Asset Lifecycle Information Management - Methodology, Principles and Information Models

Best Practice Document

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Revision History

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3	2025-11-17	Issue reviewed by the Association Team
4	2026-02-10	Final version for publication

Contents

1 Introduction

Efficient access to consistent, structured data is essential for the digitalisation of process industries. However, such data is often scattered across a variety of sources and applications. Each software vendor and database architect uses their own data models and semantics. Consequently, collecting and consolidating information to optimise design, construction, and operations can be labour-intensive and prone to error.

Transferring information between software tools or stakeholders throughout the asset lifecycle remains complex, particularly when data is embedded in documents rather than made available as machine-readable datasets. Furthermore, it is challenging to formally document requirements, trace them throughout the engineering process, and verify their fulfilment in the completed facility.

Asset Lifecycle Information Management (Integrated Engineering) is inherently complex for both capital projects and operations. This encompasses the definition, planning, construction, commissioning, operation, maintenance and decommissioning of a facility. The overarching objective is to build and operate a process plant that can reliably produce the required products in the necessary quantities and qualities to meet business objectives safely and efficiently.

Since most process plants are operated for over 30 years, proper maintenance, regular updates, and operational optimisation are essential. Studies in the chemical industry indicate that approximately 70% of engineering activities occur during operation, with only 30% being conducted during the initial investment project[1].

In order to efficiently manage the information of process plants over the asset lifecycle a framework, concepts and work processes (business processes) are needed to specify, produce, exchange, check and secure information, as well as process roles. This is particularly important for development, engineering and construction, where we need to harmonised project management procedure and align them with the information requirements. In the BIM world this is provided by the ISO 19650. Unfortunately, there is no comprehensive international standard for project management including information management in the process industry but there is an “industry best practice” has been implemented by major oil and gas companies, chemical companies, engineering firms and consultants.

Significant alignment has already been achieved between the various associations dealing with information models in the process industry. At the last PIDMIC (Process Industry Data Model Integration Conference) at the Achema 2024 it was decided to develop a common " best practice" for asset lifecycle information management to provide definitions, a project management framework, the basic principles of information management and an overview of the available information models and their implementation.
DEXPI has developed a draft that has been aligned with the different organisations and it is being issued as a common "best practice" by the involved associations on their various communication channels.

1.1 Purpose and Approach of this Document

- This document is considered as an "industry best practice". It sets out the best practices for managing structured information management throughout the asset lifecycle in the process industry. It presents a unified methodology for planning, modelling and

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[1] Source: Evonik Industries

managing engineering data throughout all phases, including investment projects and plant upgrades, and ongoing operations and maintenance activities.

The document fulfils the following tasks:

- It shall serve as a "best practice document" on asset information management.
- It shall provide definitions
- and provide a framework for project management
- and the basic principles of information management.
- An overview of the available information models and how they are used.

The objective is to enable a shift from traditional document-based engineering (common at digital maturity levels[2] 0 and 1) to a fully integrated, information model-based approach supported by a digital twin (in line with digital levels 3 and 4). The intention is not merely to digitise diagrams, but to establish robust, interoperable information models that evolve with the project and remain consistent across disciplines and lifecycle phases.

Although conventional formats such as drawings, spreadsheets and documents will continue to play a role, they will now be understood as views or deliverables derived from a centralised information model.

This “best practice document” will provide guidance on the structuring and applying of chemical process and plant models. