacturing Networks)* project. Table 6 summarises the core characteristics of the C2NET project, including its funding, actor roles, data use, and assessed relevance for CoLife.

Case Name	Source	Country / Region	Project Type	Data Use	Type of Collaboration	Funding	Value Co-Creation Elements	Relevance
C2NET	CORDIS-id636909	EU	EU H2020	Supply network data sharing for production planning	SMEs, supply chain partners, platform providers	H2020-EU.2.1.1. (ICT)	Collaborative planning tools, supply-side data governance	High

Table 6: Key characteristics of the C2NET project

This project developed a *cloud-based platform* to enable SMEs and larger industrial partners for *supply chain collaboration* optimisation through real-time data collection, decision support, and secure information exchange (European-Commission-CORDIS, 2025). Its ambition was to make advanced planning and optimisation tools accessible without requiring heavy IT investment, thereby lowering entry barriers for SMEs while ensuring interoperability across heterogeneous systems.

The project introduced four main components: the *Data Collection Framework* (DCF), which integrated IoT and legacy systems; the *User Collaborative Portal* (UCP) for shared dashboards and collaborative decision-making and Optimiser module for production and logistics planning; and *Collaboration Tools* (COT), including mobile applications for real-time access (Qureshi et al., 2017). These elements illustrated how *cloud manufacturing* can support cross-company planning and implementation, especially in complex supply chains.

Industrial pilots in automotive, hydraulics, cosmetics, and metalworking confirmed the approach. For example, in the automotive pilot project, *collaborative Material Requirements Planning (MRP)* reduced shortages by coordinating suppliers and OEMs based on shared demand forecasts (Andres et al., 2017). In the hydraulics pilot, *production scheduling optimisation* showed efficiency gains through heuristic and metaheuristic methods (Katasonov et al., 2017). Across pilots, SMEs reported benefits from *real-time visibility, shared optimisation models, and integration of legacy Enterprise Resource Planning (ERP) system* via the DCF (Qureshi et al., 2017).

In addition to technical enablers, C2NET also addressed socio-economic and security dimensions. The company used methods such as ECOGRAI to assess the impact of collaborative platforms and developed ontology-based frameworks for IoT security and adaptive trust (Mozzaquatro, Jardim-Goncalves & Agostinho, 2017). These contributions focused on *trust, governance, and interoperability* are prerequisites for sustainable partnerships.

For CoLife, C2NET provides a relevant benchmark by demonstrating how *cloud-based ecosystems* can (1) bridge legacy and IoT data sources, (2) enable *cross-firm optimisation* without sacrificing data sovereignty, and (3) support *measurable value creation* in SME-dominated networks. It also highlights the importance of aligning *technical infrastructures* such as DCF, interoperability, and optimisation engines with *organisational mechanisms* which are trust, corporate governance, and socio-economic assessment. These lessons construct CoLife's aspiration for designing a *win-win-win model*, where SMEs large companies, and society benefit from shared lifecycle data.

4.1.4 Fortissimo 2

The Fortissimo 2 project (H2020, 2015-2018) extended the use of *High-Performance Computing* (HPC), simulation, and *High-Performance Data Analytics* (HPDA) for European SMEs by evolving the Fortissimo Marketplace a one-stop platform connecting HPC centres, ISVs, service providers, and industrial users (European-Commission-CORDIS, 2025; Diaz, 2017). This institutional framework complemented the technical infrastructure and ensured that experiments could be translated into repeatable services.

Table 7 summarises the core characteristics of the Fortissimo 2 project, including its funding, actor roles, data use, and assessed relevance for CoLife.

Case Name	Source	Country / Region	Project Type	Data Use	Type of Collaboration	Funding	Value Co-Creation Elements	Relevance
Fortissimo 2	CORDIS-id680481	EU	EU H2020	HPC-based data-driven simulations for design & production	Tech providers, research partners, SMEs	H2020-EU.2.1.1. (ICT)	Shared HPC services, collaborative cloud simulations	High

Table 7: Key characteristics of the Fortissimo 2 project

Fortissimo 2's model was based on application experiments and Open Calls that tested new business cases and converted successful pilots into sustainable services listed on marketplace (Sawyer, Arlandini, David, et al., 2016; Sawyer, Arlandini, Liparas, et al., 2018).

From a *collaboration* perspective, the project acted as a *brokerage ecosystem*, orchestrating SMEs, HPC providers, and domain experts. The marketplace was continuously improving in terms od usability, accounting and billing, multilingual content, training, and help desk support to lower the barriers for new users (Diaz, 2017; Liparas et al., 2018). This institutional framework complemented the technical infrastructure and ensured that experiments could be translated into repeatable services.

The impact was significant. 79 success stories were documented, over 30% of partners were SMEs, many of whom were *using HPC for the first time*, and both public calls were overwhelmingly well received, indicating strong latent demand (Sawyer, 2019; Murovec et al., 2018). Business benefits ranged from reduced time-to-market and cost savings to improved product design, in areas such as additive manufacturing, wave energy, and automotive simulation.

Relevance to CoLife; While Fortissimo 2 was not centred on asset lifecycle data, it provides a transferable model of *ecosystem orchestration* and *service sustainability*. By combining *technical enablers* (HPC/HPDA services) with *institutional mechanisms* (marketplace governance, billing, KPIs, multilingual support), it shows how collaborative platforms can turn one-off experiments into lasting services. For CoLife, the lesson is clear: *fair participation depends as much on brokerage, usability, and appropriation mechanisms as on technical capability.*

4.1.5 XS2I4MS

The XS2I4MS (Access to I4MS) project was a *Coordination and Support Action* (CSA) under the second phase of the I4MS initiative. Its purpose was not technology development but the *coordination, mentoring, and dissemination* needed to strengthen Digital Innovation Hubs (DIHs) and extend SME access to advanced Information and Communication Technology (ICT) adoption. Through brokerage, mentoring, and community building, the project became a catalyst for scaling the I4MS ecosystem across Europe (European-Commission-CORDIS, 2025; Karanikolova, Gijsbers & Butter, 2018).

Table 8 summarises the core characteristics of the XS2I4MS project, including its funding, actor roles, data use, and assessed relevance for CoLife.

Case Name	Source	Country / Region	Project Type	Data Use	Type of Collaboration	Funding	Value Co-Creation Elements	Relevance
XS2I4MS	CORDIS-id678860	EU	EU H2020 I4MS	Dissemination & scaling of I4MS pilots and services	DIHs, competence centers, SME networks	H2020-EU.2.1.1. (ICT), I4MS	Community building, policy linkages, cross-border scale-up	High

Table 8: Key characteristics of the XS2I4MS project

A central achievement was the establishment and support of 29 DIHs, which received structured mentoring, brokerage opportunities, and feasibility study support. These hubs served as regional anchors that lowered entry barriers for SMEs and ensured geographical diversity in digital transformation activities (Karanikolova, Gijsbers & Butter, 2018).

XS2I4MS also developed knowledge infrastructures which made ecosystem governance. A *database of suppliers and users* mapped technology providers and adopters across HPC, robotics, laser, and CPS fields (Bollhöfer & Holsten, 2016). A *database of competence centres and platforms* provided SMEs with a catalogue of accessible infrastructures (Braun, 2017). A repository and demonstration booklet showcased ICT applications in SMEs, linked to Technology Readiness Levels (TRLs) and sectors, allowing for comparisons between regions (Huertas & Jakupovic, 2018).

In addition, XS2I4MS ran large-scale surveys (European Manufacturing Survey 2015) to assess ICT adoption. Findings confirmed that SMEs lagged behind large firms in areas such as production processes, plant-level IT, and lifecycle data tools (e.g., PLM, real-time control), underscoring the need for DIH as capability enablers (Gotsch, 2016).

Governance and collaboration were further strengthened with mentoring frameworks, brokerage events, interactive webinars, and annual I4MS conferences. These mechanisms help to bring together SMEs, large enterprises, technology providers, financiers, and policymakers, helping to align diverse actors around shared challenges and co-creation opportunities (Gijsbers, Butter & Karanikolova, 2017).

Relevance to CoLife; XS2I4MS demonstrates that structured governance tools such as fact sheets, demonstrators, surveys, and databases can be as critical as technical platforms in enabling SME participation. It provides transferable lessons on how to design mentoring frameworks, repositories, and brokerage mechanisms that formalise collaboration, reduce uncertainty, and ensure win-win-win value creation by combining SME competitiveness, ecosystem governance, and societal diffusion of digital skills.

4.1.6 DOME 4.0

The DOME 4.0 project (Horizon 2020, 2020-2024) builds a Digital Open Marketplace Ecosystem (DOME) for industrial data and services, designed to overcome fragmentation in European manufacturing data spaces. The marketplace integrated *ontologies, FAIR principles, provenance mechanisms, and governance models* to ensure that data assets are findable, interoperable, and tradeable under sovereign conditions (European-Commission-CORDIS, 2025; Vizcaino et al., 2024; Chiacchiera, Vizcaino, et al., 2020).

Table 9 summarises the core characteristics of the DOME 4.0 project, including its funding, actor roles, data use, and assessed relevance for CoLife.

Case Name	Source	Country / Region	Project Type	Data Use	Type of Collaboration	Funding	Value Co-Creation Elements	Relevance
DOME 4.0	CORDIS-id953163	EU, UK-led	EU H2020 Project	B2B data sharing, semantic interoperability, knowledge extraction	Open data marketplace, multi-sector data providers & users, research & industry co-creation	H2020-EU.2.1.3., H2020-EU.2.1.5.	Open innovation, multi-actor data use, new product & process development	High

Table 9: Key characteristics of the DOME 4.0 project

The project's contribution lies in creating an ontology-driven architecture that links *marketplace assets* (datasets, APIs, workflows) with *data usage policies and clearing mechanisms*. Tools such as MarketPlace Ontology (MPO), data provenance services, and semantic catalogues ensure transparent value chain and allows SMEs, research organisations, and large enterprises to share data without losing control (Ghedini, Hashibon & Friis, 2022; Hashibon & Dorp, 2023). Successful examples in manufacturing and materials engineering validate these concepts by implementing *data governance, auditability and FAIR compliance* to cross-organisation workflows.

In terms of *collaboration*, DOME 4.0 emphasises *community building and interoperability* *with other EU initiatives*, for example, OntoCommons, GAIA-X, and IDSA. Deliverables report joint activities, training models (Lhumos), and cooperation frameworks to align governance patterns across projects (Huertas, Jakupovic & Yates, 2024; Cavalcanti et al., 2022). This institutional framework complements the technical enablers by ensuring shared meanings, trust and sustainable market governance.

Relevance to CoLife; While focused on marketplace-level data ecosystems rather than specific asset lifecycle processes, DOME 4.0 demonstrates hoe *FAIR data, semantic interoperability*, and sovereign data-sharing governance can sustain multi-actor ecosystems. Its ontology and provenance models offer direct inspiration for CoLife's ambition to design a *win-win-win collaboration model*, where trust, fairness, and system-level value creation are embedded into lifecycle data exchanges.

4.1.7 iDev40

The iDev40 project (Integrated Development 4.0) was an Electronic Components and Systems for European Leadership (ECSEL) joint undertaking bringing together semiconductor firms, SMEs, and research partners (European-Commission-CORDIS, 2025).

Table 10 summarises the core characteristics of the iDev40 project, including its funding, actor roles, data use, and assessed relevance for CoLife.

Case Name	Source	Country / Region	Project Type	Data Use	Type of Collaboration	Funding	Value Co-Creation Elements	Relevance
iDev40	CORDIS-id783163	EU, Austria-led	EU H2020	Integrated data platforms, IoT, connected product & process networks	Industrial supply network, tech providers, research partners	ECSEL Joint Undertaking (H2020)	Digital co-design, shared supply chain intelligence, collaborative platform	High

Table 10: Key characteristics of the iDev40 project

Its ambition was to establish *digitally integrated development chains* for electronic components and systems, ensuring continuity across design, production, and service. By positioning data as the foundation for integration, iDev40 creates a continuous digital thread the connects heterogeneous partners and lifecycle stages (European-Commission-CORDIS, 2025).

The main focus was on overcoming ecosystem fragmentation. The results highlight advances in AI-powered knowledge management, enabling distributed team to share lessons and feedback through *knowledge cycles and reflection tools* (Krumm, Fessl & Schneider, 2021). In manufacturing contexts, *digital twins and Single Source of Truth* (SSoT) frameworks were introduced to integrate design, testing, and production data, improving traceability and reducing errors (Gasparri & Baschirotto, 2021). In terms of governance perspective, iDev40 embedded mechanisms for IP protection, federated access rights, and auditability within collaborative platforms, balancing openness with data sovereignty (European-Commission-CORDIS, 2025). The project also illustrated predictive quality analytics and yield estimation methods that use cross-lifecycle data to reduce defect rates, illustrating how *feedback loops* can sustain continuous improvement (Mauerer & Ramsauer, 2021).

For CoLife, iDev40 provides valuable insights into collaborative governance models for lifecycle data. It shows how *federated architectures, digital twins, and AI-based feedback systems* can maintain data continuity, build trust across heterogeneous actors, and create win-win-win outcomes.

4.1.8 ReTraCE

ReTraCE (Realising the Transition toward the Circular Economy) is an H2020 (2018-2023) MSCA-ITN that develops policy, stakeholder, and measurement frameworks to accelerate circularity at regional and supply-chain levels (European-Commission-CORDIS, 2025). Work Package 4 links policy design, stakeholder mapping, and measurement: D4.1-D4.6 move from regional policy context and stakeholder models to a Regional Circular Economy Assessment Framework (RCEAF) and business-model insights, establishing a coherent pipeline from who needs to act to how progress in evidenced (Arsova, Garcia, et al., 2021).

Table 11 summarises the core characteristics of the ReTraCE project, including its funding, actor roles, data use, and assessed relevance for CoLife.

Case Name	Source	Country / Region	Project Type	Data Use	Type of Collaboration	Funding	Value Co-Creation Elements	Relevance
ReTraCE	CORDIS-id814247	EU	EU H2020 MSCA-ITN	Lifecycle data for circular supply chains and sustainability	Industry, academia, policy clusters	Marie Skłodowska-Curie Actions, H2020	Collaborative circular business models, new governance frameworks	High

Table 11: Key characteristics of the ReTraCE project

ReTraCE extends triple/quadruple helix thinking to a CE (Circular Economy)-centric Quintuple Helix (QNH) that integrates civil society and the natural environment with the academy-industry-government core, supporting trilateral networks and hybrid organisations that coordinate circular actions at NUTS-2 (Nomenclature of Territorial Units for Statistics, Level

2) regional scale. This provides a concrete stakeholder mapping and engagement blueprint for mylti-actor initiatives (Arsova, Genovese, et al., 2020; Arsova, Garcia, et al., 2021).

The programme assembles integrated assessment methods, MFA (Material Flow Analysis), LCA (Life Cycle Assessment), LCC (Life Cycle Cost), Social-LCA, and proposes roadmap for selecting and combining methods to track environmental, social, and economic outcomes across product and supply-chain lifecycle; this culminates in a participatory indicators dashboard for circular supply chains. These tools emphasise multi-criteria, multi-stakeholder evaluation and explicity target the digital evidence needed to monitor a circular transition (Coleman et al., 2022; Brint et al., 2022). ReTraCE frames regional circular change as systemic, requiring explicit drivers/barriers analysis and policy support alongside data and metrics; the RCEAF positions governance levers and stakeholder roles within a consistent measurement context (Arsova, Garcia, et al., 2021).

Evidence work packages highlight that CE performance must combine economic, environmental, and social dimensions; beyond-GDP (Gross Domestic Product) indicators and TBL (Triple Bottom Line (framework assessing sustainability through environmental, social, and economic dimensions)) syntheses show gaps in current practice and the need for multi-dimensional KPIs that credibly reflect shared benefits (Arsova, Genovese, et al., 2020; Bimpizas-Pinis, Calzolari, et al., 2020). Reviews within ReTraCE identify digital technologies and partner integration as enablers of Circular Supply Chains (CSCs), a direct link to lifecycle data continuity and cross-firm data sharing needed for predictive quality, reverse logistics, and product-as-a-service (Brint et al., 2022).

For CoLife's *collaborative ALM* focus, ReTraCE contributes: (1) a stakeholder logic (QNH) that clarifies *who must share what* across the lifecycle; (2) a *measurement stack* (integrated methods + dashboard) that operationalises *win-win-win KPIs* across actors; and (3) a regional policy lens that embeds *governance* and *incentives* into data-sharing arrangements. Together these elements inform CoLife's playbook on *lifecycle data sharing*, *usage-conditioned access*, and *benefit-sharing* backed by verifiable indicators (Brint et al., 2022; Arsova, Garcia, et al., 2021; Coleman et al., 2022).

4.1.9 OPENZDM

OPENZDM (Open Platform for Realising Zero Defects in Cyber-Physical Manufacturing) is a Horizon Europe project (2022-2025) developing an open, standards-aligned platform that combines Non-Destructive Inspection (NDI), digital twins and AAS to cut waste and energy via ZDM across multiple pilot lines. The CORDIS fact sheet foregrounds NDI, DT and AAS as core keywords and situates the work under the Made-in-Europe ZDM topic, with five representative lines targeted for demonstration (European-Commission-CORDIS, 2025).

Table 12 summarises the core characteristics of the OPENZDM project, including its funding, actor roles, data use, and assessed relevance for CoLife.

Case Name	Source	Country / Region	Project Type	Data Use	Type of Collaboration	Funding	Value Co-Creation Elements	Relevance
OPENZDM	CORDIS-id101058673	EU, Greece-led	Horizon Europe	Open platform for CPS, digital twins, asset admin shell	Multi-actor, open supply chain	Horizon Europe	Zero-defect, waste reduction, shared platform	High

Table 12: Key characteristics of the OPENZDM project

OPENZDM prototypes ISO 23247, compliant digital twins aligned with RAMI 4.0 for an automotive assembly line, enabling real-time defect detection and early containment (as-built measurement $\rightarrow$ feedback to process control). This establishes a standards-based digital thread for in-line quality control (Melo et al., 2024). NDIs and inspection assets are digitalised via AAS (identification, hierarchy, capabilities sub-models) and exposed through reactive AAS (REST APIs) for runtime data exchange into the ZDM framework improving interoperability and traceability across systems (Treuk et al., 2024).

Methodologically, the project defines the AAS metadata model, hybrid DT toolset, data-driven quality modules, and a decision-support tool in D4.2 – Methodologies and first implementations, together with the initial platform business layer (LMS, AIMEN & INTRA, 2023). A companion position paper clarifies how CPS and DT converge within RAMI 4.0, reinforcing the architectural placement of OPENZDM's building blocks (Pires et al., 2024).

To ensure that lifecycle data are decision-grade, the consortium specifies calibration and measurement-uncertainty methods for LLT (Learning and Lessons Template), vision/IR and X-ray NDIs (D3.3), linking metrology to ZDM decisions (false positives/negatives, conformity) (UNIVPM et al., 2023). Data governance is set out in the Data Management Plan with explicit FAIR practices (INTRA & LMS, 2022).

OPENZDM's impact/exploitation deliverables document IPR (Intellectual Property Rights) arrangements, Key Exploitable Results (KERs) (e.g., AAS data models, DT toolset, analytics, decision tool, platform), initial business models, and standardisation engagement (CEN/CENELEC for ZDM; IDTA (Industrial Digital Twin Association) for AAS sub-models). These artefacts operationalise ecosystem governance (who contributes what data, under which rights, how results are monetised or shared)(AIMEN et al., 2024). The earlier plan for impact management defines stakeholder targeting, KPIs and dissemination mechanisms to sustain multi-actor collaboration beyond pilots (F6S, INTRA & LMS, 2022).

Technically, OPENZDM integrates NDI systems with the platform to achieve IT/OT convergence, predictive quality and process reconfiguration reducing scrap and energy while improving product quality (Medici et al., 2023). Institutionally, the exploitation/IPR plan links measured outcomes (quality yield, downtime, rework) to KER diffusion and business uptake, enabling firm-level ROI, ecosystem capability growth (standards-based interoperability) and societal benefits (lower resource use) a win-win-win consistent with CoLife's collaboration model (AIMEN et al., 2024).

OPENZDM offers (1) a *standards-anchored pattern* (ISO 23247, RAMI 4.0, AAS) for *sovereign, interoperable lifecycle data sharing* across firms; (2) a *metrology + FAIR* stack that keeps the *digital thread* trustworthy end-to-end; and (3) *governance artefacts* (IPR plan, KERs, standardisation liaisons) that make *participation durable and monetisable*, all directly reusable in CoLife's playbook for fair collaboration and value sharing (Melo et al., 2024; LMS, AIMEN & INTRA, 2023; AIMEN et al., 2024).

4.1.10 i4Q

The i4Q project (Industrial Data Services for Quality control in Smart Manufacturing, Horizon 2020, 2021- 2024) developed a flexible platform of data-driven services to improve *ZDM* through continuous quality monitoring, predictive a anlytivs, and lifecycle integration (European-Commission-CORDIS, 2025).

Table 13 summarises the core characteristics of the i4Q project, including its funding, actor roles, data use, and assessed relevance for CoLife.

Case Name	Source	Country / Region	Project Type	Data Use	Type of Collaboration	Funding	Value Co-Creation Elements	Relevance
i4Q	CORDIS-id958205	EU	Horizon 2020	Industrial IoT, data services, zero-defect QC	Multi-actor ecosystem	H2020	Shared QC protocols, ecosystem trust	High

Table 13: Key characteristics of the i4Q project

Its aim was to enable manufacturers, especially SMEs, to collect, process, and govern high-quality data across design, production, and reconfiguration processes, thereby ensuring *trustworthy decision-making* (European-Commission-CORDIS, 2025).

i4Q created an ecosystem of industrial pilots where machine builders, technology providers, and end-users co-developed and validated solutions. Governance mechanisms included requirements frameworks (D1.9) and guidlines (D5.4) that structured collaboration across heterogeneous actors, balancing data sharing and sovereignty with contractual and technical safeguards (TUB, CERTH & FACTOR, 2021). A key contribution was the creation of data quality frameworks (D3.9) and *data services* that were capable of monitoring, validating, and enriching production data in real time. This ensured that lifecycle data, from design specifications to shop-floor measurements, maintained their semantic integrity and cloud be reused for predictive quality analysis and process reconfiguration (BIBA et al., 2022).

i4Q emphasised the *principles of FAIR*, provenance, and traceability through *data governance models* embedded in its platform architecture (D1.9). By providing clear ,metadata and accountability structures, the project enabled SMEs and larger enterprises to participate in shared data ecosystem s without losing control (European-Commission-CORDIS, 2025). Industrial pilots demonstrated measurable gains, which are improved OEE, reduced scrap and downtime, and faster line reconfiguration (D5.10). These benefits were framed within guidelines and toolkits that could be transferred to other industries, ensuring value distribution at three levels: corporate return on investment, ecosystem resilience, and social sustainability (UPV et al., 2022).

i4Q provides CoLife with an operational model for *industrial data services* that align with *ALM needs*: Collaboration: structured governance and pilot-based co-creation. Lifecycle data: real-time quality frameworks and semantic continuity. Governance: FAIR and sovereignty-preserving architectures. Value logic: KPI-linked outcomes that embody *win-win-win models*.

4.1.11 ZDMP

The ZDMP (Zero Defect Manufacturing Platform) was an H2020 initiative (2019-2023), which involved 31 partners across 11 countries, aimed at developing an open, interoperable platform to enable zero-defect processes and products in connected smart factories (European-Commission-CORDIS, 2025). ZDMP combined *data acquisition, AI-based analytics*, and *digital twins* with supply-chain-wide collaboration to reduce defects and rework across sectors including automotive and construction (Lazar et al., 2019; Martin et al., 2023).

Table 14 summarise the core characteristics of the ZDMP project, including its funding, actor roles, data use, and assessed relevance for CoLife.

Case Name	Source	Country / Region	Project Type	Data Use	Type of Collaboration	Funding	Value Co-Creation Elements	Relevance
ZDMP	CORDIS-id825631	EU	Horizon 2020	Plug-in apps, end-to-end data flows	Open ecosystem	H2020	App marketplaces, SME engagement	High

Table 14: Key characteristics of the ZDMP project

At its core, ZDMP operationalised zero-defect logic through zApps, modular applications such as the zAnomalyDetector and zDigitalTwin. In the automotive pilot such as FORD, MRHS, and ETXE, these tools enabled defect prediction in engine block machining and die casting, reducing external rejection rates from 4500 ppm to 1450 ppm, well below both FORD's 4932 ppm requirement and ZDMP's 3500 ppm target (Martin et al., 2023). In the construction pilots (steel tubes, stone tiles), the platform supported sensor-based monitoring and equipment wear detection, the possibility of early maintenance action, and improved process continuity.

From a *collaborative ecosystem* perspective, ZDMP demonstrated how suppliers and OEMs could share sensitive quality data across organisational boundaries. The project emphasised *governance mechanisms*, including audit trails, role-based access, and usage controls, to balance data sovereignty with joint benefits (Lazar et al., 2019); Cáceres et al., 2023). This aligns with CoLife's goal for a fair distribution of benefits and managing tensions between Short-term ownership interests and long-term ecosystem learning.

For *lifecycle data*, ZDMP illustrated a combination of shop-floor sensors, PLCs (Programmable Logic Controllers), and ERP systems into shared analytics environments, supported by the Global Architecture Specification (Tomas et al., 2023). This enhanced the digital thread, connected casting, machining, and final product quality validation (Lazar et al., 2019). At the same time, it created challenges in interoperability and trust that directly relate to CoLife's ambition to design repeatable collaboration models for asset lifecycle data.

The project also addressed the issue of *value co-creation* through benefits based on KPIs. In addition to reducing defects, results were reduced scrap, fewer reworks, and predictive maintenance capabilities (Martin et al., 2023). These results were confirmed in pilot evaluations under WP9 (Work Package 9) (Kirchberger et al., 2023), which generated both economic value (productivity, cost savings) and societal/environmental value (waste reduction). The emphasis on win-win-win outcomes is strongly aligned with CoLife's focus on the equitable distribution of value across firms and society.

4.1.12 QU4LITY

The QU4LITY project (Horizon 2020, 2019–2022) is the largest European initiative in the field of *ZDM*, involving more than 45 partners across 13 countries. It aimed to implement and demonstrate Autonomous Quality (AQ) in 14 industrial pilots covering automotive, electronics, white goods, aeronautics, steel, and discrete manufacturing (European-Commission-CORDIS, 2025).

Table 15 summarises the core characteristics of the ZDMP project, including its funding, actor roles, data use, and assessed relevance for CoLife.

Case Name	Source	Country / Region	Project Type	Data Use	Type of Collaboration	Funding	Value Co-Creation Elements	Relevance
QU4LITY	CORDIS-id825030	EU	Horizon 2020	Autonomous quality management, big data analytics	Multi-sector, open platform	H2020	Open testbeds, SME co-creation	High

Table 15: Key characteristics of the QU4LITY project

QU4LITY advanced ZDM by combining digital twins, shop-floor sensors, AI-driven analytics, and interoperable data platforms with collaborative governance models (Greidanus, 2021; Sølvsberg, Eleftheriadis & Myklebust, 2020).

A central innovation was the creation of an *open ZDM ecosystem*, integrating large manufacturers (e.g., Siemens, Philips, Whirlpool, Continental, Thyssenkrupp) with SMEs and digital technology providers. Governance mechanisms were tested in DIHs and an open-call programme, which funded additional SME-driven experiments to validate and expand the platform (Polcaro & Mato, 2019; Polcaro, 2022). This aligns with CoLife's goal on multi-actor collaboration and ensuring SMEs participate on fair terms.

QU4LITY pilots projects operationalised the digital discipline with integrating real-time shop-floor data with design and service information. For example, Philips and Siemens demonstrated *digital twins of manufacturing equipment* to enable continuous quality monitoring and predictive maintenance (Soldatos & Kefalakis, 2020; Greidanus & Wortel, 2021). Data was standardised through OPC UA, RAMI 4.0, and Asset Administration Shells, ensuring interoperability between heterogeneous machines and IT/OT systems ((SQS) & (INNO), 2020). These practices are directly related to CoLife's objective of *lifecycle data continuity*.

Governance was addressed through a federated platform architecture that combined cloud, edge, and fog nodes for data sharing under sovereignty-preserving rules (Gracia, 2020; JSI et al., 2019). The results illustrated compliance with standards (e.g., ISO, IEC) and mentioned *cybersecurity, traceability*, and *usage control policies*. This aligns with CoLife's ambition to design governance models that allow actors to retain control of their data while facilitating ecosystem-level learning.

QU4LITY's pilot projects reported significant performance improvements, which are reduced scrap rates, higher OEE, shorter time-to-market, and lower maintenance costs. For example, Continental demonstrated predictive quality in Electronic Control Unit (ECU) manufacturing, while Whirlpool validated predictive maintenance for white goods assembly lines ((TID) et al., 2020; ATLAS, 2022). These results demonstrate *win-win-win value creation*: companies achieved direct ROI, ecosystems benefited from reusable digital assets and governance models, and society benefited from reduced waste and improved sustainability.

QU4LITY demonstrates how autonomous quality and interoperable data platforms can turn one-off pilots into *scalable, collaborative ecosystems*. Its integration of *lifecycle data, SME participation, sovereignty-preserving governance*, and system-level KPIs directly informs CoLife's playbook for collaborative ALM.

4.1.13 MONSOON

The MONSOON project (Horizon 2020, 2016–2019) focused on introducing a cross-sectoral data platform for process industries, particularly aluminium and plastics (European-Commission-CORDIS, 2025).

Table 16 summarises the core characteristics of the MONSOON project, including its funding, actor roles, data use, and assessed relevance for CoLife.

Case Name	Source	Country / Region	Project Type	Data Use	Type of Collaboration	Funding	Value Co-Creation Elements	Relevance
MONSOON	CORDIS-id723650	EU	H2020	Site-wide data monitoring, predictive modeling	Data labs, cross-sector	H2020	Real-time data sharing, continuous process improvement	High

Table 16: Key characteristics of the MONSOON project

Its main aim was to enable real-time process control and predictive decision-making by combining multi-scale models, runtime container frameworks, and *advanced analytics* into an integrated ecosystem (Schlutter et al., 2020; Gaschler, Rossini, et al., 2017).

MONSOON brought together technology providers, industrial end-users, and research organisations in a *multi-actor collaboration* covering two distinct domains. The project demonstrated how cross-sectoral learning (e.g., transferring analytics between aluminium and plastics) can accelerate innovation and reduce costs. Governance mechanisms included shared data spaces and common frameworks for model deployment and lifecycle management, which ensured transparency and trust among partners (Pieri, Vafeiaids, et al., 2017; NPn et al., 2017).

A key innovation was the creation of a digital thread that linked raw shop floor sensor data with higher-level analytics and decision support systems. The real-time communications framework allowed for continuous data flows in plant boundaries, while the *lifecycle management plugin* transformed operational data to *environmental KPIs* (e.g., CO2 emissions, energy use, waste) (Maigron, Rossini, et al., 2019; Liang et al., 2017). These practices connect with CoLife's objective of *lifecycle data continuity* and connecting industrial operations with sustainability outcomes.

The MONSOON architecture contained runtime containers for model deployment and validation, ensuring that analytics could be transferred to plants while maintaining governance and traceability. The project also outlined applicable standards (ISO, IEC) and helped develop recommendations for *interoperability and secure data exchange* across heterogeneous systems (Antonio & Caballero, 2019; Gaschler, Sarnovsky & Devasya, 2016).

The pilots showed measurable improvements: aluminium plants achieved predictive maintenance and energy efficiency gains, while plastics manufacturers reduced defects and scrap rates through early anomaly detection. At the ecosystem level, the cross-sectoral transfer of models reduced duplication and created *shared learning benefits*. For society, the emphasis on *environmental KPIs* linked industrial competitiveness with sustainability objectives, demonstrating a *win-win-win logic* (Maigron, Gaschler, et al., 2020; Pieri, Baldo, et al., 2019).

MONSOON explained about how data-driven process industries can use Inter-sectoral cooperation, lifecycle data management, and sustainability-focused KPIs to deliver tangible industrial and societal benefits. What made direct application to CoLife's goal of building scalable and fair collaboration models for ALM are the integration of runtime container frameworks, data governance controls, and cross-sectoral knowledge transfer.

4.1.14 DataMust

The DataMust project , part of Nokia's Veturi programme, addresses the challenge of underutilised *urban data* by creating *local data marketplaces* based on *edge computing* (Business-Finland, 2025a). The goal is to accelerate carbon neutrality in the built environment while optimising the energy consumption of digital infrastructure. By processing and sharing data locally, the project reduces dependence on centralised cloud computing and supports more efficient, low-carbon cities (BusinessFinalnd, 2023a).

Table 17 summarises the core characteristics of the DataMust project, including its funding, actor roles, data use, and assessed relevance for CoLife.

Case Name	Source	Country / Region	Project Type	Data Use	Type of Collaboration	Funding	Value Co-Creation Elements	Relevance
DataMust	Business Finland	Finland	Co-Innovation Veturi	Local edge computing, secure data marketplace, trusted sharing	Multiple companies + research (Nokia Veturi, VTT, Sitowise)	EU RRF funding, Co-Innovation, Nokia Veturi program	Trust-building for data sharing, edge data use, incentive models for joining the ecosystem	High

Table 17: Key characteristics of the DataMust project

DataMust operates as a *co-innovation* project, jointly developed by companies and research organisations including VTT, Sitowise, Cozify, Loihde Analytics, nollaE, COBA International, and Nokia. Municipal partners such as the City of Espoo and international actors (Las Rozas Innova, Sacyr, Spain) ensure cross-border relevance. The governance backbone is the Nokia Data Marketplace, which manages contracts between data providers and users, secured by blockchain to guarantee *traceability and trust* (BusinessFinalnd, 2023a).

DataMust illustrates how sensor data from buildings (e.g., temperature, energy use, air quality) can be transformed into actionable insights when processed locally. By embedding edge computing directly in the built environment, it enables *continuous lifecycle data flows* without the need for large-scale cloud transfers. This approach supports scalability, interoperability, and *sustainable management of the data lifecycle* (BusinessFinalnd, 2023a). The project introduces blockchain-secured contracts that leave a digital footprint of each transaction, improving accountability and *data sovereignty*. A particular innovation is the *cell-based trust model*, where data sharing begins within trusted groups and expands as governance matures. This creates a replicable model for managing asymmetric incentives and for motivating participation in data sharing at the ecosystem level (BusinessFinalnd, 2023a).

These real estate and construction pilot projects demonstrate how shared data can lead to energy savings, reduced emissions, and smarter building operations. The *win-win-win model* is visible, which are property owners gain efficiency, municipalities progress toward carbon neutrality goals, and society benefits from lower emissions and improved sustainability. The project also has global export potential, positioning Finnish companies to lead in sustainable smart city solutions (BusinessFinalnd, 2023a).

DataMust offers CoLife lessons on combining *data sovereignty*, edge-based lifecycle data, and blockchain-enabled governance. Its *multi-actor collaboration* and *contractual trust mechanisms* illustrate how industrial asset lifecycle ecosystems can evolve into *fair, scalable, and sustainability-aligned data sharing* models.

4.1.15 KONE Veturi

The KONE Veturi program (2021–2024) (Business-Finland, 2025a), funded by Business Finland under its Veturi initiative, illustrates how a leading industrial player can orchestrate a large-scale *ecosystem for collaborative innovation*. With over 200 partners from industry, academia, and public research, KONE addressed the dual challenge of urbanisation and sustainability by focusing on innovations in smart buildings, greenfield services, digital twins, and construction productivity (BusinessFinalnd, 2024; KONE, 2024).

Table 18 summarises the main features of the KONE Veturi project, which include its funding, actor roles, data use, and assessed relevance for CoLife.

Case Name	Source	Country / Region	Project Type	Data Use	Type of Collaboration	Funding	Value Co-Creation Elements	Relevance
KONE Veturi	Business Finland	Finland	Veturi Ecosystem	Digital twins, real-time data flows, data-driven urban mobility	Large ecosystem: 200+ partners, co-innovation, co-development	Business Finland Veturi funding, partner co-financing	Mission-driven ecosystem, shared road map, clear roles for SMEs, universities	High

Table 18: Key characteristics of the KONE Veturi project

One of the main achievements was the development of KONE SiteFlow, a digital platform that integrates real-time data from construction elevators to improve building site logistics. This service innovation, jointly tested with ecosystem partners, not only received the Tall Buildings Council Innovation Award but also demonstrated how *data-driven collaboration* can lead to operational efficiencies and new market opportunities (BusinessFinalnd, 2024). Parallel efforts in *digital twin simulation* activated optimisation of people flows in urban transport hubs, which improved user experience and reduced congestion through predictive analytics. These cases highlight the program's dual focus on technical solutions and ecosystem governance (BusinessFinalnd, 2024; KONE, 2024).

From a CoLife perspective, the KONE Veturi case underlines several points. First, the program demonstrates how *ecosystem governance* can align shared responsibilities through a clearly defined road map maintained by the leading company. Second, it shows how *data as a strategic asset*, from building sites to city infrastructures, can be mobilised for value co-creation across partners. Finally, the initiative exemplifies a win-win-win logic: KONE gains new business opportunities, partners benefit from co-financed R&D and piloting, and society advances toward more sustainable urban living.

4.1.16 Nokia Competitive Edge

The Nokia Competitive Edge initiative, started in 2022 as a Business Finland Veturi program, is a flagship ecosystem targeting advances in edge computing and 5G-enabled digitalisation (Business-Finland, 2025a). With co-funding from the EU Recovery and Resilience Facility (RRF), the project mobilises 10–15 co-innovation efforts, including XR (Extended Reality) Space, SmartE3, and QLeap, aiming to build a turnover of €1 billion by 2030 and create more than 200 jobs in Finland (BusinessFinalnd, 2023b).

Table 19 summarises the main features of the Nokia Competitive Edge project, which include its funding, actor roles, data use, and assessed relevance for CoLife.

Case Name	Source	Country / Region	Project Type	Data Use	Type of Collaboration	Funding	Value Co-Creation Elements	Relevance
Nokia Competitive Edge	Business Finland	Finland	Leading Company Project (Veturi)	Industrial edge computing, decentralized data processing, data markets	Ecosystem: Nokia + 10–15 Co-Innovation projects	EU RRF + Business Finland Veturi; multiple research & SME partners	Edge computing for trusted data spaces; energy efficiency, real industrial IoT pilots	High

Table 19: Key characteristics of the Nokia Competitive Edge project

At its core, the project addresses the exponential growth of data generated in industrial, healthcare, and consumer contexts, where cloud-only solutions are insufficient. By distributing processing to the network edge, it improves latency, energy efficiency, and security, thereby enabling new forms of automation and sustainable operations (BusinessFinalnd, 2023b).

From a *collaboration and governance* perspective, Competitive Edge exemplifies how a leading company model structures an open ecosystem. Nokia creates the network, but the value is illustrated through partnerships with SMEs, universities, and global players. The ecosystem structure is designed to be open but governed by co-innovation agreements, ensuring shared rights, responsibilities, and incentives (BusinessFinalnd, 2023b).

In terms of *lifecycle data management*, edge computing strengthens the digital thread by enabling faster, contextualised processing of sensor and process data directly at production sites. This reduces bottlenecks in feedback loops, improving design–production–service integration (BusinessFinalnd, 2023b).

For *value creation*, Competitive Edge couples efficiency and sustainability logics: verified energy savings, reduced emissions, and productivity improvements are distributed across actors. The *win-win-win framing* is explicit: firms achieve competitiveness and ROI, the Finnish economy gains stronger technological leadership, and environmental benefits are realised through greener data infrastructures (BusinessFinalnd, 2023b).

4.1.17 Valuechain.com Ecosystem

The Valuechain.com Ecosystem (H2020, grant ID 717690, 2016-2017) was launched to bring a scalable cloud platform for *data-driven supply chain optimisation*. The platform integrates structured and unstructured data from multiple tiers, applying *predictive analytics* to generate scenario-based planning and risk mitigation strategies. This enables real-time visibility, improved decision support, and enhanced *collaboration* across vertically and horizontally integrated manufacturing networks (BusinessFinalnd, 2015a).

Table 20 summarises the main features of the Valuechain.com project, which include its funding, actor roles, data use, and assessed relevance for CoLife.

Case Name	Source	Country / Region	Project Type	Data Use	Type of Collaboration	Funding	Value Co-Creation Elements	Relevance
Valuechain .com Ecosystem	CORDIS-id723650	EU, UK-led	EU SME Instrument Phase 2	Real-time analytics, supply chain risk monitoring, dynamic network collaboration	Vertical and horizontal SME networks, supply chain partners	SME Instrument Phase 2	Real-time visibility, dynamic reconfiguration, collaborative decision support	High

Table 20: Key characteristics of the Valuechain.com Ecosystem project

From a governance perspective, the project focused on reducing the fragmentation of inter-company data exchange by introducing a shared digital environment that supports SME participation. This supports CoLife's goal in *sharing lifecycle data* and overcoming barriers to trust and interoperability. The initiative demonstrated the feasibility of platform-enabled business models, which is validating adoption through 22 pilot trials, and projecting a significant market opportunity in five years (BusinessFinalnd, 2015a).

Valuechain.com shows how sharing data between the ecosystem can make *supply chains* stronger, *waste reduction*, and enhancing competitiveness for SMEs. Its focus on SME business model innovation is particularly relevant for CoLife, as it highlights how collaborative ecosystems can share value more fairly between large firms and smaller partners.

4.1.18 MAYA

The MAYA project (H2020, 2015-2018) (European-Commission-CORDIS, 2025) focused on developing multi-disciplinary simulation and DT platforms to support the lifecycle of CPS in manufacturing. Its core contribution was a microservice-based middleware that ensured *real-digital synchrinisation* of CPS, enabling scalable and modular digital twin management along the plant lifecycle (Ciavotta et al., 2017).

Table 21 illustrates the main features of the MAYA, which include its funding, actor roles, data use, and assessed relevance for CoLife.

Case Name	Source	Country / Region	Project Type	Data Use	Type of Collaboration	Funding	Value Co-Creation Elements	Relevance
MAYA	CORDIS-id678556	EU	EU H2020 Project	Simulation and real-time synchronization of asset lifecycle data in factories (design, production, optimization, reconfiguration)	Multi-partner industrial ecosystem: Volkswagen, FinnPower, Siemens, Politecnico di Milano, DFKI, and other research & tech providers	H2020-EU.2.1.1. (ICT), FoF (Factories of the Future)	Collaborative development of shared digital twin tools, knowledge transfer between research and industry, real-world pilots to benchmark performance improvements	High

Table 21: Key characteristics of the MAYA project

A main innovation was the MAYA Support Infrastructure (MSI), which combined big data analytics with microservices to manage CPS registration, DT creation, synchronisation, and simulation orchestration. Through this, CPS could continuously update their digital avatars via functional models that processed shop-floor data, improving *predictive maintenance and lifecycel decison-making* (Ciavotta et al., 2017; Negri, Fumagalli & Macchi, 2017).

The project also developed collaborative multidisciplinary simulation frameworks, integrating tools from different engineering domains to model material flow, automation logic, and 3D behaviour in a coordinated manner (Brandstetter & Wehrstedt, 2018). To improve interoperability, MAYA promoted the use of open standards for behavioural models such as PLCOpenXLM, which accelerating virtualisation commissioning and reduces engineering efforts in discrete manufacturing (Meyer & Krause, 2018).

For CoLife, MAYA is particularly relevant in three respects. First, it demonstrates how *lifecycel data sharing* through digital twins can be operationalised, connecting design, operation, and maintenance phases in a continuous loop (Macchi et al., 2018). Second, its governance approach, using secure, role-based middleware for DT management, offers insights into trust and confidentiality in collaborative ecosystems (Ciavotta et al., 2017). Third, MAYA explicitly links *value co-creation* with data-deriven services: simulation models and DTs create a *win-win-win situation* by reducing commissioning time for manufacturers, enabling predictive maintenance for operators, and supporting sustainability goals by minimising waste and downtime (Weyer et al., 2016; Macchi et al., 2018).

4.1.19 FP3–IAM4RAIL

The FP3-IAM4RAIL project (Intelligent Asset Management for Rail, Horizon Europe, 2022-2026) (European-Commission-CORDIS, 2025) solves the challenge of integrated rail asset management by combining *real-time monitoring, DTs,* and *AI-based decision support* across both fixed and rolling stock assets. Its ambition is to minimise LCC, extend *asset lifetime*, and *improve Reliability, Availability, Maintainability*, and *Safety* (RAMS) of the European railway system (Villalmanzo, Cortés, et al., 2025; Villalmanzo, Borinato, et al., 2025).

Table 22 illustrates the main features of the FP3–IAM4RAIL, which including its funding, actor roles, data use, and assessed relevance for CoLife.

Case Name	Source	Country / Region	Project Type	Data Use	Type of Collaboration	Funding	Value Co-Creation Elements	Relevance
FP3 - IAM4RAIL	CORDIS-id101101966	EU	Horizon Europe Flagship Project (Europe's Rail Joint Undertaking)	Cross-border integration of asset condition data, real-time monitoring, AI-enabled risk prediction	Rail operators, national infrastructure managers, EU research organisations, technology suppliers	Horizon Europe – Europe's Rail Joint Undertaking	Shared digital twin models, multi-actor governance, cross-country asset management strategies	High

Table 22: Key characteristics of the FP3-IAM4RAIL project

The project develops seven integrated demonstrators that validate technologies such as Condition-Based Monitoring (CBM), predictive maintenance algorithms, robotics for inspection and intervention , and Next-Generation wireless Communication Network (NG-TCN) (Villalmanzo, Borinato, et al., 2025; Alsaba et al., 2024). These demonstrators are closely aligned with the Europe's Rail Multi-Annual Work Programme (MAWP) and feature quantified KPIs including:10-25% reductions in maintenance costs, 25% fewer service failures, 10% higher rolling stock availability, and 20% reduction in design/manufacturing time (Villalmanzo, Borinato, et al., 2025).

Architecturally, FP3-IAM4RAIL proposes an Intelligent Asset Management System (IAMS) built on three layers: (1) business level which is strategic and operational asset management plans,(2) application level which is data analytics, decision support systems and Traffic Management System (TMS) integration, and (3) technology level which is data platforms, wayside/on-board sensors, and standardised interfaces (Borinato et al., 2024). This layered approach focuses interoperability and enables the integration of external data sources (e.g., weather, maintenance reports) into lifecycle management.

In addition, the project focuses on human-centric innovation within exoskeletons and augmented reality tools to support railway workers in maintenance tasks, highlighting the role of workforce ethics, safety and well-being as part of smart asset management (Gauttier et al., 2024).

For CoLife, IAM4RAIL is highly relevant because of three aspects. First, it illustrates *cross-actor collaboration* between infrastructure managers, operators, OEMs, and technology providers in comprehensive model for *lifecycle data sharing*, linking on-board, wayside, and enterprise systems through open standards and wireless communication technologies. Third, its combination of KPIs, IAMS architecture, and worker-centric solutions is an example of a *win-win-win model*: operators achieve reduced costs and improved reliability, suppliers achieve new markets for interoperable solutions, and society benefits from safer, greener, and more efficient rail transport.

4.1.20 CBIM

The CBIM project (Cloud-based Building Information Modelling, Horizon 2020-2024) (European-Commission-CORDIS, 2025) focuses on how cloud, semantic, and AI-driven technologies can enable collaborative, lifecycle-based Building Information Modelling (BIM) across distributed actors in the construction and asset-management domains. It also highlights the automation of information, interoperability, and lifecycle data exchange in ontology-based data models, graph databases, and AI-assisted digital twins (Z. Wang, Ouyang & Sacks, 2023; Utkucu et al., 2024; Guyo & T. Hartmann, 2024).

Table 23 highlights the main features of the CBIM, including its funding, actor roles, data use, and assessed relevance for CoLife.

Case Name	Source	Country / Region	Project Type	Data Use	Type of Collaboration	Funding	Value Co-Creation Elements	Relevance
CBIM	CORDIS-id860555	EU	EU H2020 Project	Cloud-based building information models integrating design, operation, and maintenance phases	Tech providers, construction firms, software developers	H2020-EU.2.1.1. (ICT)	Shared BIM services, cost efficiencies, digital twin implementation across building lifecycle	High

Table 23: Key characteristics of the CBIM project

CBIM proposed a *cloud-integrated data ecosystem* that connects design, construction, and operation phases through a *linked-data ontology*. The framework combined IFC (Industry Foundation Classes)-based building geometry, sensor-derived operational data, and domain-specific ontologies to create consistent digital representations. These are supported with graph-based data persistence models that are Neo4j and RDF triple stores, that have been shown to outperform traditional relational databases in managing highly interrelated building and environmental datasets (Guyo & T. Hartmann, 2024). This architectural change underpinned scalable *data sharing and analysis* across multiple stakeholders in the built-environment lifecycle.

From technical side, the project developed several AI-enhanced modules. One of them used ensemble learning to automatically clasiify architectural and MEP (Mechanical, Electrical, and Plumbing) BIM objects, combing semantic keyword search, rule-based interface, machine learning geometric features, and deep learning visual models. The group achieved over

90% classification accuracy, drastically reducing manual model correction and improving interoperability between BIM and performance-analysis tools (Utkucu et al., 2024). Another stream advanced graph-based connectivity detection and Scan-vs-BIM workflows to support as-built digital twin construction, ensuring that geometry and semantics evolve together throughout the asset lifecycle (Drobnyi, Li & Brilakis, 2024).

CBIM illustrated the application of *semantic frameworks for Demand-Flexibility (DF) control* in virtual and real buildings, combining RDF-based ontologies (e.g., Brick, SAREF) with control platforms (e.g., BOPTEST and VOLTTRON). This allowed portable, plug-and-play supervisory controls that could be deployed in heterogeneous building environments without re-programming (Andrade Pereira et al., 2024). In parallel, complementary studies (Chang et al., 2022) identified dimensions of information quality that are important to asset management decisions and demonstrated how semantic consistency, provenance, and trust underpin effective data management.

CBIM's results strongly align with CoLife's vision of *collaborative asset-lifecycle* ecosystems; (1) It operationalises *lifecycle data continuity* through open standards (IFC → RDF → graph database), directly supporting CoLife's effort of cross-phase data integration. (2) Its ontology-driven governance model exemplifies structured *trust and interoperability mechanisms* among design firms, technology providers, and asset owners. (3) By linking AI-enhanced BIM, digital twins, and energy-flexibility control, CBIM demonstrates how shared lifecycle data can create *win–win–win value*: efficiency achievements for firms, improved decision intelligence for asset managers, and sustainability benefits for society.

4.1.21 RAGTIME

The RAGTIME project (Risk-based Approaches for Asset Integrity Multimodal Transport Infrastructure Management, H2020, 2016-2020) (European-Commission-CORDIS, 2025) developed an integrated Advanced Asset Integrity Management (AAIM) framework to optimise the technical, financial, and governance dimensions for critical transport infrastructures throughout their lifecycle. Its main innovation lies in combining risk-based decision-support, lifecycle costing, and muti-criteria prioritisation into a single software platform for Infrastructure Managers (IMs) and Operators (IOs) (Lenart et al., 2017; Osmani et al., 2018).

Table 24 highlights the main features of the RAGTIME, including its funding, actor roles, data use, and assessed relevance for CoLife.

Case Name	Source	Country / Region	Project Type	Data Use	Type of Collaboration	Funding	Value Co-Creation Elements	Relevance
RAGTIME	CORDIS-id690660	EU	EU H2020 Project	Risk-based frameworks for monitoring asset conditions across life-cycle stages	Transport operators, infrastructure managers, research organisations	H2020-EU.3.4. (Mobility for Growth)	Shared risk governance models, integrity management protocols	High

Table 24: Key characteristics of the RAGTIME project

RAGTIME conceptualised infrastructure management through three interdependent modules: governance, finance & risk, and technical management. Together, these formed a comprehensive AAIM cycle that supports planning, design, operation, and maintenance of assets in multimodal networks (Lenart et al., 2017). At its core, the Decision-Support System (DSS) integrates a Risk Assessment and Risk Transfer Module with a Prioritisation of Interventions Module, linking perfoemance-based probabilistic (M1) and predictive (M2) models. This two-level approach allows infrastructure owners to assess Expected Annual Loss (EAL), select mitigation strategies (insurance, maintenance, SHM (Structural Health Monitoring)), and optimise interventions via multi-criteria decision methods such as ELECTRE (Osmani et al., 2018).

The DSS quantifies both technical fragility and financial exposure, producing cash-flow scenarios that combine risk, cost, and socio-environmental benefits. It connects real-time SHM data and predictive degradation models to governance decisions, establishing a feedback loop between engineering and finance. This combination is an example of data-driven lifecycel management consistent with CoLife's emphasis on shared data assets and governance transparency.

RAGTIME's AAIM framework was derived from a broad mapping of European asset-management standards, inclusing ISO 55000, PAS 55, and PAIRC guidlines, and aligned with prior EU actions such as AM4INFRA and SAFE-10-T (Lenart et al., 2017). According to the surveys with 14 countries and multiple infrastructure agencies (road, rail, air, water), the project identified gaps in governance maturity, interoperability, and risk-based planning. Its multi-actor consortium, including research institutes (TECNALIA, ZAG), infrastructure owners (Network Rail, AISCAT), and insurers (AON), demonstrated a collaborative governance ecosystem that combines public and private perspectives on safety, resilience, and finance (Gussoni et al., 2018).

By merging engineering data (SHM, deterioration models) with financial indicators (EAL, LCC), RAGTIME advanced *integrated lifecycle data* sharing. The platform enabled *data-*

driven prioritisation of maintenance versus insurance decisions, producing measurable savings through risk-informed O&M (Operations and Maintenance) and improved business continuity. The inclusion of socio-environmental indicators (e.g., disruption, safety, emissions) expanded the value proposition beyond cost reduction toward systemic sustainability benefits, a concrete expression of the *win–win–win logic* among industry actors, asset owners, and society (Gussoni et al., 2018; Osmani et al., 2018).

RAGTIME offers a directly applicable governance and data-integration model for CoLife. The combination of risk-based decision-support, financial–technical data integration, and multi-actor governance is aligned with CoLife's goal of creating trusted collaborative ecosystems for lifecycle asset management and shared value creation.

4.1.22 AUTOWARE

The AUTOWARE project (Wireless Autonomous, Reliable and Resilient Production Operation Architecture for Cognitive Manufacturing, H2020 FoF-723909, 2016–2020) (European-Commission-CORDIS, 2025) developed a cognitive digital manufacturing framework that enables autonomous, reconfigurable, and resilient manufacturing environments. The project created CPS, Time-Sensitive Networking (TSN), and fog-to-cloud orchestration into a unified Reference Architecture (RA) to support self-aware, self-configuring factories (Laibarra et al., 2018; TTT & SFKL, 2019; SQS et al., 2020).

Table 25 highlights the main features of the AUTOWARE, including its funding, actor roles, data use, and assessed relevance for CoLife.

Case Name	Source	Country / Region	Project Type	Data Use	Type of Collaboration	Funding	Value Co-Creation Elements	Relevance
AUTOWARE	CORDIS-id723909	EU	EU H2020 I4MS	Industrial IoT & CPS for data-driven automation across asset lifecycle	Open platform with manufacturers, SMEs, and tech providers	H2020-EU.2.1.1. (ICT), I4MS	Multi-sided ecosystem, SME pilot experiments, flexible industrial data sharing	High

Table 25: Key characteristics of the AUTOWARE project

AUTOWARE introduced a layered architecture spanning *orchestration & digital-twin, cloud and simulation, information processing, data distribution and fog computing, industrial communications and control, and security & certification layers* (Laibarra et al., 2018). These layers operationalised interoperability between Operational Technology and Information Technology systems, creating an open environment where machines, robots, and analytics services could collaborate dynamically.

The Reference Architecture (RA) connected three neutral experimentation facilities, SmartFactory KL, JSI, and Tekniker, with industrial pilots at SMC Pneumatics and Stora Enso. Each pilot design validated independent decision loops for planning, control, and learning in real industrial contexts. The RA served as the blueprint for digital service deployment, enabling flexible combinations of edge, fog, and cloud components while ensuring data integrity and synchronization through IEEE 802.1 TSN-based deterministic Ethernet (TTT & SFKL, 2019).

A key AUTOWARE innovation was its KPI-driven lifecycle monitoring framework linking business, technical, and organisational performance indicators (Laibarra et al., 2018). the project enabled continuous assessment of productivity, flexibility, and resource efficiency, by combining real-time operational data from machines with higher-level business KPIs. The Reference Architecture ensured that design, execution, and analysis layers shared contextual data in open APIs and semantic mappings, creating full data continuity across lifecycle phases.

In the deterministic communication domain, AUTOWARE developed and tested TSN for guaranteed low-latency communication and dynamic network reconfiguration. The solution eliminated vendor lock-ins and provided a manufacturer-independent interoperability layer, a critical prerequisite for data trust and governance in connected manufacturing ecosystems (TTT & SFKL, 2019).

Beyond technology, AUTOWARE established a collaborative digital-manufacturing ecosystem linking research centres, SMEs, and technology providers through the INHANCER platform, a Digital Shopfloor Alliance and marketplace for automation services (Kirstein et al., 2018). The ecosystem followed open-innovation and regional anchoring principles, promoting knowledge exchange, training, and SME participation. Governance was based on shared KPI frameworks, open APIs, and reference-architecture compliance, aligning partners under transparent data-management and exploitation rules.

AUTOWARE is an example of creating *win-win-win value* for stakeholders: (1) Industry achieves benefits from modular, plug-and-produce manufacturing cells and reduced downtime through self-configuration. (2) Technology providers and SMEs achieved access to shared infrastructures and data platforms for co-development and testing. (3) Society profited from improved resource efficiency and safer, human-centric work environments enabled by collaborative robotics and cognitive automation.

For CoLife, AUTOWARE demonstrates a transferable model for cross-phase data sharing, trust-based governance, and ecosystem-level coordination. It links lifecycle management, *real-time data orchestration*, and *open collaboration*, precisely the ingredients for sustainable asset-data ecosystems.

4.1.23 NEXT-NET

The NEXT-NET project (Next Generation Technologies for Networked Europe, H2020 NMB P-CSA-2017, 2017–2019) (European-Commission-CORDIS, 2025) established a strategic foresight and research-agenda framework for European industrial and logistics networks. Its goal was to define future supply-chain scenarios for 2030 and a European Strategic Research and Innovation Agenda (SRIA) linking *digitalisation*, *sustainability*, and *resilience* (ZLC & ITIA, 2018; Barros, Senna & Zimmermann, 2019; Stute et al., 2018).

Table 26 highlights the main features of the NEXT-NET, including its funding, actor roles, data use, and assessed relevance for CoLife.

Case Name	Source	Country / Region	Project Type	Data Use	Type of Collaboration	Funding	Value Co-Creation Elements	Relevance
NEXT-NET	CORDIS-id768884	EU	EU H2020 Coordination & Support Action	Stakeholder data integration for future supply chain scenarios	Industry clusters, research orgs, policy advisors	H2020-EU.2.1.1. (ICT)	Cross-sector foresight, roadmap co-creation, multi-stakeholder governance	High

Table 26: Key characteristics of the NEXT-NET project

NEXT-NET adopted a *multi-layer foresight approach* combining quantitative data analysis, Delphi studies, expert workshops, and technology roadmapping to anticipate structural transformations in supply networks. The project developed in four scenarios, Local-for-Local, Circular Networks, Agile Resilience, and Digital Globalisation, each reflecting distinct combinations of technology maturity, trade dynamics, and sustainability orientation (Stute et al., 2018). These scenarios were mapped against enabling technologies such as AI, IoT, blockchain, additive manufacturing, and data-driven lifecycle management, and highlighting their systemic role in future supply ecosystems.

The outcomes were consolidated into a *Strategic Research and Innovation Agenda* that identified priority domains for Europe: *data interoperability and standards, digital supply-chain governance, circular-economy integration, and human-centric innovation*. This SRIA formed the foundation for the Made-in-Europe Partnership and has been used to align EU and national R&I (Research and Innovation) programs toward a coordinated industrial policy (Barros, Senna & Zimmermann, 2019).

NEXT-NET implemented a *FAIR-compliant Data Management Plan* (D5.6) ensuring that data produced within the project remained findable, accessible, interoperable, and reusable. Data were hosted with the Innovation Place intranet, managed by PNO, with open access with nextnetproject.eu. The project explicitly participated in the Horizon 2020 Open Research Data Pilot and committing to transparency while maintaining privacy under GDPR (EU 2016/679) (ZLC & ITIA, 2018).

The governance model distinguished between public results (published online) and data restricted by experts, balancing openness and confidentiality. This structure provides a model for *data governance in collaborative foresight ecosystems*.

NEXT-NET established a *multi-stakeholder collaboration network* which is including research institutes, manufacturing associations (EFFRA, VTT), logistics companies, and policy bodies. Through over 20 workshops and expert panels, it engaged more than 200 participants from industry, academia, and governance, fostering shared ownership of foresight results (Stute et al., 2018). The process itself embodied collective intelligence, a distributed model of collaboration that aligns well with CoLife's notion of ecosystem co-creation and trust-based coordination.

For CoLife, NEXT-NET provides an exemplary framework for *collaborative knowledge governance* and *data-driven foresight*, both important for managing industrial asset-lifecycle ecosystems. It demonstrates how systemic data collection, scenario modelling, and open access to shared knowledge assets can enable win–win–win outcomes across industry, research, and society: (1) *Industry* gains a roadmap for digital and circular transformation. (2) *Research and policymakers* benefit from open, harmonised data on technology trends. (3) *Society* gains from sustainable and resilient production models informed by collective foresight.

4.1.24 Onto-DESIDE

The Onto-DESIDE project (Ontology-Based Decentralised Data Sharing for Industrial Circular Ecosystems, Horizon Europe, 2022–2025) (European-Commission-CORDIS, 2025) develops a semantic and decentralised infrastructure that creates secure and ontology-driven data exchange in industrial value networks. It aims to address the crucial problems of the Circular Economy, specifically the lack of trustworthy, machine-readable lifecycle data, by creating a shared ontology network and a decentralised platform for automated collaboration (Blomqvist et al., 2023; Stekovic et al., 2022; Panasiuk et al., 2023).

Table 27 highlights the main features of the Onto-DESIDE, including its funding, actor roles, data use, and assessed relevance for CoLife.

Case Name	Source	Country / Region	Project Type	Data Use	Type of Collaboration	Funding	Value Co-Creation Elements	Relevance
Onto-DESIDE	CORDIS-id101058682	EU, Sweden-led (Linköping University)	EU Horizon Europe	Decentralized B2B data sharing, semantic interoperability, privacy protection	Multi-sector industrial partners, research orgs, SME clusters	Horizon Europe (RIA), Digital Industry and Space	Shared standards, secure data collaboration, cross-industry applicability	High

Table 27: Key characteristics of the Onto-DESIDE project

Onto-DESIDE implements the Open Circularity Platform (OCP), an open, privacy-preserving framework based on semantic interoperability and ontology networks. Its main component, the Circular Economy Ontology Network (CEON), provides a common vocabulary that describes materials, products, actors, processes, and value exchanges in industries (Blomqvist et al., 2023).

The CEON ensures both vertical interoperability (within a sector) and horizontal interoperability (across sectors), linking with EU initiatives such as OntoCommons, the European Open Science Cloud (EOSC), and European Data Spaces. All modules comply with FAIR principles and use open standards, RDF, OWL, and DCAT, to guarantee machine interpretability and data re-use.

The Open Circularity Platform (D4.4) is implemented as a Solid-based decentralised data-sharing network, where each actor controls its own data vault (Solid pod) while allowing verifiable queries through SPARQL endpoints and linked-data interfaces. Access control is managed with Decentralised IDentifiers (DIDs) and Verifiable Credentials, ensuring data sovereignty and trust between participants (Mulder & Meester, 2023).

Three industrial use-cases demonstrate cross-domain applicability: (1) Construction: The OCP created the reusability and traceability of building components by connecting deconstruction, recycling, and tendering datasets in shared ontologies. (2) Textiles: Semantic mapping of product data, Product Circularity Data Sheets (PCDS), and digital product passports such as circularity. ID improved supply-chain transparency and verified sustainability claims. (3) Electronics: Blockchain-anchored origin data allowed traceability of critical raw materials with manufacturing and recycling chains (Oberhauser, Amee & Panasiuk, 2023).

Onto-DESIDE validated the automated exchange of ontology-based lifecycle data between distributed actors without central intermediaries, which is a critical capability for future data-driven industrial ecosystems. The data-governance model follows FAIR and GDPR requirements, ensuring data protection and transparency. Documentation uses the Data Catalogue Vocabulary (DCAT), and access control relies on cryptographically verifiable proofs rather than central authentication (Stekovic et al., 2022).

The Standardisation Plan (D2.7) aligns results with ISO 59040 (Product Circularity Data Sheet), ISO / TC 323 Circular Economy, CEN/TC 473, and ISO/IEC JTC 1 AI / Blockchain, promoting harmonisation between digital product passports, lifecycle assessment, and material traceability standards (Panasiuk et al., 2023).

Onto-DESIDE demonstrates win–win–win value creation (Oberhauser, Amee & Panasiuk, 2023; Stekovic et al., 2022): (1) Industrial actors gain cost-efficient, standardised mechanisms for exchanging and verifying product data. (2) Technology providers benefit from open-source ontology modules and a decentralised platform architecture. (3) Society benefits from greater transparency, resource efficiency, and trust in circular value networks.

For CoLife, Onto-DESIDE provides a directly transferable framework for semantic lifecycle-data interoperability and trust-by-design governance, showing how ontologies and decentralised architectures can enable collaborative, cross-industry asset-data ecosystems.

4.1.25 ForZDM

The ForZDM project (Dynamic Manufacturing System for Zero Defect Manufacturing, Horizon 2020, 2016–2019) (European-Commission-CORDIS, 2025) tried to improve ZDM strategies in *data-driven control*, *multi-stage feedback loops*, and *lifecycle knowledge management*. It addressed the persistent challenge of defect propagation in complex, multi-stage production systems such as aerospace shafts, train axles, and medical devices (Magnanini, Eger, et al., 2019; Eger et al., 2020).

Table 28 summarises the main characteristics of the ForZDM, which is included its funding, actor roles, data use, and assessed relevance for CoLife.

Case Name	Source	Country / Region	Project Type	Data Use	Type of Collaboration	Funding	Value Co-Creation Elements	Relevance
ForZDM	CORDIS-id723698	EU	H2020	ICT tool integration, multi-stage ZDM	Supply chain, research centres	H2020	Defect root cause analysis, knowledge sharing	High

Table 28: Key characteristics of the ForZDM project

The project developed a generic ZDM architecture integrating data acquisition, machine learning, digital twins, and decision support systems for early defect prevention and downstream compensation. This architecture enabled *multi-level data feedback* and allowed information from inspection and measurement to adjust upstream and downstream processes dynamically. (Magnanini, Colledani & Caputo, 2023; Reiff et al., 2023). The core of the ForZDM framework is the Downstream Compensation Strategy (DCS), which recalibrates subsequent production stages based on previously identified deviations. This approach uses adaptive control algorithms change flow models to link product and process quality in real time (Magnanini, Eger, et al., 2019). This integration of physical sensing, simulation models, and closed-loop control created a foundation for *data continuity and learning* principles that are central to CoLife's approach to lifecycle data ecosystems.

ForZDM's knowledge architecture operated on three layers: (1) A *data collection layer* that continuously acquisition of process, quality, and machine parameters via IoT and CPS devices; (2) *Analytics layer*, which is AI-enabled detection and prediction of deviations using statistical and causal models (3) The *knowledge layer* is about formalised rules and insights stored as reusable data assets. Data integration was achieved through semantic interoperability, such as AutomationML, OPC-UA, and MTConnect, which are enabling multi-partner access to quality data without loss of context (Magnanini, Colledani & Caputo, 2023; Reiff et al., 2023). Moreover, the use of digital twins supported lifecycle traceability, connecting product design data, in-process deviations, and maintenance outcomes into a continuous improvement loop. This lifecycle-based data governance model parallels CoLife's vision of trusted, multi-actor data ecosystems, where contextual knowledge flows securely across organisational boundaries.

Governance in ForZDM adopted a *hybrid model* that balanced central DSS coordination with *distributed autonomy* at local control levels. Each industrial partner managed its own datasets in secured APIs and role-based access control (Magnanini, Eger, et al., 2019). The framework's collaborative data exchange between OEMs and SMEs demonstrated how distributed decision-making can preserve intellectual property while enabling system-wide optimisation, a practical precursor to the principles of fair data sharing in CoLife.

ForZDM achieved measurable industrial and systemic value:

1. *Operational value*, which is reduced scrap and rework through predictive compensation and adaptive control (Eger et al., 2020).
2. *Economic value*, which is shorter ramp-up times and improved process yield, raising throughput by 15–30%.

3. *Sustainability value*, which is less energy and material waste through early defect prevention and reuse of process data (Magnanini, Eger, et al., 2019).

The project's data-driven collaboration and lifecycle learning approach strongly resonate with CoLife's *win–win–win model*, where value creation spans industry efficiency, environmental sustainability, and societal benefit. However, its consortium-bounded data governance limited openness and long-term cross-ecosystem interoperability, an area CoLife explicitly extends.

4.1.26 DISCO

The DISCO project focused on the commercialisation of Valuechain.com, a scalable cloud-based platform designed to enhance supply chain collaboration and performance through real-time data integration and predictive analytics (European-Commission-CORDIS, 2025). The platform enabled SMEs in manufacturing to connect with partners, capture both structured and unstructured data, and optimise supply chain operations via multiple scenario planning (BusinessFinalnd, 2015b).

Table 29 summarises the core characteristics of the DISCO, including its funding, actor roles, data use, and assessed relevance for CoLife.

Case Name	Source	Country / Region	Project Type	Data Use	Type of Collaboration	Funding	Value Co-Creation Elements	Relevance
DISCO	CORDIS-id685232	EU, UK-led	EU H2020	Real-time supply chain data sharing and predictive analytics for collaborative production	Multi-SME supply chain partners, platform providers, research orgs	H2020-EU.2.1.1. (ICT)	Data-driven optimisation, open platform for SME co-innovation, predictive risk management	Medium

Table 29: Key characteristics of the DISCO project

By solving fragmented and manual information exchange, DISCO introduced a disruptive approach to building dynamic supply chain networks. Key performance indicators were customer service, equipment effectiveness, inventory cost, and overall supply chain costs, metrics that illustrate lifecycle data efficiency and collaborative governance models (BusinessFinalnd, 2015b).

DISCO provides medium relevance to CoLife. Because it does not directly target lifecycle asset management, its emphasis on real-time data sharing, supply chain visibility, and SME inclusion strongly aligns with CoLife's aims of fostering collaborative ecosystems and advancing win-win-win value creation. The case demonstrates how integrated platforms can reduce risk, reduce waste, and increase competitiveness, that are critical to lifecycle collaboration frameworks.

4.1.27 TOSCA

The TOSCA project (Manufacturing Processes and Digital Tools for More Sustainable Composite Aerostructures) (European-Commission-CORDIS, 2025) aims to solve the challenge of integrating lightweight composite materials in aerospace and ensuring recyclability and circularity. It is funded under Horizon Europe (Grant Agreement 101191394). The project develops innovative epoxy resins with thermoset-level performance but with improved recycling properties. The focus is on building a complete processing chain, covering automated fibre placement, curing, reworking, and maintenance, supported by digital tools for inspection and structural health monitoring to advance zero-defect manufacturing (Business-Finalnd, 2025).

Table 30 summarises the core characteristics of the TOSCA, including its funding, actor roles, data use, and assessed relevance for CoLife.

Case Name	Source	Country / Region	Project Type	Data Use	Type of Collaboration	Funding	Value Co-Creation Elements	Relevance
TOSCA	CORDIS-id 101191394	EU, Austria-led	Horizon Europe	Embedded sensors, structural health monitoring for zero-defect asset lifecycle	Manufacturing firms, research orgs	Horizon Europe	Zero-defect process co-creation, recycling integration	Medium

Table 30: Key characteristics of the TOSCA Ecosystem project

From a collaboration perspective, TOSCA unites industrial partners, SMEs, and research organisations across Europe, enabling cross-actor data flows in the design, production, and service phases of aerospace structures. The case demonstrates how embedded sensors and digital models facilitate continuous lifecycle data sharing, reduce defects, and enable feedback loops between production and maintenance. Governance is supported in certification frameworks for materials and processes, building trust between ecosystem actors (Business-Finalnd, 2025).

TOSCA has medium relevance with the Colife project. As TOSCA demonstrates how data-driven feedback loops and digital twins in complex production chains improve value co-creation. Although aerospace differs from Finnish heavy industries, the project provides transferable insights for the CoLife into: (1)Trust mechanisms for data use by multiple actors (certification, embedded monitoring). (2)Governance structures that balance proprietary IP with shared performance data. (3)Win-win-win outcomes: reduced scrap (economic), safer structures (social), and recyclable composites (environmental).

4.1.28 Sandvik Circular Mining

Sandvik Circular Mining (2021) is a leading industrial ecosystem initiative that incorporates the principles of Circular Economy and sustainability into mining operations (BusinessFinland, 2025a). The program is led by Sandvik Mining and Construction Oy, which is a global supplier of mining and construction technologies. This project is supported with Business Finland's Bio and Circular Finland program. The goal is to reduce the company's carbon footprint by 2030 and to align with the UN Sustainable Development Goals (SDGs), particularly in climate action, resource efficiency, and fair operations (BusinessFinalnd, 2021).

Table 31 summarises the core characteristics of the Sandvik Circular Mining, including its funding, actor roles, data use, and assessed relevance for CoLife.

Case Name	Source	Country / Region	Project Type	Data Use	Type of Collaboration	Funding	Value Co-Creation Elements	Relevance
Sandvik Circular Mining	Business Finland	Finland & Global	Leading Company Ecosystem	Automated mining, recycling data, carbon tracking	Large ecosystem: suppliers, R&D, service partners	Business Finland Bio & Circular, EU support	Shows heavy industry circularity with data-driven footprint tracking	Medium

Table 31: Key characteristics of the Sandvik Circular Mining Ecosystem project

A central element is the transition toward electrification of mining equipment. More than 600 electric loaders have been developed, reducing both emissions and underground health risks traditionally associated with diesel engines. Digitalisation and automation further support predictive operations, resource efficiency, and system-level resilience. This puts Sandvik as a leader in connecting digital twins, smart mobility, and automation with Circular Economy practices (BusinessFinalnd, 2021). At the production level, Sandvik's Turku and Tampere plants show closed-loop industrial practices. Turku connects welding robots into heat recovery systems and sources 30% of its steel from recycled materials, while Tampere operates a test mine using recycled water. Both plants employ renewable energy measures, LED lighting, and employee incentives for low-carbon mobility. These operational practices show how lifecycle resource efficiency and green innovation are systematically embedded (BusinessFinalnd, 2021).

Although Sandvik Circular Mining focuses on sustainability lifecycle data rather than engineering data continuity, the case offers transferable insights for CoLife on governance mechanisms, transparency through data sharing, and the framing of win-win-win outcomes that combine economic, environmental, and social value.

4.1.29 OPeraTIC

The OPeraTIC project (Operational Efficiency and Process Intelligence through Cognitive Manufacturing) (European-Commission-CORDIS, 2025) focuses on improving manufacturing systems with AI-driven digital twins, real-time monitoring, and adaptive control architectures. It integrates laser-based and hybrid manufacturing technologies with cognitive decision-making to achieve zero-defect manufacturing and energy-efficient processes (Pandolfi et al., 2025; Froemel et al., 2024; European-Commission-CORDIS, 2025).

Table 32 summarises the main characteristics of the OPeraTIC, which is included its funding, actor roles, data use, and assessed relevance for CoLife.

Case Name	Source	Country / Region	Project Type	Data Use	Type of Collaboration	Funding	Value Co-Creation Elements	Relevance
OPeraTIC	CORDIS-id101058409	EU, Spain-led	Horizon Europe	AI, robotics, digital twin for agile manufacturing	Large-scale, multi-sector	Horizon Europe	Agile production, multi-actor trust	Medium

Table 32: Key characteristics of the OPeraTIC project

OPeraTIC develops a cyber-physical production system (CPPS) which connects digital twins, artificial intelligence, and advanced process sensors to enable autonomous optimisation throughout the production lifecycle. The platform collects and analyses process data in real time and uses machine learning for anomaly detection, optimises parameters, and quality without manual intervention (Chaari et al., 2024).

The architecture connects virtual process models and shop-floor feedback loops with a service-oriented and compatible framework based on OPC UA, MQTT and ROS 2 communication layers. This ensures data continuity between design, manufacturing, and quality control, also making integration with enterprise systems such as MES, PLM, and ERP. OPeraTIC validated its concepts in four industrial pilots, which are automotive, aeronautics, lighting, and white goods, each representing different processes and lifecycle challenges (Froemel et al., 2024). In automotive manufacturing, predictive algorithms decreased defect rates in laser-welding by over 30%, highlighting the potential of AI-assisted process control. The aeronautics pilot demonstrated energy and reliability improvements in simulation-based digital twins. Lighting and white-goods pilots demonstrated the modular integration of smart sensors and adaptive control, enhancing production flexibility. The pilots confirmed the feasibility of continuous data exchange within factory boundaries, improving intra-organisational lifecycle visibility from design to production (Froemel et al., 2024).

The governance framework in OPeraTIC relied on federated data management and shared technical protocols for balancing interoperability with data governance (Jacobides, Cennamo & Gawer, 2018). The pilots were limited to consortium members, suggesting that knowledge exchange and governance were established within rather than across organisations (Froemel et al., 2024; Chaari et al., 2024).

While the architecture incorporated open-source tools and standard interfaces (OPC UA, ROS 2, MQTT), multi-stakeholder coordination beyond project partners was limited. As a result, OPeraTIC advanced technical interoperability and lifecycle data continuity but did not establish an ecosystem-level governance model or shared value-creation mechanisms, an important distinction from CoLife's emphasis on cross-actor collaboration and lifecycle data ecosystems (Pandolfi et al., 2025; Froemel et al., 2024).

OPeraTIC provides technical value by improving real-time process efficiency, product quality, and sustainability through digital-twin analytics (Pandolfi et al., 2025). It also illustrates how federated architectures can protect industrial data sovereignty.

However, its value-co-creation dimension remains mostly internal, oriented toward process optimisation rather than cross-enterprise collaboration or shared decision-making (Chaari et al., 2024).

For CoLife, OPeraTIC offers relevant technological insight into data interoperability and lifecycle monitoring, but limited guidance on governance or ecosystem-scale co-creation. Consequently, it serves as a technical enabler reference rather than a systemic collaboration model for CoLife.

4.1.30 DAT4.ZERO

DAT4.ZERO (Horizon 2020, 2020-2024) (European-Commission-CORDIS, 2025) develops an integrated approach to Zero Defect Manufacturing built on trusted data pipelines, AI/ML analytics, and Digital Quality Management (DQM) to prevent defects throughout the product and process lifecycle. The main contribution of the project is a system-level framework that aligns data quality assurance, AI model reliability, and cross-partner data governance to enable evidence-based decisions in complex industrial environments (Todhunter et al., 2020; Eleftheriadis, Fernandez & Eren, 2020; European-Commission-CORDIS, 2025).

Table 33 summarises the main characteristics of the DAT4.ZERO, which is included its funding, actor roles, data use, and assessed relevance for CoLife.

Case Name	Source	Country / Region	Project Type	Data Use	Type of Collaboration	Funding	Value Co-Creation Elements	Relevance
DAT4.ZERO	CORDIS-id958363	EU	Horizon 2020	Data reliability, smart sensors for defect prevention	Supply chains, factories, RTOs	H2020	Data quality, ecosystem reliability	Medium

Table 33: Key characteristics of the DAT4.ZERO project

The DAT4.ZERO framework couples data quality management, such as profiling, curation, and lineage, with AI services such as diagnosis, prognosis, and prescriptive control, and virtual/soft sensors that fuse heterogeneous signals with quantified uncertainty. A layered architecture separates: (1) data acquisition and pre-processing, (2) AI model management, such as training, validation, and drift monitoring, and (3) decision support integrated into MES/PLM/ERP contexts. The goal is reliable analyses during the design and repeatable ZDM interventions (Todhunter et al., 2020; Sen et al., 2022; Eleftheriadis, Fernandez & Eren, 2020).

DAT4.ZERO enables the continuity of the quality data lifecycle by defining common data contracts, semantic mappings, and virtual sensor abstractions that travel with the asset/process. Industrial pilots demonstrate: (1) reduction of false alarms through uncertainty-aware inference, (2) faster root-cause analysis through curated and tracked datasets, and (3) closed-loop quality control linking prediction to parameter adaptation (Todhunter et al., 2020; Sen et al., 2022).

DAT4.ZERO's value proposition is threefold: operational, which is fewer defects and faster anomaly isolation; technical, which is robust and reusable data assets; and organizational, which is shared DMP (Data Management Plan) and clearer responsibilities for data management. For CoLife, its strongest contributions are data-governance templates, lifecycle-quality data continuity, and trustworthy analytics. However, ecosystem collaboration is largely project-consortium and plant-focused rather than open, cross-sector data spaces. Hence, the case informs CoLife's technical and governance layers, but is less explicit on multi-actor market mechanisms and win-win-win value sharing beyond the consortium.

4.1.31 OPTIMAI

The OPTIMAI project (Optimised Industrial IoT and AI for Zero-Defect Manufacturing; Horizon 2020, 2021–2024) (European-Commission-CORDIS, 2025) develops an integrated digital ecosystem that combines AI, Augmented Reality (AR), Digital Twins, Blockchain, and smart sensors to enable ZDM. Its ambition is to merge operational excellence with ethical, explainable, and trustworthy AI through interoperable, data-driven processes (Henriksson & Hurley, 2021; Henriksson, 2021; Rubattino & Rossi, 2021).

The project aims to create a holistic framework for data acquisition, traceability, lifecycle integration, and ethical governance across manufacturing value chains. It demonstrates how industrial AI can be embedded within FAIR data environments while ensuring human oversight and GDPR compliance (Mastos, 2021).

Table 34 summarises the main characteristics of the OPTIMAI, which is included its funding, actor roles, data use, and assessed relevance for CoLife.

Case Name	Source	Country / Region	Project Type	Data Use	Type of Collaboration	Funding	Value Co-Creation Elements	Relevance
OPTIMAI	CORDIS-id958264	EU	Horizon 2020	AI-enabled sensors, virtualisation for zero-defect	SME networks, RTOs	H2020	Co-created AI toolkits, risk minimisation	Medium

Table 34: Key characteristics of the OPTIMAI project

OPTIMAI's architecture follows a three-layer approach, which includes (1) Perception layer: comprising smart optical sensors, edge devices, and virtual sensors for real-time quality inspection, (2) Cognitive layer: integrating AI-driven decision support, predictive analytics, and digital-twin synchronization to provide autonomous control and early fault detection, (3) Governance and collaboration layer: employing blockchain and semantic metadata to ensure traceability, integrity, and cross-partner accountability (Alexiou & Sideris, 2021).

The system supports bidirectional data exchange between physical and digital assets, closing the feedback loop between design, operation, and maintenance. Its use of FIWARE and NGSIv2 protocols guarantees interoperability and modular integration, while ROS2 middleware connects AI modules to cyber-physical systems (Alexiou & Sideris, 2021).

This architecture forms the backbone of OPTIMAI's lifecycle data strategy and ensuring that data generated during operation helps drive predictive and proactive decision-making throughout the product lifecycle. The Data Management Plan (Rubattino & Verardi, 2021a; Rubattino & Rossi, 2021) defines how project data is collected, stored, and shared according to FAIR principles. It establishes a clear taxonomy of data types, owners, access levels, and reuse policies. Metadata is assigned Persistent Identifiers (PIDs), and access rights are categorised as open, restricted, or confidential. The DMP also integrates ethical data-handling workflows, ensuring transparency and accountability in AI-driven decision-making (Rubattino & Verardi, 2021a).

A strong emphasis is placed on human-in-the-loop oversight to prevent automation bias. The Ethics and Legal Requirements deliverable (D2.2) (Mastos, 2021) establishes mandatory data anonymisation, consent management, and bias reduction. It further specifies explainability metrics for AI models and role-based accountability for operators, developers, and data controllers. Therefore, OPTIMAI operationalises the European Commission's Ethical Guidelines for Trustworthy Artificial Intelligence (Rubattino & Rossi, 2021) by implementing ethical principles in design.

Data overnance is also tied to verifying data integrity with blockchain, which maintains an immutable ledger of manufacturing events. This ensures that every data transaction can be audited, providing a foundation of trust and traceability.

These pilots demonstrate end-to-end lifecycle data sharing across design, production, and maintenance. Digital twins are continuously updated with process data, allowing parameter adjustments and closed-loop feedback between the virtual and physical systems (Mastos, 2021).

OPTIMAI employs a multi-actor governance and exploitation framework formalised in D8.6 and D8.9 (Rubattino & Verardi, 2021b). IP is managed under a Joint Exploitation Plan (JEP) where each partner co-owns specific Key Exploitable Results. Governance of data and IP rights is maintained through: shared responsibility matrices, freedom-to-operate assessments, and mechanisms for external licensing to third-party users under negotiated terms. The project also introduced an *ethics board* responsible for auditing compliance with data-protection and transparency principles. This structure ensures that both technical and ethical governance evolve together.

OPTIMAI's value creation spans three dimensions, which are (1) Operational: achieving measurable reductions in defects, energy use, and downtime through AI-driven process optimisation (Alexiou & Sideris, 2021; Rubattino & Verardi, 2021b), (2) Technological: providing a reusable, modular architecture with open interfaces (FIWARE, NGSIv2, ROS2) and trusted ledgers for traceability (Alexiou & Sideris, 2021;Rubattino & Verardi, 2021a), (3) Societal and ethical: embedding fairness, transparency, and accountability into industrial AI applications (Mastos, 2021; Rubattino & Rossi, 2021).

For CoLife, OPTIMAI is relevant as a reference model for data integrity, lifecycle traceability, and ethical governance. It demonstrates how trust mechanisms such as blockchain, metadata, and FAIR workflows can improve collaboration. OPTIMAI remains a closed industrial consortium with limited external access or cross-sectoral data exchange. Its collaboration model is project-centric rather than ecosystem-driven.

4.1.32 Z-Fact0r

The Z-Fact0r project (Zero-Defect Manufacturing Strategies towards On-Line Production Management for European FACTORies, H2020 2016-2020) (European-Commission-CORDIS, 2025) developed an *integrated cyber-physical ecosystem* to detect, predict, prevent, and repair product defects across multi-stage manufacturing processes. It combines semantic interoperability, KPI-driven governance, and re-manufacturing loops to achieve continuous quality improvement while minimising waste (Grevenitisi & Faria, 2018; HOLONIX, 2019).

Table 35 summarises the main characteristics of the Z-Fact0r, which is included its funding, actor roles, data use, and assessed relevance for CoLife.

Case Name	Source	Country / Region	Project Type	Data Use	Type of Collaboration	Funding	Value Co-Creation Elements	Relevance
Z-Fact0r	CORDIS-id723906	EU	H2020	Inline data collection, multi-step defect prediction	Multi-actor supply chain	H2020	Quality prediction, shared dashboards	Medium

Table 35: Key characteristics of the Z-Fact0r project

Z-Fact0r's architecture is based on a Service-Oriented Architecture (SOA) that orchestrates five functional Z-modules: Z-Detect, Z-Predict, Z-Prevent, Z-Repair, and Z-Manage. These modules interact through a middleware using MQTT, HTTP, and RESTful APIs supported by both relational and semantic triple-store databases (MySQL Apache Jena). The Incremental Integration Strategy (IIS) in D5.1 formalised modular validation cycles, performance monitoring, and regression tests, ensuring that each component build could be introduced without disrupting system consistency (Grevenitisi & Faria, 2018). This architecture demonstrates how *progressive lifecycle integration* between sensors, analytics, and decision systems can enable a continuously improving quality loop.

Z-Fact0r introduced a data knowledge flow, from sensor acquisition to semantic enrichment and decision support, and closing the loop between manufacturing and design phases. Deliverable D4.2 validated the Z-Prevent module's predictive analytics layer, which models KPIs linking energy use, defect rates, and throughput. These KPIs underpin a governance logic for preventive decision-making and self-calibration of process parameters (MAY et al., 2017).

The Z-Repair module (D2.3) extends lifecycle management into additive re-manufacturing, enabling re-use of defective parts through 3D-printing–based repair pathways and hybrid laser–deposition techniques (CETRI, 2018; CERTH, CETRI & DATAPIXEL, 2018). This closed-loop process supports circular production and measurable material savings, integrating Z-Prevent's KPI feedback into the decision flow (MAY et al., 2017). Together, the modules create a digital thread linking that is detection → prevention → repair → management, advancing both sustainability and productivity objectives (Grevenitisi & Faria, 2018; HOLONIX, 2019; MAY et al., 2017).

Data governance is embedded in the middleware through role-based access control and ontology-driven semantics, ensuring that partners can share contextualised data without disclosing proprietary details (Grevenitisi & Faria, 2018). The semantic framework designed by EPFL enabled controlled interoperability between heterogeneous sources, an early precursor of later federated data-sharing logic (HOLONIX, 2019; MAY et al., 2017).

Industrial validation (D5.2) across MICROSEMI, DURIT, and NECO pilots confirmed reductions in false alarms, improved defect-prediction accuracy, and higher yields of re-worked components (HOLONIX, 2019). The Integration Discipline from D5.1 established continuous verification and traceable decision loops, which form a tangible model of lifecycle data continuity (Grevenitisi & Faria, 2018; HOLONIX, 2019).

Deliverable D7.3 outlined a Technology Adoption Roadmap that links Z-Fact0r outputs to Industry 4.0 digital-maturity benchmarks, while D9.1 detailed dissemination in the Zero-Defect Manufacturing Cluster to share APIs, ontologies, and interoperability guidelines (Confindustria, 2020).

For CoLife, Z-Fact0r offers great insights into data governance, lifecycle integration, and controlled interoperability. Its *ontology-based data model*, *KPI-driven decision logic*, and *repair-oriented circular framework* illustrate how lifecycle data can generate shared industrial and environmental value (Grevenitisi & Faria, 2018; MAY et al., 2017; Confindustria, 2020).

4.1.33 GO0D MAN

The GO0D MAN project (aGent Oriented Zero Defect Multi-stage mANufacturing, Horizon 2020, 2016–2019) (European-Commission-CORDIS, 2025) developed a Multi-Agent System (MAS) architecture for distributed decision-making, predictive quality control, and autonomous process optimisation in multi-stage manufacturing. The project aimed to reduce defects and resource waste by integrating CPS, AI-based analytics, and smart inspection tools into a ZDM framework (Leitão et al., 2018; J. Barbosa et al., 2018).

Table 36 is about the main characteristics of the GO0D MAN, which is included its funding, actor roles, data use, and assessed relevance for CoLife.

Case Name	Source	Country / Region	Project Type	Data Use	Type of Collaboration	Funding	Value Co-Creation Elements	Relevance
GO0D MAN	CORDIS-id723764	EU	H2020	Multi-agent system for ZDM	CPS networks, SME clusters	H2020	Real-time process control, cost savings	Medium

Table 36: Key characteristics of the GO0D MAN project

GO0D MAN introduced a service-oriented, which is an agent-based architecture designed to connect Operational Technology with IT layers through a network of autonomous, collaborative agents. Four main agent types, which are Product Type Agent (PTA), Product Agent (PA), Resource Agent, and Independent Meta Agent (IMA), were responsible for coordination, negotiation, and learning across production stages (Leitão et al., 2018). The agents communicate through standard protocols such as MQTT, OPC-UA, and REST APIs, which ensure interoperability between factory devices and analytics components (Barbosa & Angioni, 2018). The IMA collects data from distributed agents to generate adaptive control rules, while local agents execute real-time process adjustments to prevent defect propagation. This approach created a closed feedback loop throughout the entire production chain, enabling predictive adaptation rather than reactive quality correction. The integration of Smart Inspection Tools (SITs) further strengthened data continuity. SITs combine sensor integration, machine vision, and advanced control logic to collect rich production data and feed it into MAS-based analytics (J. Barbosa et al., 2018). The architecture, therefore, represents an early digital-thread model, connecting design → operation → quality control within a unified cyber-physical layer.

GO0D MAN's Knowledge Management Environment (KME) operationalised data-driven learning across distributed agents. Data captured by SITs is first contextualised locally (via RAs), then analysed globally by the IMA to infer defect-causality patterns. The resulting knowledge artefacts, decision rules, and predictive models are disseminated back to agents for continuous improvement (Leitão et al., 2018). Deliverable D2.3 and the related paper Data Assets for Decision Support in Multi-Stage Production Systems (Utz & Falcioni, 2018) illustrate how the system builds decision support ontologies using AutomationML and ADOxx metamodels. These ontologies enable semantic alignment between heterogeneous process data and higher-level analytics, enhance the traceability, explainability, and reuse of knowledge assets. This mechanism of distributed learning and rule-sharing is similar to CoLife's aim to create *collaborative lifecycle data ecosystems*, where data collected in one context can inform decisions in another.

Governance in GO0D MAN is defined through autonomous agent communities and by following the Foundation for Intelligent Physical Agents (FIPA) interaction standards. Each agent has explicit roles, permissions, and decision autonomy, promoting decentralised trust while maintaining semantic consistency (Leitão et al., 2018). This distributed governance model allows *collaboration without central control*, ensuring that process decisions emerge through negotiation between intelligent agents rather than fixed hierarchies. The ontology-driven MAS ensures that all communication follows a shared semantic model, forming a precursor to the *federated and trusted collaboration frameworks* pursued in CoLife. From an interoperability perspective, GO0D MAN adopted OPC-UA and MQTT for real-time communication, while AutomationML and RDF-based ontologies ensured that process knowledge could be exchanged between different stages and factories. These technical enablers support data interoperability, transparency, and contextualisation, key requirements for CoLife's lifecycle data governance.

GO0D MAN demonstrated important *industrial and systemic value*: (1) *Operational value*: Defect rates were reduced through real-time process correction and adaptive rule updates (J. Barbosa et al., 2018). (2) *Technological value*: The MAS structure provided an early blueprint for autonomous coordination and lifecycle data continuity. (3) *Societal and environmental value*: The ZDM approach led to lower material waste, energy use, and rework, which aligning with sustainability goals (Leitão et al., 2018). For CoLife, GO0D MAN serves as a technical and conceptual predecessor. It introduces the logic of federated collaboration and distributed governance that CoLife expands to multi-actor ecosystems. The project's integration of MAS, ontologies, and data-driven learning demonstrates how lifecycle knowledge can be managed across autonomous entities. However, GO0D MAN remained closed within the consortium, focused on intra-factory quality collaboration rather than cross-industry data ecosystems. Thus, while it provides essential architectural lessons, it stops short of CoLife's win–win–win model of systemic, fair-data collaboration.

4.1.34 ZAero

The ZAero project (Zero-Defect Manufacturing for Composites, Horizon 2020, 2015–2019) (European-Commission-CORDIS, 2025) addressed the challenge of quality assurance in aerospace composite manufacturing, which is trying to achieve ZDM through data-driven monitoring, digital twins, and adaptive process control. The project developed an integrated system linking process simulation, in-situ sensing, AI-based defect detection, and decision support tools to prevent defects before they propagate (Zambal, Eitzinger, et al., 2019; Zambal, Heindl & Eitzinger, 2019).

Table 37 summarises the main characteristics of the ZAero, which includes its funding, actor roles, data use, and assessed relevance for CoLife.

Case Name	Source	Country / Region	Project Type	Data Use	Type of Collaboration	Funding	Value Co-Creation Elements	Relevance
ZAero	CORDIS-id723698	EU	H2020	Inline defect control, digital lifecycle	Aerospace supply chain	H2020	Quality-driven data flows	Medium

Table 37: Key characteristics of the ZAero project

ZAero's architecture integrates *Cyber-Physical Systems* and *Digital Twins* into a modular control framework that spans design, lay-up, curing, and inspection stages. Data from fibre-placement machines, autoclave curing, and ultrasonic inspection were collected via OPC-UA and stored in a central defect database, accessible through a QlikView-based decision dashboard. The Digital Twin replicated the manufacturing process using Finite Element (FE) and Discrete Event Simulation (DES) models, that were dynamically synchronised with sensor data from curing ovens and inspection devices (Steringer et al., 2019; Zörrer et al., 2019). This bi-directional feedback loop allowed engineers to adjust temperature, vacuum, and lay-up parameters in real time, effectively creating a closed-loop adaptive control system. Additionally, the project used high-frequency dielectric and flow sensors to track resin infiltration and curing kinetics, feeding the data into quality prediction algorithms (Gleuher et al., 2019). This helped a continuous data flow across physical and virtual layers, an early implementation of lifecycle data continuity that aligns with CoLife's digital ecosystem logic.

ZAero transformed composite manufacturing data into reusable knowledge assets. The Defect Database integrated production, inspection, and simulation data to support long-term learning. It linked process parameters such as temperature, pressure, and fibre tension with defect classifications such as porosity, delamination, or fibre misalignment that were derived from AI-assisted ultrasonic and thermal imaging (Zambal, Heindl & Eitzinger, 2019). A key element was the *Defect Correlation Model (DCM)*, which identified cause–and–effect relationships between production deviations and final part quality. This model caused predictive quality management and supported cross-partner learning between industrial and research stakeholders (European-Commission-CORDIS, 2025). Lifecycle knowledge was shared through governed access policies among Airbus (OEM), suppliers (Hexcel, FIDAMC), and research institutes (Fraunhofer, TU Munich). This ensured *traceability without data leakage*, following a federated sharing approach, closely reflecting CoLife's governance objectives for trusted multi-actor data exchange.

Governance in ZAero was based on a *collaborative, role-oriented framework*. Each partner owned its process data but contributed derived models and metadata to the shared repository. Access rights were formalised through Non-Disclosure Agreements (NDAs) and data classification policies defining which datasets were open, restricted, or partner-confidential(Rodriguez et al., 2019; European-Commission-CORDIS, 2025). Interoperability was achieved through standardised data formats such as HDF5, CSV, and AutomationML, and API-based connectors that integrated Siemens NX, ANSYS, and MES systems. The project also introduced a Business Analytics layer, which is enabling data visualisation, KPI tracking, and root-cause analysis through QlikView dashboards (Zambal, Eitzinger, et al., 2019). The collaboration model thus exemplified a federated industrial data space, each partner retained control of proprietary data but shared high-level insights, building collective intelligence.

ZAero created measurable improvements in product quality, resource efficiency, and decision reliability. Automated defect detection reduced inspection time by 40%, while adaptive process improvement reduced scrap and rework rates by 25% (Zambal, Heindl & Eitzinger, 2019; European-Commission-CORDIS, 2025). From a CoLife perspective, ZAero demonstrates how *lifecycle data integration and multi-partner collaboration* can deliver shared industrial, environmental, and societal value: (1) Industrial value, which is about the reduced downtime and faster certification through predictive control. (2) Environmental value, which is about Lower material and energy waste in autoclave curing and lay-up. (3) Societal value, which is about Improved reliability and safety in composite aerospace components. Its defect knowledge repository and federated data governance mirror CoLife's principles of trust-based collaboration and lifecycle learning. However, ZAero's ecosystem remained sector-specific and consortium-bounded, limiting scalability to open cross-sector data spaces.

4.1.35 STREAM-0D

The STREAM-0D project (Simulation in Real Time for Manufacturing with Zero Defects, Horizon 2020, GA 723082, 2016–2020) developed an adaptive, simulation-driven control framework that aims for ZDM through the combination of reduced-order models (ROMs), real-time data acquisition, and digital-twin technology. Coordinated by the Instituto Tecnológico de Aragón, the consortium brought together industrial partners from the automotive sector, such as ZF Active Safety and Fersa Bearings, with leading research institutions including LMS Patras and Ecole Centrale de Nantes. The central goal of the project was to connect multi-physics process simulation with sensor feedback and adaptive control so that manufacturing systems could predict, detect, and mitigate defects in real time (European-Commission-CORDIS, 2025).

Table 38 summarises the main characteristics of the STREAM-0D, which includes its funding, actor roles, data use, and assessed relevance for CoLife.

Case Name	Source	Country / Region	Project Type	Data Use	Type of Collaboration	Funding	Value Co-Creation Elements	Relevance
STREAM-0D	CORDIS-id723082	EU	H2020	Real-time defect prediction, simulation-driven quality	Multi-actor production lines	H2020	Integrated decision suppor	Medium

Table 38: Key characteristics of the STREAM-0D project

The STREAM-0D architecture integrated multiphysics modelling with data-driven control loops that spanned design, production, and quality-assurance stages. Each production line was represented by a digital twin running reduced-order simulations on embedded controllers, which allowed real-time decision-making based on process variability (Stavropoulos, Papacharalampopoulos & Petridis, 2020; Papacharalampopoulos, Petridis & Stavropoulos, 2020). The digital-twin workflow was structured so that high-fidelity finite-element simulations were first developed offline to capture the physical behaviour of forming, curing, or extrusion processes. These were then transformed into simplified alternative models through predictive techniques and order-reduction algorithms, before applied online for adaptive control. As sensor data streamed from shop-floor devices, the reduced models updated continuously, which is creating a closed feedback loop between the physical system and its virtual replica. This design achieved high-accuracy, real-time control without the need for high-performance computing infrastructure, providing a scalable approach to data-driven manufacturing control, particularly suitable for small and medium-sized enterprises.

STREAM-0D created a continuous data flow between digital twin simulations and real production systems, which is enabling feedback learning throughout the product lifecycle. Sensor readings from forming lines, temperature probes, and optical inspection systems were automatically collected and fed back into the digital models, recalibrating simulation parameters in near-real time. The resulting knowledge was stored in a shared project database accessible through a secured consortium platform (DAYONE, 2016). This bidirectional exchange of data connected design models and operational processes, which is ensuring the insights gained during production could inform future design iterations and maintenance strategies. Such a mechanism reflects CoLife's vision of lifecycle learning within trusted data ecosystems, where knowledge continuity and contextual reuse enhance both efficiency and reliability.

The governance model of STREAM-0D followed a federated collaboration logic, ensuring that industrial partners maintained ownership of their production data while allowing reduced and anonymised models to be shared for validation within the consortium (DAYONE, 2016).

Collaboration was coordinated through a secure web-based data-exchange environment with clearly defined access roles distinguishing research, industrial, and communication permissions (European-Commission-CORDIS, 2025). This governance-by-design approach balanced confidentiality with the need for transparency, supporting trust among partners.

From a technical standpoint, interoperability was achieved through standardised communication inte (Stavropoulos, Papacharalampopoulos & Petridis, 2020; Papacharalampopoulos, Petridis & Stavropoulos, 2020). By coupling multi-physics solvers with Industry 4.0-compatible sensor networks, STREAM-0D demonstrated how secure, modular architectures can facilitate cross-partner learning while maintaining data sovereignty, a principle central to CoLife's collaborative data governance objectives (Stavropoulos, Papacharalampopoulos & Petridis, 2020; Papacharalampopoulos, Petridis & Stavropoulos, 2020).

The industrial demonstrators implemented within STREAM-0D validated the approach and demonstrated clear operational benefits. Real-time control of forming and curing processes improved process yield by between ten and twenty per cent, while reducing variability and scrap rates across pilot production lines (European-Commission-CORDIS, 2025; DAYONE, 2016). According to the project's technical papers, adaptive digital-twin control systems allowed continuous recalibration of process parameters, leading to more stable product quality and shorter lead times (Stavropoulos, Papacharalampopoulos & Petridis, 2020; Papacharalampopoulos, Petridis & Stavropoulos, 2020).

The project created value at multiple levels: industrially, through improved precision and predictive process control (Papacharalampopoulos et al., 2020); environmentally, by minimising material and energy waste during production (European-Commission-CORDIS, 2025); and socially, by strengthening the competitiveness and digital maturity of European manufacturing ecosystems (DAYONE, 2016).

For CoLife, STREAM-0D provides a tangible illustration of how simulation-driven data ecosystems can integrate design and operational knowledge to create systemic value. Its combination of reduced-order modelling, real-time feedback control, and federated collaboration demonstrates a pragmatic pathway toward the kind of trusted, lifecycle-oriented data governance that CoLife aims to foster (European-Commission-CORDIS, 2025). Although STREAM-0D remained primarily a consortium-bound initiative, the technical and organisational methods it developed, particularly its emphasis on data reuse, interoperability, and governance-by-design, are directly transferable to CoLife's pursuit of win–win–win industrial ecosystems (Stavropoulos, Papacharalampopoulos & Petridis, 2020; Papacharalampopoulos, Petridis & Stavropoulos, 2020; DAYONE, 2016).

4.1.36 KEKO Smart Real Estate

The KEKO Smart Real Estate project (Business Finland Co-Innovation 2020–2021) represents a pioneering Finnish initiative toward creating data-driven, carbon-neutral, and user-centric smart buildings. Coordinated by YIT with VTT Technical Research Centre of Finland as the research partner, the two-year ecosystem project brought together key industrial actors, KONE, Nokia, Caverion, Halton, and Netox, to develop an interoperable framework for real-estate data sharing and digital-twin-based building management (Business-Finland, 2025b). The outcome was the internationally awarded Workery+ Vallila concept, a living-lab environment in Helsinki recognized as the Smartest Building in the World 2021 for its intelligent energy control, indoor-air management, and user experience integration.

Table 39 summarises the main characteristics of the KEKO Smart Real Estate project, which includes its funding, actor roles, data use, and assessed relevance for CoLife.

Case Name	Source	Country / Region	Project Type	Data Use	Type of Collaboration	Funding	Value Co-Creation Elements	Relevance
KEKO Smart Real Estate	Business Finland	Finland	Co-Innovation / Ecosystem	Shared building data, digital twin for energy & lifecycle	Multi-company (YIT, KONE, Nokia, VTT)	Business Finland Co-Innovation funding	Open standard for shared data, lifecycle management, energy efficiency	Medium

Table 39: Key characteristics of the KEKO Smart Real Estate project

KEKO was established as a Business Finland Co-Innovation ecosystem, where each partner contributed R&D under a shared roadmap coordinated by YIT and VTT. The ecosystem design promoted cross-organisational learning and co-development across construction, ICT, and facility-service sectors. Collaboration was anchored in the Vallila living-lab pilot, where partners tested and validated digital services for energy optimisation, indoor climate regulation, and predictive maintenance. This collaborative setting exemplified a multi-stakeholder innovation ecosystem, aligning industrial and research interests through clearly defined governance roles and shared KPIs. The Business Finland framework ensured funding transparency and coordinated the creation of both technological solutions and new business models (Business-Finland, 2025b).

A central achievement of KEKO was the integration of building-lifecycle data from diverse property-management systems into a common digital platform. Data from heating, ventilation, lighting, occupancy, and maintenance subsystems were aggregated and standardised to enable joint analytics across the building's lifecycle. This enabled energy-efficiency gains, cost savings, and improved user comfort (Business-Finland, 2025b).

The project advanced the open-source Idun RealEstate Core standard, designed as a global modelling language for digital control of buildings, now adopted by platforms such as Microsoft Azure Digital Twins. Through collaboration with partners such as Nuuka Solutions and Granlund, KEKO demonstrated how open data architectures can connect proprietary systems while maintaining data sovereignty for each stakeholder (Business-Finland, 2025b). The ecosystem also developed a Smart Building Planning Guide to disseminate governance practices for future projects, promoting the idea that measurable data enables manageable operations.

KEKO generated significant industrial, environmental, and societal value. Industrially, it created a replicable model for smart, energy-optimised office environments that enhance productivity and flexibility. Environmentally, it reduced energy consumption through AI-based HVAC control and lifecycle-based carbon-footprint assessment. Socially, it improved user health, comfort, and well-being by linking real-time environmental data to space utilisation (Business-Finland, 2025b).

From a CoLife perspective, KEKO offers a compelling precedent for data-driven ecosystem collaboration in the built-environment domain. Its governance model, combining open data standards, shared infrastructure, and federated ownership, illustrates how multi-partner ecosystems can manage lifecycle data responsibly while achieving shared value creation. The integration of digital twins, open APIs, and cross-organisational data reuse directly parallels CoLife's vision of trusted collaboration and win–win–win value co-creation across industrial data ecosystems.

4.2 Cross-case synthesis and observed practices

For the cross-case synthesis, 36 benchmarking cases were analysed to reveal the cross-cutting patterns that underpin collaborative and data-driven asset lifecycle management. The purpose of the synthesis is not merely to restate individual project results but to interpret how governance, technological integration, and incentive mechanisms jointly influence value co-creation across diverse industrial ecosystems. The analysis goes beyond descriptive comparison and instead focuses on the systemic regularities that emerged across clusters. These regularities provide the interpretive foundation for the thematic analysis in Chapter 5, where they are examined against the theoretical pillars of asset lifecycle management, collaborative ecosystem practices, and value co-creation and data-driven business models.

4.2.1 Overview of emerging patterns

Across all case studies, technological maturity alone did not guarantee success. The critical determinant of sustained collaboration was the ability to manage lifecycle data across organisational boundaries and translate that continuity into operational and strategic value. The synthesis reveals three recurring insights. First, *lifecycle integration*, often referred to as the digital thread, remained the key constraint on value realisation (Usher et al., 2020; Magnanini & Eger, 2019). Second, *governance and trust mechanisms*, rather than technological complexity, determined whether partnerships would survive beyond pilot phases (Chiacchiera & Hashibon, 2022; Luedtke & Blomsma, 2023; Alsaba et al., 2024). Third, l*ong-term data sharing* focused on fair incentive systems and transparent mechanisms for recognising contribution and reward (BOSCH et al., 2020). Together, these findings illustrate that the greatest challenges in collaborative asset lifecycle management are institutional and organisational, not technical (Tomas et al., 2023).

4.2.2 Asset lifecycle and zero-defect manufacturing cluster

Projects within the Zero-Defect Manufacturing and lifecycle integration clusters, such as ZDMP (2019-2023), QU4LITY (2019-2022), ForZDM (2016-2021), OPTIMAI (2021-2024), MAYA (2015-2018), STREAM-0D (2016-2020), and ZAero (2016-2019), demonstrated that improvements in yield and quality were achieved only when design, production, and service data were integrated into a continuous feedback loop (Magnanini & Eger, 2019). This pattern confirms that digital-thread maturity was the connecting factor that separated incremental pilots from systemic impact (Tomas et al., 2023; Negri, Roda, et al., 2017). In cases like MAYA (2015-2018), STREAM-0D (2016-2020), and ZAero (2016-2019), where PLM and ALM environments were connected, design modifications were driven by live operational feedback, leading to measurable improvements in reliability and performance (Eitzinger, 2019). Conversely, projects that pursued complete semantic harmonisation before data exchange experienced delays and stagnation, suggesting that pragmatic alignment combining minimal shared vocabularies with rigorous provenance tracking was more effective in achieving time-to-value (Mauro et al., 2021). These findings indicate that data continuity depends as much on governance and organisational routines as on technical interoperability (Martin et al., 2023; Magnanini & Eger, 2019).

4.2.3 Collaborative ecosystems and governance cluster

The governance-oriented cases, including DOME 4.0 (2020-2024), Onto-DESIDE (2022-2025), and FP3–IAM4RAIL (2022-2026), revealed that the structure of orchestration directly shapes ecosystem inclusiveness and scalability. Neutral or consortium-based coordination encouraged broader SME participation, while keystone-led models such as ZDMP

(2019-2023) and Valuechain.com (2016-2017) scaled rapidly but created dependency risks (Chiacchiera & Hashibon, 2022; Luedtke & Blomsma, 2023). This confirms that speed and inclusiveness form an inherent trade-off in ecosystem design (Alsaba et al., 2024; Polcaro, Jara, et al., 2018). Additionally, projects that implemented detailed DMPs, including OPEN-ZDM (2022-2025) and DAT4.ZERO (2020-2024) established clear roles, responsibilities, and access tiers, which created transparency and accountability among partners (BOSCH et al., 2020; F6S, INTRA & LMS, 2022). These DMPs acted as de facto social contracts, making trust observable and enforceable (Benedicto & Luca, 2019; Hashibon & Dorp, 2023). Similarly, initiatives that certified boundary resources such as APIs, SDKs, and datasets showed by BEinCPPS (2015-2018) and MIDIH (2017-2020) gained higher levels of reuse and partner retention (Polcaro, Jara, et al., 2018; Benedicto & Luca, 2019). In contrast, ecosystems lacking such certification or structured DMPs faced fragmentation, inconsistent data quality, and early partner withdrawal. The evidence confirms that effective governance relies on both formalised rules and visible instruments of trust (Chiacchiera & Hashibon, 2022; Luedtke & Blomsma, 2023).

4.2.4 Data ecosystems and business-model innovation cluster

The cases clustered around data-driven business models and monetisation strategies, such as Z-Fact0r (2016-2020), GO0D MAN (2016-2019), OPTIMAI (2021-2024), and Valuechain.com (2016-2017), demonstrated that measurable incentive mechanisms are essential for sustaining participation after project funding ends (HOLONIX, 2019; Utz & Falcioni, 2018; Rubattino & Verardi, 2021a). Shared-savings and usage-based licensing schemes, which linked fees or rewards to verified Key Performance Indicators, ensured continued collaboration and data quality (Rubattino & Rossi, 2021; Guyo & T. Hartmann, 2024). The CBIM (2020-2024) and DAT4.ZERO (2020-2024) projects illustrated the importance of treating datasets and APIs as structured products, equipped with versioning, quality scores, and service-level agreements (BOSCH et al., 2020; Guyo & T. Hartmann, 2024). This productisation enabled reuse across industrial contexts and accelerated ecosystem scalability (Rubattino & Verardi, 2021a; Brandstetter & Wehrstedt, 2018). Additionally, regulatory developments, particularly the EU Data Act, GDPR, and NIS2, pressured platform operators such as DOME 4.0 (2020-2024) and Onto-DESIDE (2022-2025) to adopt neutrality duties and policy-enforced usage control (Hashibon & Dorp, 2023; Luedtke & Blomsma, 2023). These requirements shifted governance models away from exclusivity toward more open and equitable arrangements (Rubattino & Rossi, 2021; Guyo & T. Hartmann, 2024). Ecosystems that ignored contractual or regulatory frameworks struggled to maintain data contributions, proving that sustainable value creation demands explicit appropriation logic and compliance-aligned governance (HOLONIX, 2019; Utz & Falcioni, 2018).

4.2.5 Circular Economy and sustainability cluster

The sustainability-oriented cases, such as ReTraCE (2018-2023), NEXT-NET (2017-2019), and Sandvik Circular Mining (2021), extended the notion of value co-creation to environmental and societal dimensions (Bimpizas-Pinis, Genovese, et al., 2021; Barros, Senna & Zimmermann, 2019; BusinessFinalnd, 2021). They illustrated that circular outcomes such as reduced material waste and extended asset life were only credible when supported by transparent provenance systems and verifiable lifecycle data (Bimpizas-Pinis, Genovese, et al., 2021; Stute et al., 2018). Projects that embedded traceability and auditability into their data infrastructures were able to link environmental indicators directly to operational performance (BusinessFinalnd, 2021; Barros, Senna & Zimmermann, 2019). These examples demonstrate the viability of the win-win-win principle, where economic, environmental, and societal gains reinforce one another. These findings emphasise that circular benefits emerge not as a by-product of technology but through coordinated governance and measurement practices that translate sustainability goals into data-driven accountability (Bimpizas-Pinis, Genovese, et al., 2021; Stute et al., 2018).

4.2.6 Summary and transition to discussion

In summary, the cross-case synthesis highlights that the maturity of the digital thread illustrates the upper limit of achievable value, while the quality of governance and the presence of trust instruments decide whether ecosystems persist beyond their initial funding cycle (Tomas et al., 2023; Chiacchiera & Hashibon, 2022; Guyo & T. Hartmann, 2024). Furthermore, fair and transparent incentive mechanisms, combined with productised data assets, transform short-term collaborations into scalable and repeatable partnerships (BOSCH et al., 2020; Rubattino & Rossi, 2021). These observations collectively validate the conceptual triad developed in the theoretical framework: *Asset lifecycle integration (A-claims)*, *Collaborative governance and ecosystem quality (C-claims)*, and *Value co-creation and appropriation (V-claims)*. The next chapter expands upon these findings by analysing how the observed practices align with, diverge from, or extend existing theoretical expectations, ultimately translating them into strategic design principles for the CoLife project.

5 Discussion and thematic synthesis

The purpose of this chapter is to interpret the benchmarking results through the theoretical lenses established in Chapter 2 and the empirical clusters described in Chapter 4. Whereas the previous chapter presented what the cases revealed, this discussion focuses on why and how those outcomes emerged, what they imply for the evolution of collaborative asset-lifecycle management, and how they advance theoretical and practical understanding. The synthesis is structured around three analytical dimensions derived from the study's theoretical pillars: *A-claims (Asset Lifecycle integration)*, *C-claims (Collaborative governance)*, and *V-claims (Value co-creation)*. Together, they provide a framework for analysing the interdependencies between technical, organisational, and economic mechanisms that underpin data-driven industrial ecosystems.

This thematic discussion proceeds in three sections. First, Section 5.1 compares the theoretical expectations with empirical findings from the 36 benchmarking cases, revealing confirmation points, divergence, and extension. Second, Section 5.2 translates these comparative insights into strategic implications for the CoLife project, which identifies what lessons are transferable to the Finnish industrial context. Finally, Section 5.3 combines the results to a conceptual "win-win-win" collaboration model that integrates the economic, environmental, and societal dimensions of value creation.

5.1 Comparing theoretical insights and empirical findings

This section presents benchmarking results that use the three analytical perspectives introduced earlier: A-claims, C-claims, and V-claims. These perspectives make a structured basis for comparing theoretical expectations with the observed practices in European and Finnish industrial initiatives. The analysis focuses on where empirical developments align with the literature and where gaps, limitations, or divergences remain.

5.1.1 Asset lifecycle management and the digital thread (A-claims)

The theoretical framework explains asset lifecycle management as a strategic capability that is linking the design, production, and service phases with an unbroken digital thread (Stark, 2022; ISO 55000, 2024; Lee et al., 2015). It also focuses on information continuity, real-time traceability, and predictive control as levers of operational excellence (Tao et al., 2019). Empirical analysis supports these claims, but it adds organisational and policy dimensions which are often overlooked by theory. In ZDMP D052 (2023), the platform's four-tier architecture, Developer, Enterprise, Platform, and Edge, achieved end-to-end data flows by combining API gateways, message buses, and secure authentication layers, demonstrating that technical interoperability can be engineered when governance is embedded in design. The ForZDM D4.3 (2021) and OPTIMAI D1.3 (2021) deliverables likewise showed that yield improvements and defect reduction became measurable only when design and operation were connected through continuous feedback loops. These outcomes confirm Stark's proposition that data integration is the main constraint on value realisation. However, the benchmarking cases also reveal that lifecycle integration is not purely a technical problem. MAYA D2.1 (2017) and STREAM-0D (2016-2020) reported that feedback channels broke down whenever ownership of engineering data was ambiguous. This finding extends Yin (2018), suggesting that closing lifecycle loops in multi-actor environments demands clear governance routines for version control and change validation. ZDMP (2019-2023) further demonstrated that integration succeeds only when identity management, policy enforcement, and security are considered as first-class components of the digital thread (Tomas et al., 2023; Lazar et al., 2019). Thus, the empirical evidence both confirms and refines the theory by reframing ALM as a socio-technical coordination challenge rather than a purely technological one.

Figure 4 summarises the analytical pathway linking theoretical expectations of lifecycle integration with empirical observations from the benchmarking cases, highlighting how asset-lifecycle maturity depends on socio-technical coordination.

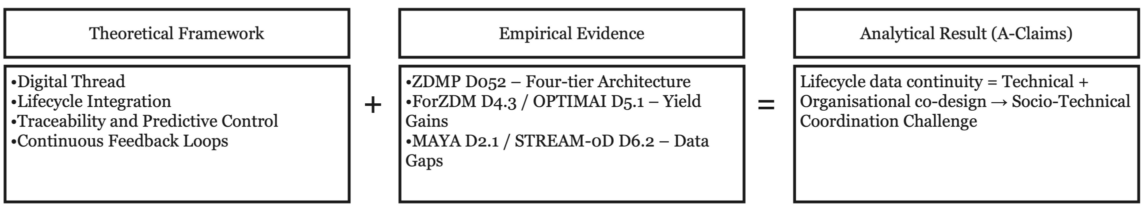

Figure 4: Analytical logic of asset lifecycle management (A-claims)

Figure 5 illustrates the lifecycle data flow across phases, highlighting the broken feedback loop at the end-of-life stage and the CoLife could introduce governance intervention to reconnect it.

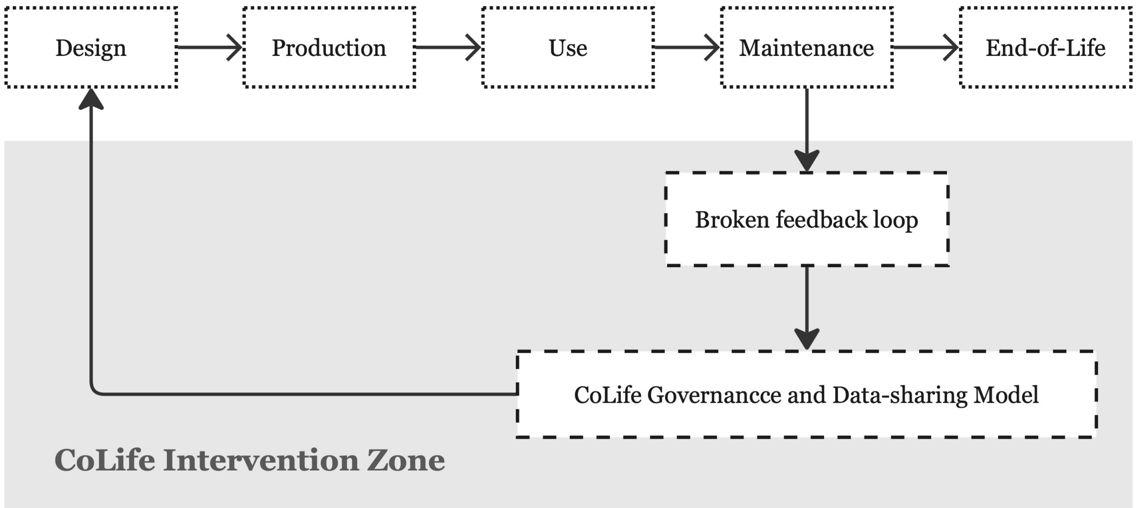

Figure 5: Lifecycle data continuity and CoLife intervention loop

The figure emphasises that while many projects achieve technical integration between design and use, end-of-life data often fails to return upstream. The CoLife governance model could introduces shared data protocols and feedback mechanisms to close this loop.

As depicted in Figure 5, achieving seamless data continuity requires more than technical integration. The following CoLife takeaways distil the practical lessons derived from the *A-claims* analysis and indicate how they can guide lifecycle governance within the Playbook.

CoLife Takeaway 1: Technical integration must be accompanied by institutionalised data-sharing agreements and governance protocols that ensure every lifecycle phase, especially end-of-life, is represented in the digital thread.

CoLife Takeaway 2: The CoLife Playbook can adopt a *closed-loop feedback* principle, requiring each participating actor to provide data outputs that feed the next phase, thereby maintaining information continuity and improving predictability.

5.1.2 Collaborative ecosystem governance (C-claims)

The ecosystem literature argues that orchestration choice, trust, and boundary resources determine collaboration longevity and scalability (Adner, 2017; Jacobides et al., 2018; Tiwana, 2014). This expectation aligns closely with the empirical findings. DOME 4.0 D4.1 (2022), and Onto-DESIDE D5.2 (2023) showed that neutral or consortium-based coordination fostered broad SME participation, whereas keystone-led arrangements like ZDMP (2019-2023) gained faster scaling but concentrated decision power. FP3–IAM4RAIL D2.6 (2024) and D10.1 (2023) illustrate a contrasting case: a closed consortium governance model under Europe's Rail JU that emphasised technical coordination across clusters rather than ecosystem inclusiveness. These contrasts empirically confirm Jacobides et al.'s predicted trade-off between inclusiveness and efficiency. Moreover, the governance artefacts were introduced in DAT4.ZERO D2.8 (2020) and OPENZDM (2022-2025) notably Data Management Plans defining ownership, access tiers, and responsibilities acted as enforceable *social contracts*, a pattern anticipated by Curry et al. (2022).

Yet the data also diverge from theoretical expectations that neutral governance is universally desirable. The ZDMP D052 (2023) architecture demonstrates that strong keystone control can improve reliability by embedding secure installation, token-based access, and audit logs directly into platform components. Governance here is executed through code rather than post-hoc agreements. Consequently, practice reveals a continuum rather than a binary choice between centralised and decentralised orchestration. This empirical nuance extends governance theory by highlighting that policy-as-code mechanisms, automated enforcement of security and identity policies, are now integral to ecosystem trust. In summary, while the theoretical discourse stresses relational governance and coordination, the cases demonstrate the rise of technical governance infrastructures as measurable trust instruments.

Figure 6 summarises how the benchmarking results validate and extend collaborative governance theory. Empirical evidence shows that while open models (DOME 4.0, Onto-DESIDE) promote inclusiveness, closed coordination structures such as FP3–IAM4RAIL (2022-2026) prioritise integration efficiency. Across cases, governance evolves from relational to technical forms, where policy-as-code and auditable security mechanisms become key instruments of trust.

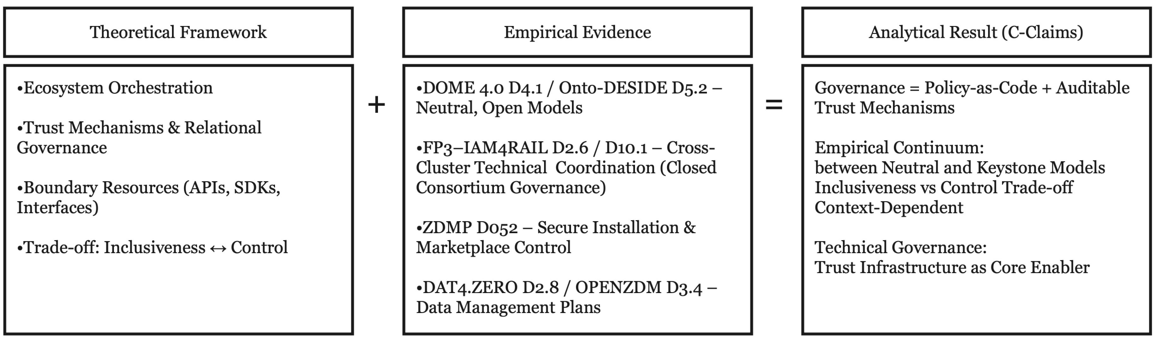

Figure 6: Analytical logic of collaborative ecosystem governance (C-claims)

Figure 7 illustrates the range of governance models observed in the benchmarking cases, which range from open-neutral to keystone-led coordination. CoLife's target can position lies in the adaptive hybrid zone, balancing inclusiveness and efficiency in policy-as-code mechanisms and auditable trust infrastructures.

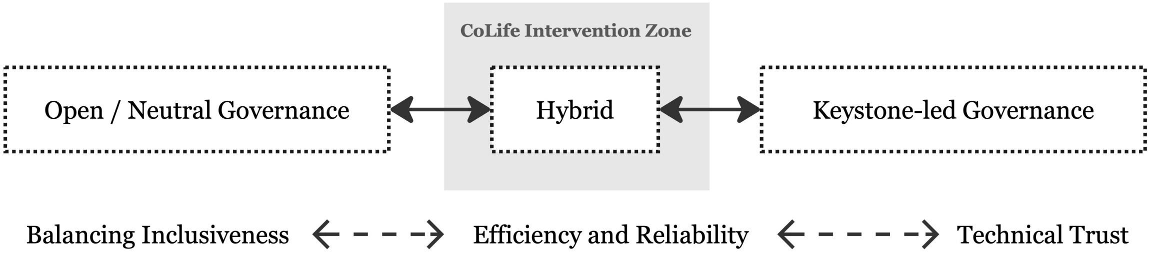

Figure 7: Governance continuum in collaborative ecosystems

In this continuum, CoLife could be positioned in the hybrid zone combining the openness of neutral models with the technical reliability and policy enforcement characteristic of keystone arrangements.

Based on these findings, the following CoLife takeaways translate the *C-claims* analysis to practical guidance for structuring collaborative governance in the Playbook.

CoLife Takeaway 3: The CoLife Playbook can integrate policy-as-code mechanisms into its governance model. Automated enforcement of access rights, version control, and data integrity can institutionalise trust, reducing dependence on informal or relational agreements.

CoLife Takeaway 4: Rather than selecting a single model for coordination, CoLife can recognise a continuum of governance models, from open-neutral to keystone-led, and guide partners in selecting context-appropriate coordination depending on maturity, risk tolerance, and desired scalability.

5.1.3 Value co-creation and data-driven business models (V-claims)

Theories of servitisation and data-driven business models conceptualise data as a strategic asset that enables new forms of revenue generation, fairness, and collaborative incentives (Teece, 2010; Porter & Heppelmann, 2014; Ritter & Pedersen, 2019). The benchmarking analysis confirms this principle but reveals that only a subset of European industrial ecosystems have progressed beyond prototypes toward measurable economic appropriation.

Evidence from CBIM D2.2 (2020) and DAT4.ZERO D2.8 (2024) confirms the translation of fairness and reciprocity into concrete mechanisms. Both projects operationalised usage-based licensing and shared-savings contracts, allowing partners to capture value proportionally to verified performance outcomes. Similarly, Z-Fact0r D1.4 and D2.3 (2018) embedded pay-for-performance logic in KPI-driven quality management and circular re-work solutions such as the Z-REPAIR toolkit, converting defect-reduction and remanufacturing efficiency into quantifiable business gains. These practices illustrate how performance-linked data flows transform technical results into sustained collaboration incentives.

Further progress will appear in OPTIMAI D2.5 and D8.7 (2022–2023), which realised AI-as-a-Service marketplace functionality in its dual catalogue of algorithms and pre-recorded data. Here, value creation shifted from internal efficiency to data production, where datasets and AI models were packaged with versioning, quality metrics, and service level agreements, forming tradeable digital assets. This step substantiates Teece's (2010) claim that appropriation arises once knowledge becomes modular, reusable, and governable.

The DOME 4.0 D6.3 and D6.4 (2024) deliverables reinforce this evolution by demonstrating open-API and FAIR-data interoperability as economic infrastructure. Industrial feedback during the project's Open-Day workshops confirmed readiness among participants to act both as data providers and consumers indicating the emergence of fair-data transactions within a transparent governance framework. DOME 4.0 (2020-2024) thus extends theoretical discourse on data sharing by proving that openness and monetisation are not contradictory but co-dependent: standardised semantics and policy-enforced interoperability enable trustworthy market exchanges, aligning with the "fair data economy" perspective that underpins the CoLife concept.

An additional contribution arises from the developer-tier infrastructure of ZDMP D052 (2023), which integrates a Marketplace, Application Builder, and collaboration workflows. This environment accelerates application supply, reduces integration costs, and enhances ecosystem liquidity, a mechanism rarely acknowledged in servitisation theory. Developer enablement, in this context, represents an economic multiplier: lowering technical entry barriers broadens network density and amplifies the total potential for value exchange.

Figure 8 demonstrates that V-claims evolve along a continuum: from efficiency-based ROI (Z-Fact0r (2016-2020)) to structured data governance (DAT4.ZERO (2020-2024)), from productised AI-service offerings (OPTIMAI (2021-2024)) to open-data market frameworks (DOME 4.0 (2020-2024)), and finally to scalable developer ecosystems (ZDMP (2019-2023)). The empirical evidence thus extends the theoretical framing of value co-creation from business-model design toward ecosystem-infrastructure design, where governance, interoperability, and openness themselves constitute strategic assets.

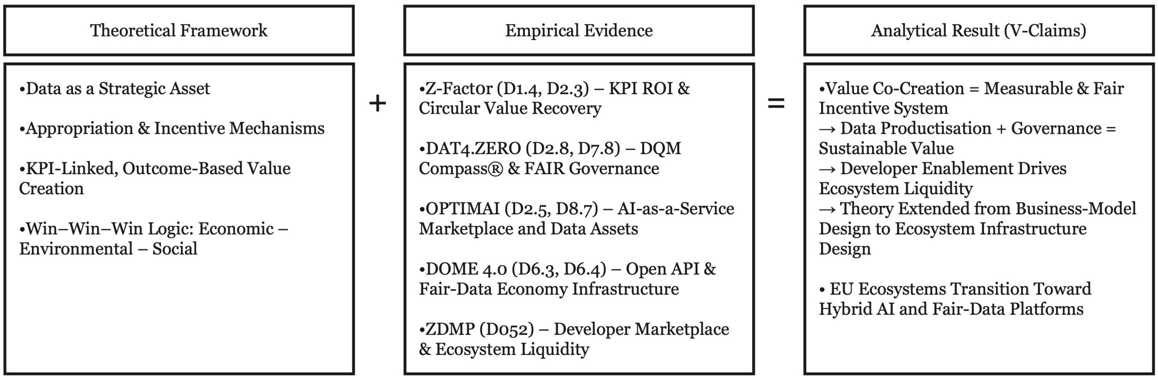

Figure 8: Analytical logic of value co-creation and data-driven business models (V-claims)

Figure 9 visualises how data-driven ecosystems evolve from technical data management toward systemic value co-creation. It depicts the sequential transformation of raw engineering data into governed, monetised, and finally circular value flows. The CoLife intervention can be positioned at the centre of this continuum, where fair-data governance and developer enablement act as the catalytic mechanisms that convert data continuity into measurable and sustainable value creation.

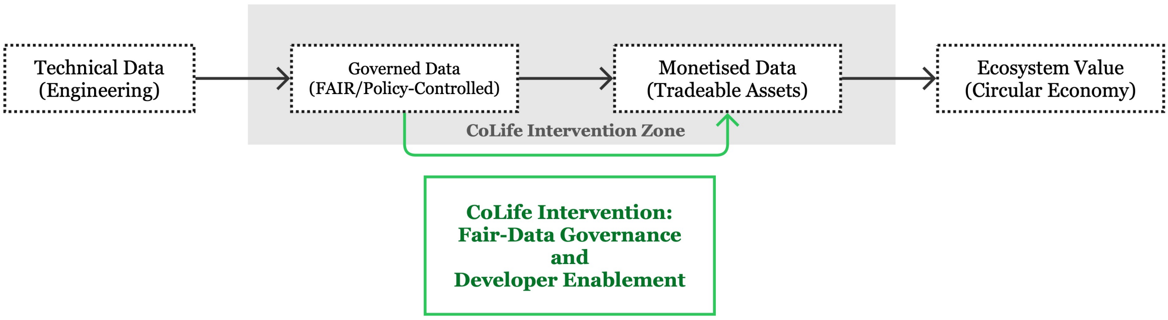

Figure 9: Evolution of value cco-vreation in data-driven ecosystems

The diagram illustrates the progression from technical to economic value creation. CoLife's intervention is expected to ensure that governance mechanisms and developer enablement convert data continuity into sustainable, measurable value co-creation.

Building on the synthesis illustrated in Figure 9, the following CoLife takeaways van translate the *V-claims* analysis into actionable guidance for developing value co-creation mechanisms within the Playbook.

CoLife Takeaway 5: The CoLife Playbook can define data-as-a-service templates which link technical datasets with contractual and quality metadata. This ensures data assets are not only shareable but tradeable, that supporting fair-value distribution and long-term ecosystem incentives.

CoLife Takeaway 6: To operationalise the fair-data-economy, CoLife can adopt a layered value architecture that connects (1) data producers, (2) governance services, and (3) application developers. Each layer must both consume and enrich lifecycle data, forming measurable feedback loops of economic, environmental, and social value.

The strategic implications that derive from the A-, C-, and V-claims establish a coherent blueprint for CoLife's future development. Lifecycle data continuity provides the enabling infrastructure, hybrid governance defines the trust architecture, and fair-data value mechanisms translate collaboration into measurable incentives. These three dimensions converge into a unified vision in which CoLife functions not as a static platform but as a dynamic coordination mechanism connecting technical, organisational, and economic layers of the industrial ecosystem. The next section builds upon this synthesis by outlining how these interdependent elements can be operationalised into a win-win-win collaboration model that ensures equitable value creation for companies, policymakers, and society alike.

5.2 Toward a win-win-win collaboration model for CoLife

Building on the strategic implications derived from the A-, C-, and V-claims, this section develops a conceptual model that may guide the CoLife project in designing collaboration practices for industrial lifecycle data ecosystems. Rather than presenting CoLife as a fully defined governance framework, the model should be understood as a theoretically informed proposal that synthesises benchmarking insights and identifies areas where CoLife could strengthen existing practices. The term *win-win-win* is used here to indicate a configuration in which industrial actors, institutional stakeholders, and society can all benefit simultaneously from lifecycle data sharing, contingent on the presence of governance and value mechanisms that distribute outcomes fairly. In this framing, CoLife is viewed as a collaborative infrastructure, a potential coordination layer that connects technical data continuity, governance mechanisms, and fair incentive structures, rather than a static platform or software solution.

5.2.1 Conceptual Integration and Model Logic

The benchmarking synthesis indicates that successful industrial data ecosystems align technical integration (A-claims), governance trust (C-claims), and value co-creation mechanisms (V-claims) within a unified operational architecture. Where these dimensions remain fragmented, as is often the case in existing European platforms, collaboration tends to rely on bilateral exchanges, limiting scalability, transparency, and long-term reciprocity. Conversely, when technical, organisational, and economic mechanisms reinforce one another, joint learning and coordinated decision-making become more systematic.

From this perspective, CoLife's contribution is not to prescribe a fixed governance structure, but to identify how these three dimensions could be connected in the Finnish context. The proposed model suggests that lifecycle data infrastructures provide the technical foundation for continuity; governance mechanisms such as policy-as-code and auditable usage control provide institutional legitimacy; and economic arrangements translate governed data into measurable incentives for participating actors. Rather than treating these as isolated building blocks, the model positions them as mutually reinforcing layers.

Within this integrated configuration, the win-win-win logic emerges as a potential outcome of balanced collaboration. For industrial actors, potential benefits include improved operational efficiency, reduced coordination costs, and enhanced innovation capacity through access to harmonised, high-quality lifecycle data. In addition, shared data infrastructures may enable new service models, data-enabled products, and competitive market positioning, strengthening firms' motivation to participate. Institutional actors, such as regulators and public agencies, may benefit from transparent, standardised data flows that support compliance, monitoring, and sustainability reporting. Societal value may materialise through reduced resource waste, extended asset lifetime, and knowledge spill-overs that contribute to the green transition. These benefits are not inherent but contingent on credible mechanisms that link data contribution to appropriation, which CoLife could seek to articulate and test. Thus, the model highlights a potential space for future design and experimentation rather than representing current implementation status.

5.2.2 Proposed Framework and Strategic Function

Figure 10 visualises the proposed CoLife Win-Win-Win Model as a triad in which lifecycle data infrastructure, governance mechanisms, and value architecture operate in mutual reinforcement. The triangular configuration highlights that no single dimension independently ensures collaboration; durability arises when technical data flows are supported by institutional trust and economically viable distribution of value. The figure should therefore be interpreted as a conceptual guideline grounded in benchmarking insights, not a depiction of an already established CoLife solution.

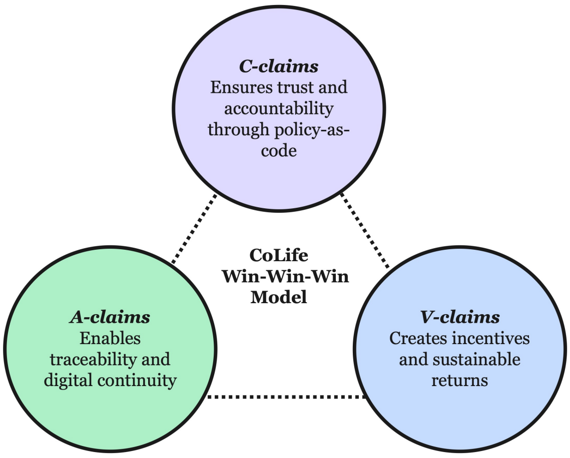

Figure 10: The CoLife Win-Win-Win Collaboration Model

Strategically, the model frames CoLife as a potential coordination mechanism that could inform national-level approaches to lifecycle data collaboration. Its contribution is not to replace existing platforms but to provide a scaffold through which industrial actors, researchers, and regulators may interact under shared rules, aligned incentives, and verifiable data flows. Institutionalising this configuration in the CoLife Playbook may support ecosystems that are both scalable and sufficiently fair, addressing observed challenges such as sustaining collaboration beyond funded project cycles. Ultimately, the model provides a foundation for designing collaboration patterns, regulatory alignment, and economic mechanisms in future phases of CoLife. Further work would require empirical validation, stakeholder negotiation, and co-design efforts to specify how these principles operate in real industrial settings.

6 Conclusion

This final chapter summarises the key findings of the benchmarking study and reflects on their implications for developing the CoLife concept. It brings together the theoretical, empirical, and strategic insights that were spoken in earlier chapters to show how asset lifecycle continuity, collaborative governance, and data-driven value creation collectively enable sustainable industrial collaboration. The chapter also outlines the study's specific contributions to the CoLife Playbook and discusses its limitations.

6.1 Summary of key findings

This thesis addressed the main research question: *How do collaborative ecosystems manage asset lifecycle data to enable value co-creation and fair data sharing practices among stakeholders*? The findings show that lifecycle data are managed effectively only when three interdependent mechanisms operate together: (1) technical integration that ensures data continuity across lifecycle phases, (2) institutional governance mechanisms, such as policy-as-code, auditable access control, and contractual metadata, that legitimise data sharing, and (3) value architectures that translate contribution into measurable business and societal returns. When these mechanisms are aligned, ecosystems can move beyond bilateral data exchange toward multi-actor value creation. However, benchmarking outcomes show persistent fragmentation at end-of-life, uneven incentive structures, and reliance on project-based coordination, indicating that current ecosystems remain incomplete and need more systematic governance to sustain collaboration over time.

Regarding collaborative practices and actor roles (Sub-Q1), the analysis shows that ecosystems are structured in a hybrid orchestration involving coordinators, infrastructure providers, technology suppliers, and regulatory bodies. Rather than relying only on relational trust, leading cases increasingly embed governance through shared identifiers, boundary resources, machine-readable consent, and contractual usage metadata. These mechanisms can decrease coordination costs and may enable more symmetric participation between SMEs and larger firms, supporting scalable collaboration at different levels of the supply chain.

In examining how data function as a strategic asset (Sub-Q2), the study finds that data create strategic and business value when they are treated as governed digital assets rather than operational residuals. Strategic data use supported predictive maintenance, lifecycle performance optimisation, evidence-based compliance, and new service-oriented business models. These outcomes, however, depended on interoperability standards and enforceable usage rights, illustrating that strategic value arises at the intersection of technical and institutional mechanisms.

Regarding value co-creation and fairness (Sub-Q3), ecosystems exhibited a continuum ranging from bilateral exchanges to multilateral governance structures that linked rights, responsibilities, and benefits. Fairness increased when contribution was traceable, benefits were linked to verifiable usage, and governance encoded enforceable reciprocity rather than informal agreements. Cases where governance remained relational tended to concentrate value around orchestrators, while emerging models using auditability and policy-as-code enabled more balanced allocation of returns.

Finally, *the benchmarking makes strategic insights for the Finnish context (Sub-Q4)*, highlighting opportunities to strengthen lifecycle data collaboration with institutionalising shared infrastructures and aligning incentives beyond funded project cycles. Priorities include reinforcing lifecycle visibility beyond operational phases, codifying compliance into machine-executable governance, and supporting innovation in open yet accountable interfaces. These insights suggest a pathway for CoLife to explore hybrid governance models that balance openness with enforceability.

Taken together, these findings establish that successful asset lifecycle data ecosystems need coordinated integration of technical continuity, institutional legitimacy, and economic reciprocity. This positions lifecycle data not merely as a technical resource but as a strategic infrastructure for sustainable industrial collaboration.

6.2 Contributions to the CoLife playbook

As the CoLife Playbook has not yet been established, this thesis does not aim to prescribe a complete or operationalised version of it. Instead, it offers evidence-based building blocks that can guide its formation. These contributions synthesise the insights derived from the A-claims, C-claims, and V-claims analyses and translate them into a coherent conceptual scaffold for designing national-level approaches to lifecycle data collaboration. Together, the findings of the study point to one overarching message: sustainable and fair asset-lifecycle collaboration requires the aligned functioning of lifecycle data continuity, programmable governance, and equitable value-sharing mechanisms.

The first contribution concerns lifecycle data continuity. The analysis shows that lifecycle data must be treated not as a project-specific technical artefact but as a shared, long-term infrastructure that spans design, production, use, maintenance, and end-of-life. CoLife could support such continuity by encouraging shared identifiers, transparent data protocols, and feedback loops that reconnect information from later lifecycle stages back into early design phases. Positioning lifecycle data continuity as an infrastructure rather than a tool enables not only technical interoperability but also organisational learning and system-wide resilience across Finnish industry.

The second contribution relates to governance. The benchmarking cases show that trust increasingly depends on programmable and auditable mechanisms, policy-as-code routines, automated access control, usage enforcement, and traceability, rather than solely on relational agreements. CoLife's role is therefore not to select a single governance model, but to define a hybrid governance zone that balances the inclusiveness of open models with the reliability and enforceability characteristic of keystone-led arrangements. Embedding programmable governance into the future Playbook would allow collaboration to scale beyond bilateral contracts and support accountable data sharing over the long term.

The third contribution concerns value co-creation. The study shows that value emerges only when data flows are linked to fair and transparent incentive structures. CoLife can provide conceptual templates for creating data-as-a-service assets that combine contractual, quality, and semantic metadata; for developing usage-based or outcome-based agreements; and for aligning contribution with appropriation in a measurable manner. In doing so, CoLife can help ensure that lifecycle data collaboration produces economic value for firms, regulatory value for public actors, and environmental and societal value in line with the fair data economy.

When integrated through the win-win-win model, these contributions do not suggest a fixed solution but rather provide a scaffold through which CoLife may connect technical, institutional, and economic layers into a unified approach. In this configuration, lifecycle data continuity enables traceability and feedback loops, programmable governance provides legitimacy and accountability, and value-architecture mechanisms ensure fair distribution of benefits across industrial, regulatory, and societal actors. The combined implication is that CoLife can function not as a static platform, but as a national-level coordination mechanism capable of harmonising lifecycle data practices in Finland and supporting fair, sustainable, and scalable industrial collaboration.

These insights offer a theoretically grounded and empirically validated starting point for developing the CoLife Playbook. At the same time, they highlight that further progress will depend on co-design with industrial stakeholders, regulators, and ecosystem partners to specify how these principles can be institutionalised in real operational settings.

6.3 Research limitations and suggestions for future research

Through this process, several *limitations* apply. First, the study is based on secondary data sources, including reports, project deliverables, presentations, and academic publications, rather than primary interviews. This inevitably restricts the depth of insight into organisational dynamics and actor perspectives. However, reliance on secondary data is consistent with the benchmarking approach, where the aim is to synthesise practices across a large number of initiatives rather than to conduct in depth ethnographies (Saunders, Lewis & Thornhill, 2019; Camp, 1989). Benchmarking studies commonly rely on secondary material to ensure coverage and comparability. Second, the benchmarking approach creates a balance between breadth and depth. By covering 36 cases, the analysis identifies transferable patterns and thematic clusters across diverse initiatives. The trade-off is that it cannot provide the comprehensive narratives or ethnographic detail that single-case methods might offer (Yin, 2018; Camp, 1989). Third, while technical aspects such as algorithm design or hardware optimisation, or detailed Information Technology protocol specifications were not analysed in depth, they were included when they directly illustrated how collaborative practices and governance mechanisms enable effective and fair data sharing. This boundary reflects a methodological focus on the sociotechnical interplay of standards and governance rather than purely technical design (GFMAM, 2024; Firdausy et al., 2022; ISO 55000, 2024).

This thesis has benchmarked collaborative, data-driven practices to support the development of the CoLife concept. While the results provide a strong foundation, several directions remain open for future study. Future research should continue testing how the CoLife framework performs in real contexts and explore its potential across different technological and organisational settings.

- Testing the CoLife model in practice: The next step is to apply the win-win-win collaboration model in real pilot projects. Future studies could examine how lifecycle data continuity, hybrid governance, and fair-data value exchange function when implemented by companies and research partners. Such pilots would demonstrate whether improved data sharing leads to measurable gains in trust, efficiency, or sustainability. These findings would help CoLife refine its Playbook and demonstrate its concrete benefits to industrial and policy stakeholders.
- Following how collaboration evolves: Many benchmarking cases indicated that collaboration changes over time as trust, data literacy, and governance maturity develop. Future research could follow CoLife-type ecosystems through different stages, from early setup to stable, long-term operation, to identify what supports lasting cooperation. This would also help understand how governance rules and incentives adapt when projects shift from development to real business use.
- Expanding from the real to the digital and virtual worlds: An important next step is to explore how CoLife's concepts could operate across real, digital, and virtual environments. While this study focused on real-world collaboration and data exchange,

future work could analyse how virtual twins and simulation-based tools extend lifecycle visibility and enable collaborative decision-making in a *virtual world*. Linking real-world asset data with digital- and virtual-world representations could offer new ways to predict system behaviour, test scenarios, and design circular business models. This direction would connect CoLife with emerging research on digital twins, metaverse-enabled manufacturing, and data-driven virtual collaboration spaces.

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Appendix 1 CoLife search tracker

Purpose and scope

This appendix documents the systematic search and logging procedure used to identify benchmarking cases aligned with CoLife's research themes. It records the theoretical framing, clusters, keyword logic, sources, inclusion rules, and a structured keyword log (Yin, 2018). The tracker was compiled by author in July 2025, and it underpins the benchmarking dataset used in chapter 3 and 4.

Theoretical framing

The search strategy is anchored in three interrelated pillars, *Asset Lifecycle Management (ALM)*, *Collaborative Ecosystem Practices*, and *Value Co-creation*. *ALM* provides the process spine that ensures continuity of asset information from design and process planning through production, operation, maintenance, and end-of-life; it effectively defines the digital thread linking as-designed structures (BOM), as-planned processes (BOP), and as built/-maintained states, and therefore specifies the types of evidence a credible case should contain (Stark, 2022). *Collaborative ecosystem practices* explain how multi-actor work becomes feasible in practice: orchestration and role clarity, participation rules and incentives, and the allocation of data rights, liability, and dispute resolution together create governance that lowers coordination costs and makes cross-firm data sharing predictable (Tiwana, 2014; Adner, 2017; Jacobides, Cennamo & Gawer, 2018). *Value co-creation* focuses on outcomes and fairness, directing attention to how stakeholders generate measurable improvements in quality, reliability, resilience, and circularity, and how those benefits are allocated in proportion to contributions in line with CoLife's win-win-win ambition. Taken together, these pillars determine what counts as a relevant case in this study and provide the criteria used during screening and coding in the benchmarking sheet (Porter & Heppelmann, 2014; Lozano, 2012; Parker, Alstyne & Choudary, 2016).

Operational clusters

The search space is organised into five operational clusters that translate the theoretical pillars into observable domains of practice and ensure coverage of the data, governance and outcome patterns relevant to CoLife. These clusters are analytical lenses used during screening and coding; They are not mutually exclusive, and a single case may legitimately sit across more than one where its scope warrants it.

The *supply chain collaboration* cluster gathers cases in which inter-firm coordination is explicitly enabled by shared data. It focuses on routines such as collaborative planning and replenishment, supplier quality collaboration and end-to-end visibility, where operational datasets orders, forecasts, inventory positions, process and quality records, logistics milestones are exchanged under agreed roles and review cadences (Simatupang & Sridharan, 2005). This cluster matters for CoLife because it reveals whether shared information actually reduces variability and waste, improves first-pass yield and delivery reliability, and embeds fair contribution reward mechanisms so partners remain engaged. It also shows how lifecycle feedback travels beyond a single plant to upstream and downstream actors, strengthening the practical link to ALM.

The *industrial data ecosystem and marketplace* cluster concentrates on platforms and federations that treat data as governed, reusable assets. Here the emphasis is on data product catalogues with owners and service levels, semantic models and interoperability assets, identity and access services, auiditability and usage control, and the participation model that brings OEMs, SMEs and service providers into the same environment (Simatupang & Sridharan, 2005). This cluster is central to CoLife's data as an asset lens and to the feasibility of cross-firm ALM because it exposes the concrete artefacts, policies, connectors, onboarding guides, licensing patterns, pricing or incentive schemas that turn willingness to share into predictable practice at scale.

The *zero-defect manufacturing (ZDM)* cluster targets cases where quality and process capability are improved through digital sensing, analytics and closed-loop control across the lifecycle. it looks for the practical links that connect as-planned process parameters and work instructions to as-built evidence, including inline metrology, statistical process control, predictive quality models and explicit feedback into engineering change and process adjustments (Simatupang & Sridharan, 2005; Colledani et al., 2014; Lee, Bagheri & Kao, 2015. This cluster is a direct bridge from the digital thread to measurable outcomes; It provides the concrete performance basis, scrap and rework reduction, FPY and OEE improvements, reliability gains that can underpin shared-savings or outcome-based agreements in CoLife's win-win-win framing.

The *Circular Economy* (P. Hartmann et al., 2016) cluster assembles initiatives where lifecycle information supports repair, refurbish, remanufacture and materials recovery. It attends to product and material passports, bills of substance, environmental and lifecycle assessment data, reverse-logistics process design and the contractual arrangements that permit safe secondary use its relevance to CoLife lies in making the third win tangible: environmental and societal benefits are evidenced by lower waste and emissions and by traceable flows of components and materials, while the same governance and interoperability building blocks keep those exchanges auditable and investable.

The *governance and trust* cluster isolates the rule-of-the-game artefacts that make multi-actor collaboration sustainable. It examines orchestration choices and decision rights, participation criteria and certification, allocation of IP and data-usage rights, liability and dispute resolution, and the security and compliance controls identity, access, policy enforcement, logging and alignment with regulations such as GDPR, the Data Act and NIS2 that allow firms to share data with conditions (Tiwana, 2014; Adner, 2017; Jacobides, Cennamo & Gawer, 2018). For CoLife, this cluster is the hinge between technical possibility and real-world adoption: it shows how naturality, sovereignty and verifiability are designed so that contribution can be recognised and rewarded without eroding proprietary advantage.

Together these clusters ensure that the corpus includes not only technologies and datasets but also the organisational and contractual arrangements that make them effective (Jacobides, Cennamo & Gawer, 2018; Firdausy et al., 2022). During screening a case is anchored to the cluster best represented by its public artefacts; During coding, the cluster assignment guides which evidence is extracted, for example, KPI and shared saving clauses in collaboration cases (GFMAM, 2024), or catalogue entires, policies and audit trails in data-ecosystem cases (European-Commission, 2020b; Firdausy et al., 2022). This disciplined use of clusters creates a clear trace from theory to evidence and keeps benchmarking scores comparable across diverse projects, while still allowing cross-case synthesis where patterns recur.

Search strategy, keywords, and sources

Keywords were developed iteratively from scoping work, cross-sector terminology, and constructs tied to ALM, collaborative ecosystem practices, and value co-creation. Keywords are: *Asset lifecycle management* was included because it anchors the entire search to the end-to-end flow of information from design and process planning through production, operations, maintenance and end-of-life (ISO 55000, 2024). It connects directly to CoLife's process spine and to the digital thread which I evaluate in benchmarking, ensuring cases actually show traceability between BOM, BOP and as-built/as-maintained states that enable quality, reliability and circularity improvements (Stark, 2022; GFMAM, 2024).

Factories of the Future was chosen as widely used EU research and innovation label that aggregates projects in advanced manufacturing, data, automation and cyber-physical systems. Using it ensures coverage of mature European exemplars that already deal with cross-firm integration, making it relevant to CoLife's aim to identify transferable governance, standards and platform patterns (Lee, Bagheri & Kao, 2015; European-Commission, 2020b).

Digital Twin Platform was selected to capture initiatives where models, telemetry and analytics are integrated as a service layer for design, production, service feedback. It is relevant to

CoLife because twins operationalise lifecycle learning and create the data products and APIs that later support shared-savings, outcome-based contracts or ecosystem services (Porter & Heppelmann, 2015; Tao et al., 2019; GFMAM, 2024; European-Commission, 2020b).

Collaborative Industrial Ecosystem was included to surface cases where multi-actor orchestration, roles and rules are explicit. This phrase aligns with CoLife's governance lens and helps identify artefacts such as admission criteria, certification, IP/data-usage policies and dispute mechanisms that make data sharing predictable (European-Commission, 2020b; Firdausy et al., 2022; Adner, 2017).

I4MS (ICT Innovation for Manufacturing SMEs) was used to pull cases that specifically demonstrate SME onboarding, experiments and scaling support through DIHs/EDIHs. This is central for CoLife, which needs models that do not exclude smaller contributors and that show workable incentives, cost structures and support services for SME participation (European-Commission, 2020b; Braun, 2017).

DOME 4.0 was included as a known industrial data-sharing and marketplace initiative to capture concrete evidence of data product catalogues, policies and usage control (European-Commission, 2020b; Firdausy et al., 2022; Vizcaino et al., 2024). It connects to CoLife's *data as a strategic asset* lens and lets you observe how platforms structure access tiers, quality/lineage metadata and monetisation options (Otto, Teuscher & Lohmann, 2019; European-Commission, 2020b).

Supply Chain Collaboration was used to surface practical coordination mechanisms, shared quality data, and logistics/production synchronisation (Simatupang & Sridharan, 2005). It links to CoLife's ecosystem pillar and provides a context to evaluate whether shared data actually reduce lead-time variability, scrap or stockouts while assigning benefits fairly.

Industrial Data Sharing was chosen to cast a wide net on cross-firm data-exchange practices beyond one platform brand, including governance templates, technical connectors and trust mechanisms (Otto, Teuscher & Lohmann, 2019; Firdausy et al., 2022). This is directly relevant to CoLife's requirement to specify rules, identities, audits and usage control that maintain sovereignty while enabling reuse.

Zero Defect Manufacturing was included to target projects that explicitly tie data to quality and process capability improvements across forms (Colledani et al., 2014). It connects to CoLife by supplying measurable outcomes that can underpin shared-savings models and demonstrate the firm and ecosystem wins of the win-win-win logic (Porter & Heppelmann, 2015; Tao et al., 2019).

Industrial Data Ecosystem AND Collaboration was crafted to filter out purely technical repositories and capture multi-party governance and participation models (Adner, 2017; Otto, Teuscher & Lohmann, 2019). it matters for CoLife because the value is not in a database alone but in rules, roles and sustained incentives that keep participants contributing and reusing trustworthy assets (Firdausy et al., 2022; European-Commission, 2020a).

Data Sharing Platform AND Industrial was chosen to pinpoint platforms with an industrial focus, excluding generic consumer data market places (European-Commission, 2020a; Otto, Teuscher & Lohmann, 2019). It supports CoLife's need to extract industrially relevant artefacts such as connector policies, identity and access mechanisms, licence templates and sector ontologies (Firdausy et al., 2022).

Manufacturing Data Space AND Ecosystem was added to find cases that apply data space principles usage controlled sharing, sovereignty, interoperability within a governed ecosystem (Otto, Teuscher & Lohmann, 2019; Firdausy et al., 2022). It connects to CoLife by showing how FAIR data products, semantic models and certification are combined to lower collaboration risk at scale (Wilkinson et al., 2016).

Data Sharing AND Supply Chain Collaboration was selected to locate efforts where operational coordination is explicitly data enabled and governed (Simatupang & Sridharan, 2005). This helps CoLife evaluate whether measurable supply chain outcomes are tied to clear data rights, responsibilities and review cadences that keep partners aligned (European-Commission, 2020a; Firdausy et al., 2022).

Industrial Symbiosis AND Data was included to surface circularity patterns where by products, energy or capacity are matched across firms via shared data. It relates to CoLife's societal win by linking lifecycle and environmental data to real reductions in waste and emissions, and it often reveals platform and contractual mechanisms for safe exchange (European-Commission, 2020a; Firdausy et al., 2022).

Zero Defect Manufacturing AND Digital was used to ensure ZDM hits include digital enablers such as inline sensing, predictive analytics and feedback to design (Colledani et al., 2014). It strengthens CoLife's focus on the digital thread by showing how as-planned process parameters and as-built conditions are linked to defect taxonomies and corrective loops (Tao et al., 2019; Stark, 2022).

Predictive Quality AND Manufacturing was selected to capture models where machine learning and statistical methods anticipate defects, not just report them. This is relevant for CoLife's monetisation lens because predictive quality can support outcome based fees or shared-savings contracts tied to verified reductions in defects and downtime (Colledani et al., 2014; Tao et al., 2019; Porter & Heppelmann, 2015; Baines et al., 2009).

Digital Twin AND Quality Management was included to connect twin usage directly to quality systems control plans and change management. It matters for CoLife because twins that feed QMS and engineering change processes are evidence of closed-loop learning, not isolated pilots (Tao et al., 2019; Stark, 2022).

AI Driven AND predictive Maintenance was chosen to capture data-to-outcome pathways in service context where uptime and risk are priced (Lee, Bagheri & Kao, 2015). It ties to CoLife's business-model lens by providing concrete examples of pay-per-use or outcome-based contracts underpinned by telemetry, diagnostics and validated performance metrics (Porter & Heppelmann, 2015).

Smart Manufacturing AND ZDM was used to ensure the intersection of automation, connectivity and quality improvement is represented. It is relevant to CoLife because *smart* infrastructure provides the data foundation, while ZDM anchors the measurable outcomes and the governance needed to recognise contribution and allocate benefits (Colledani et al., 2014; Simatupang & Sridharan, 2005; Tao et al., 2019).

Circular Economy AND industrial was included to surface projects that operationalise repair, refurbish, remanufacture and materials recovery with data (Geissdoerfer et al., 2017). This supports CoLife's third win by tying lifecycle data to environmental KPIs and by exposing contracts and data passports needed for take-back or secondary use markets (Kirchherr, Reike & Hekkert, 2017).

Industrial Symbiosis AND Circularity was selected to emphasise multi form loops where one process's output becomes another's input, controlled by data. It connects to CoLife by revealing governance liability and measurement solutions that keep exchange safe, auditable and beneficial to all participants (Kirchherr, Reike & Hekkert, 2017; European-Commission, 2020a).

Circular Manufacturing AND Data was added to locate factory-level examples where circular practices are embedded in production planning and execution through data. It relates to CoLife's ALM and data-asset lenses by requiring product and material passports, traceability and interoperable reporting (Stark, 2022).

Circular Data Platform AND Industry was used to find platform-centric circular solutions, including catalogues, certification and usage control for environmental data (Otto, Teuscher

& Lohmann, 2019). This informs CoLife about how to package and govern sustainability-relevant data products and how to align incentives for contributors and users (Firdausy et al., 2022; European Commission, 2023).

Supply Chain Resilience AND Data Sharing was included to focus on shock-response and variability reduction enabled by shared visibility. It connects to CoLife's ecosystem outcomes by highlighting risk indicators, recovery-time metrics and the governance that makes contingency data sharing acceptable (European-Commission, 2020a).

Resilient Manufacturing AND Digital Platform was selected to capture platform-mediated practices that enhance recovery, flexibility and resource reallocation. It supports CoLife's platform and governance choices by showing which access, audit and coordination features underpin resilience at network scale (Gawer & Cusumano, 2014).

Supply Chain Collaboration AND Industry 4.0 was added to ensure that collaboration cases leverage industry 4.0 technologies, IoT, edge analytics, semantics rather than manual coordination alone. It is relevant to CoLife because it couples modern data infrastructure with rules and incentives,yielding replicable patterns for the playbook (Simatupang & Sridharan, 2005; Hauser et al., 2017).

Searches were executed on trusted sources like CORDIS (EU project repository) and Business Finland (Veturi), capturing both EU-level and Finnish national initiatives. When no direct matches were found, the tracker recorded gaps and limitations for transparency.

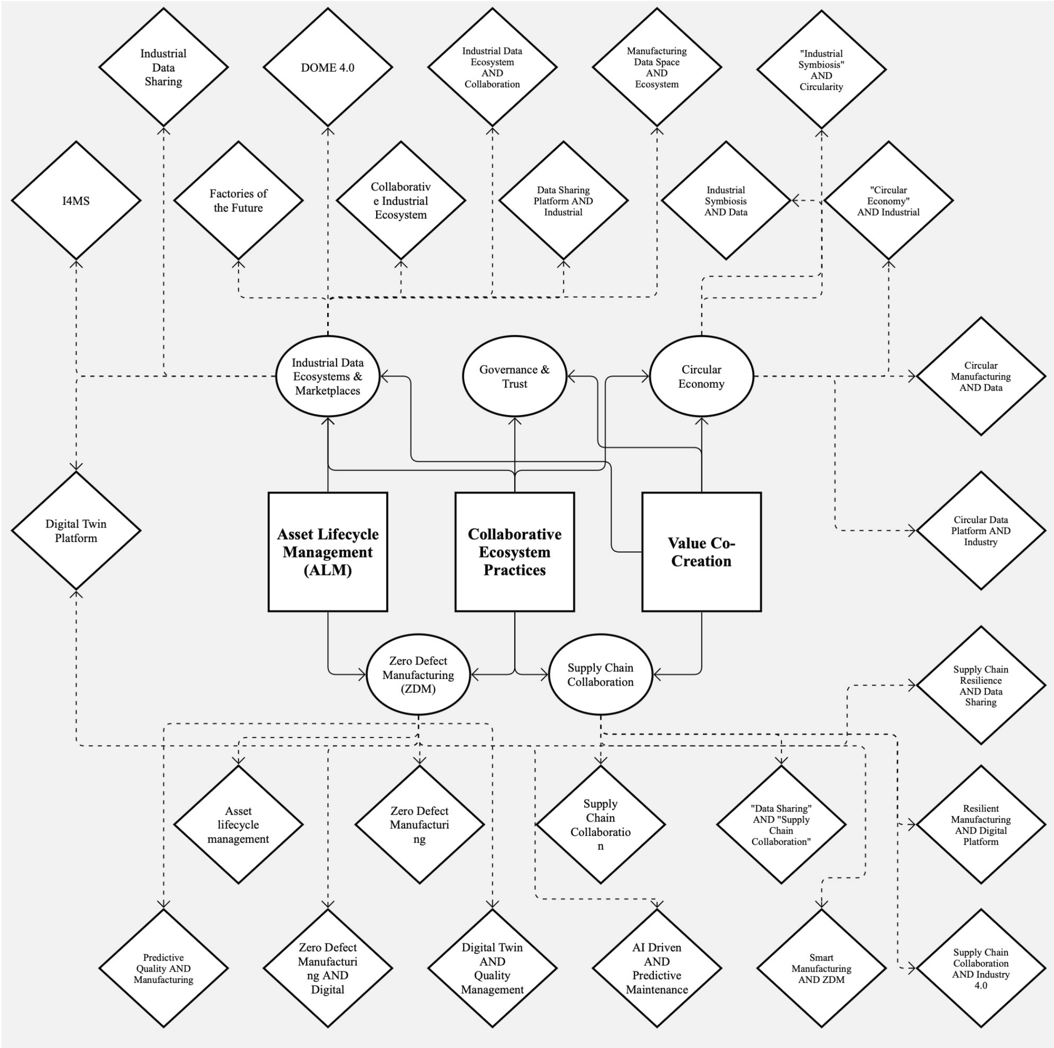

Figure 11: Theoretical pillars, search clusters, and keywords

Documentation and categorisation

All search results were documented under their cluster, then screened and annotated against predefined benchmarks: actor composition and roles; data strategy or platform design; value-creation mechanisms; governance and funding models; and fit with CoLife's vision of collaborative industrial ecosystems. The tracker directly feeds the Benchmarking Sheet, serving as the evidence base for selecting best-fit cases and guiding comparative analysis.

Inclusion criteria for the benchmarking corpus

A case was included in the benchmarking set when at least two of the following were evidenced in the public record:

1. Addresses asset lifecycle (design, production, use, maintenance, end of life)
2. Uses data as a strategic asset (sharing, interoperability, AI/analytics

3. Operates within a collaborative ecosystem (multi-stakeholder, multi-sector)
4. Provides documented outputs (platforms, standards, governance)
5. Has relevance to EU industrial digitalisation goals (e.g., industry 4.0, Circular Economy)

Keyword log (summary)

The table below summarises representative queries with their cluster mapping, source, result counts, and screening notes recorded in the tracker. It reflects the transparent search pathway and supports reproducibility.

Table 40: Keyword log

Keyword	Search Cluster	Site Used	Results Found	Notes
Asset lifecycle management	Zero Defect Manufacturing (ZDM)	CORDIS	1	It focuses on digital twins and simulation tools for asset lifecycle in smart factories; multi-partner.
Factories of the Future	Industrial Data Ecosystems and Marketplaces	CORDIS	3	relevant for asset management and sector-specific context
Digital Twin Platform	Data Ecosystems and Marketplaces and Zero-Defect Manufacturing (ZDM)	CORDIS	3	no new cross-sector industrial platform yet.
Collaborative Industrial Ecosystem	Industrial Data Ecosystems and Marketplaces	CORDIS	3	Same strong match
I4MS	Industrial Data Ecosystems and Marketplaces	CORDIS	8	strong supply-side platforms and partial governance/context
DOME 4.0	Industrial Data Ecosystems and Marketplaces	CORDIS	1	Strong match
Supply Chain Collaboration	Supply Chain Collaboration	CORDIS	5	Strong pilots for supply-side collaboration, industrial data sharing, circular governance
Industrial Data Sharing	Industrial Data Ecosystems and Marketplaces	CORDIS	1	Direct match for decentralized supply-side data sharing and governance for cross-sector ecosystems
Zero Defect Manufacturing	Zero Defect Manufacturing	CORDIS	15	Strong cluster of collaborative platforms for asset lifecycle, data sharing, supply-side governance

Keyword	Search Cluster	Site Used	Results Found	Notes
Industrial Data Ecosystem AND Collaboration	Industrial Data Ecosystems and Marketplaces	Business Finland	3	
Data Sharing Platform AND Industrial	Industrial Data Ecosystems and Marketplaces	Business Finland	2	Same as previous search phrase
Manufacturing Data Space AND Ecosystem	Industrial Data Ecosystems and Marketplaces	Business Finland	1	Strong edge computing and trusted data sharing, clear industrial relevance
"Data Sharing" AND "Supply Chain Collaboration"	Supply Chain Collaboration	Business Finland	0	No direct results found
Industrial Symbiosis AND Data	Circular Economy	Business Finland	0	No direct results found
Zero Defect Manufacturing AND Digital	Zero Defect Manufacturing	Business Finland	1	Same as previous search phrase
Predictive Quality AND Manufacturing	Zero Defect Manufacturing	Business Finland	1	Predictive testing, simulation, digital QA, large scale battery production
Digital Twin AND Quality Management	Zero Defect Manufacturing	Business Finland	0	No direct results found
AI Driven AND Predictive Maintenance	Zero Defect Manufacturing	Business Finland	0	No direct results found
Smart Manufacturing AND ZDM	Zero Defect Manufacturing	Business Finland	0	No direct results found
"Circular Economy" AND Industrial	Circular Economy	Business Finland	2	Strong heavy industry case, data and ecosystem for sustainability/Great industrial side stream reuse model
"Industrial Symbiosis" AND Circularity	Circular Economy	Business Finland	0	No direct results found
Circular Manufacturing AND Data	Circular Economy	Business Finland	1	Same as previous search phrase
Circular Data Platform AND Industry	Circular Economy	Business Finland	3	
Supply Chain Resilience AND Data Sharing	Supply Chain Collaboration	Business Finland	3	
Resilient Manufacturing AND Digital Platform	Supply Chain Collaboration	Business Finland	3	
Supply Chain Collaboration AND Industry 4.0	Supply Chain Collaboration	Business Finland	1	

Appendix 2 Benchmarking sheet

Purpose and scope

This appendix reproduces the benchmarking dataset that underpins the cross-case analysis reported in chapter 4. Its function is to offer a transparent, citable record of every case screened and the specific information extracted for comparison. The sheet was compiled by the author during July-August 2025 and will be maintained under version control throughout the thesis work. It complements Appendix 1 (the CoLife search tracker) by showing what was ultimately captured for each included case.

How to read the table

Each row response one case (EU/Horizon project, national/Veturi ecosystem, Vendor/Platform ecosystem, or company case). Columns hold the variables used in the benchmarking framework (Chapter 3.6): context, actors/collaboration, lifecycle and data, governance, value logic, and control fields (Relevance, status, action note). Short free-text fields (e.g., Notes, insight) provide one-line summaries to aid synthesis and traceability across the corpus.

Fields and coding (column-by-column)

For each case, the sheet records the official case name used for cross-referencing deliverables and the canonical *Website/Source* (for example, the CORDIS entry, programme page, or an official site) used for citation and updates. *Country/Region* indicates the geographic focus (EU, national, or multi-regional) to contextualise policy or programme differences. *Project Type* captures the funding or programme descriptor (e.g., EU H2020. Horizon Europe, EU CSA, Co-innovation/Veturi, Leading Company Ecosystem, Battery Cluster, SME Industrial Solution). *Data use* describes dominant uses of data and supports lifecycle and data space analysis. *Type of collaboration* specifies the form and scope of collaboration (research consortium, ecosystem/platform, DIH/EDIH, marketplace, or supply-chain network). The sheet also records *Governance/Funding*, noting governance mechanisms and the programme or funding context. *Value co-creation elements* summarise how benefits arise and are shared across stakeholders, including efficiency gains, quality or waste reduction, new services, resilience improvements, and sustainability outcomes.*Relevance* records the triage result against the rubric in Section3.5 (High, medium, and Low). these tags are analyst aids; during synthesis in Chapter 4, they are mapped back to the five analytic clusters.

Relevance and status legend

- High: Direct fit with lifecycle architecture/governance and explicit data-sharing across multiple actors, with clear collaboration structures and sufficient public outputs for benchmarking.
- Medium: Partial lifecycle coverage or collaboration; data/governance present but not central; still yields transferable insights.
- Low: Narrow technical scope with limited ecosystem/governance content and low transferability.

Status categories guide workflow: Priority (include in deep dive); Partial lessons (use for specific patterns only); Context (retain as background, do not generalise).

Coverage summary

The current sheet contains 40 cases with the following relevance distribution: High=25, Medium=11, Low=4. The *theme* field lists granular topics; the mapping back to the five analytic clusters occurs during synthesis (Chapter 4).

Ethics and citations

Only public documents are used. Each case row can be traced back to its public source via the Website/Source field; quotations in the thesis are short and attributed. Where documentation is thin, the case is labelled *Context* and excluded from claims about governance or value mechanisms.

Versioning and updates

This appendix reflects the sheet exported in August 2025. Subsequent edits (e.g., normalising Relevance and Theme, or adding missing deliverables) will be logged in the research notebook and described briefly in the Chapter 4 methods note.

Table 41: Benchmarking sheet

Case Name	Source	Country / Region	Project Type	Data Use	Type of Collaboration	Funding	Value Co-Creation Elements	Relevance
BEinCPPS	CORDIS-id680633	EU	EU H2020 I4MS	Real-time data from CPS for production performance and digital services	Regional pilot lines, DIHs, SME open calls	H2020-EU.2.1.1. (ICT), I4MS	Open calls for SMEs, regional cluster governance, platform co-development	High
MIDIH	CORDIS-id767498	EU	EU H2020 I4MS	Supports scale-up of digital manufacturing data services	EU-wide cluster for SMEs, DIHs, and competence centers	H2020-EU.2.1.1. (ICT), I4MS	Multi-actor governance, SME capacity building, ecosystem expansion	High
C2NET	CORDIS-id636909	EU	EU H2020	Supply network data sharing for production planning	SMEs, supply chain partners, platform providers	H2020-EU.2.1.1. (ICT)	Collaborative planning tools, supply-side data governance	High
Fortissimo 2	CORDIS-id680481	EU	EU H2020	HPC-based data-driven simulations for design & production	Tech providers, research partners, SMEs	H2020-EU.2.1.1. (ICT)	Shared HPC services, collaborative cloud simulations	High
XS2I4MS	CORDIS-id678860	EU	EU H2020 I4MS	Dissemination & scaling of I4MS pilots and services	DIHs, competence centers, SME networks	H2020-EU.2.1.1. (ICT), I4MS	Community building, policy linkages, cross-border scale-up	High
DOME 4.0	CORDIS-id953163	EU, UK-led	EU H2020 Project	B2B data sharing, semantic interoperability, knowledge extraction	Open data marketplace, multi-sector data providers & users, research & industry co-creation	H2020-EU.2.1.3., H2020-EU.2.1.5.	Open innovation, multi-actor data use, new product & process development	High
iDev40	CORDIS-id783163	EU, Austria-led	EU H2020	Integrated data platforms, IoT, connected product & process networks	Industrial supply network, tech providers, research partners	ECSEL Joint Undertaking (H2020)	Digital co-design, shared supply chain intelligence, collaborative platform	High
ReTraCE	CORDIS-id814247	EU	EU H2020 MSCA-ITN	Lifecycle data for circular supply chains and sustainability	Industry, academia, policy clusters	Marie Skłodowska-Curie Actions, H2020	Collaborative circular business models, new governance frameworks	High

Case Name	Source	Country / Region	Project Type	Data Use	Type of Collaboration	Funding	Value Co-Creation Elements	Relevance
OPENZDM	CORDIS-id101058673	EU, Greece-led	Horizon Europe	Open platform for CPS, digital twins, asset admin shell	Multi-actor, open supply chain	Horizon Europe	Zero-defect, waste reduction, shared platform	High
i4Q	CORDIS-id958205	EU	Horizon 2020	Industrial IoT, data services, zero-defect QC	Multi-actor ecosystem	H2020	Shared QC protocols, ecosystem trust	High
ZDMP	CORDIS-id825631	EU	Horizon 2020	Plug-in apps, end-to-end data flows	Open ecosystem	H2020	App marketplaces, SME engagement	High
QU4LITY	CORDIS-id825030	EU	Horizon 2020	Autonomous quality management, big data analytics	Multi-sector, open platform	H2020	Open testbeds, SME co-creation	High
MONSOON	CORDIS-id723650	EU	H2020	Site-wide data monitoring, predictive modeling	Data labs, cross-sector	H2020	Real-time data sharing, continuous process improvement	High
DataMust	Business Finland	Finland	Co-Innovation Veturi	Local edge computing, secure data marketplace, trusted sharing	Multiple companies + research (Nokia Veturi, VTT, Sitowise)	EU RRF funding, Co-Innovation, Nokia Veturi program	Trust-building for data sharing, edge data use, incentive models for joining the ecosystem	High
KONE Veturi	Business Finland	Finland	Veturi Ecosystem	Digital twins, real-time data flows, data-driven urban mobility	Large ecosystem: 200+ partners, co-innovation, co-development	Business Finland Veturi funding, partner co-financing	Mission-driven ecosystem, shared road map, clear roles for SMEs, universities	High
Nokia Competitive Edge	Business Finland	Finland	Leading Company Project (Veturi)	Industrial edge computing, decentralized data processing, data markets	Ecosystem: Nokia + 10–15 Co-Innovation projects	EU RRF + Business Finland Veturi; multiple research & SME partners	Edge computing for trusted data spaces; energy efficiency, real industrial IoT pilots	High

Case Name	Source	Country / Region	Project Type	Data Use	Type of Collaboration	Funding	Value Co-Creation Elements	Relevance
Valuechain .com Ecosystem	CORDIS-id723650	EU, UK-led	EU SME Instrument Phase 2	Real-time analytics, supply chain risk monitoring, dynamic network collaboration	Vertical and horizontal SME networks, supply chain partners	SME Instrument Phase 2	Real-time visibility, dynamic reconfiguration, collaborative decision support	High
MAYA	CORDIS-id678556	EU	EU H2020 Project	Simulation and real-time synchronization of asset life-cycle data in factories (design, production, optimization, reconfiguration)	Multi-partner industrial ecosystem: Volkswagen, FinnPower, Siemens, Politecnico di Milano, DFKI, and other research & tech providers	H2020-EU.2.1.1. (ICT), FoF (Factories of the Future)	Collaborative development of shared digital twin tools, knowledge transfer between research and industry, real-world pilots to benchmark performance improvements	High
FP3 - IAM4RAIL	CORDIS-id101101 966	EU	Horizon Europe Flagship Project (Europe's Rail Joint Undertaking)	Cross-border integration of asset condition data, real-time monitoring, AI-enabled risk prediction	Rail operators, national infrastructure managers, EU research organisations, technology suppliers	Horizon Europe – Europe's Rail Joint Undertaking	Shared digital twin models, multi-actor governance, cross-country asset management strategies	High
CBIM	CORDIS-id860555	EU	EU H2020 Project	Cloud-based building information models integrating design, operation, and maintenance phases	Tech providers, construction firms, software developers	H2020-EU.2.1.1. (ICT)	Shared BIM services, cost efficiencies, digital twin implementation across building lifecycle	High
RAGTIME	CORDIS-id690660	EU	EU H2020 Project	Risk-based frameworks for monitoring asset conditions across life-cycle stages	Transport operators, infrastructure managers, research organisations	H2020-EU.3.4. (Mobility for Growth)	Shared risk governance models, integrity management protocols	High

Case Name	Source	Country / Region	Project Type	Data Use	Type of Collaboration	Funding	Value Co-Creation Elements	Relevance
AUTOWARE	CORDIS-id723909	EU	EU H2020 I4MS	Industrial IoT & CPS for data-driven automation across asset lifecycle	Open platform with manufacturers, SMEs, and tech providers	H2020-EU.2.1.1. (ICT), I4MS	Multi-sided ecosystem, SME pilot experiments, flexible industrial data sharing	High
NEXT-NET	CORDIS-id768884	EU	EU H2020 Coordination & Support Action	Stakeholder data integration for future supply chain scenarios	Industry clusters, research orgs, policy advisors	H2020-EU.2.1.1. (ICT)	Cross-sector foresight, roadmap co-creation, multi-stakeholder governance	High
Onto-DESIDE	CORDIS-id101058682	EU, Sweden-led (Linköping University)	EU Horizon Europe	Decentralized B2B data sharing, semantic interoperability, privacy protection	Multi-sector industrial partners, research orgs, SME clusters	Horizon Europe (RIA), Digital Industry and Space	Shared standards, secure data collaboration, cross-industry applicability	High
ForZDM	CORDIS-id723698	EU	H2020	ICT tool integration, multi-stage ZDM	Supply chain, research centres	H2020	Defect root cause analysis, knowledge sharing	High
Sandvik Circular Mining	Business Finland	Finland & Global	Leading Company Ecosystem	Automated mining, recycling data, carbon tracking	Large ecosystem: suppliers, R&D, service partners	Business Finland Bio & Circular, EU support	Shows heavy industry circularity with data-driven footprint tracking	Medium
DISCO	CORDIS-id685232	EU, UK-led	EU H2020	Real-time supply chain data sharing and predictive analytics for collaborative production	Multi-SME supply chain partners, platform providers, research orgs	H2020-EU.2.1.1. (ICT)	Data-driven optimisation, open platform for SME co-innovation, predictive risk management	Medium
TOSCA	CORDIS-id 101191394	EU, Austria-led	Horizon Europe	Embedded sensors, structural health monitoring for zero-defect asset lifecycle	Manufacturing firms, research orgs	Horizon Europe	Zero-defect process co-creation, recycling integration	Medium
OPeraTIC	CORDIS-id101058409	EU, Spain-led	Horizon Europe	AI, robotics, digital twin for agile manufacturing	Large-scale, multi-sector	Horizon Europe	Agile production, multi-actor trust	Medium

Case Name	Source	Country / Region	Project Type	Data Use	Type of Collaboration	Funding	Value Co-Creation Elements	Relevance
DAT4.ZERO	CORDIS-id958363	EU	Horizon 2020	Data reliability, smart sensors for defect prevention	Supply chains, factories, RTOs	H2020	Data quality, ecosystem reliability	Medium
OPTIMAI	CORDIS-id958264	EU	Horizon 2020	AI-enabled sensors, virtualisation for zero-defect	SME networks, RTOs	H2020	Co-created AI toolkits, risk minimisation	Medium
Z-Fact0r	CORDIS-id723906	EU	H2020	Inline data collection, multi-step defect prediction	Multi-actor supply chain	H2020	Quality prediction, shared dashboards	Medium
GO0D MAN	CORDIS-id723764	EU	H2020	Multi-agent system for ZDM	CPS networks, SME clusters	H2020	Real-time process control, cost savings	Medium
ZAero	CORDIS-id723698	EU	H2020	Inline defect control, digital lifecycle	Aerospace supply chain	H2020	Quality-driven data flows	Medium
STREAM-0D	CORDIS-id723082	EU	H2020	Real-time defect prediction, simulation-driven quality	Multi-actor production lines	H2020	Integrated decision suppor	Medium
KEKO Smart Real Estate	Business Finland	Finland	Co-Innovation / Ecosystem	Shared building data, digital twin for energy & lifecycle	Multi-company (YIT, KONE, Nokia, VTT)	Business Finland Co-Innovation funding	Open standard for shared data, lifecycle management, energy efficiency	Medium
ReconCell	CORDIS-id680712	EU	EU H2020	Adaptive robot cell data integration for SME factories	Research labs, SME pilot lines, tech providers	H2020-EU.2.1.1. (ICT)	Co-created flexible robotics solutions, SME adoption support	Low
HORSE	CORDIS-id680734	EU	EU H2020 I4MS	Data exchange between CPS, robots, humans for flexible production	Industrial partners, DIHs, SMEs, research orgs	H2020-EU.2.1.1. (ICT), I4MS	Shared robotics infrastructure, local competence centers, SME pilots	Low

Case Name	Source	Country / Region	Project Type	Data Use	Type of Collaboration	Funding	Value Co-Creation Elements	Relevance
Factory2Fit	CORDIS-id723277	EU	H2020	Worker input for production system adaptation	SMEs, research labs	H2020	Co-design, participatory governance	Low
IONCOR Battery Cluster	Business Finland	Finland	Battery Cluster	Simulation, testing, quality data, predictive defect control	Cluster: contract manufacturers, tech, automotive	Business Finland battery strategy, multiple partners	Data-driven production ramp-up, near-zero defects, strong digital QA culture	Low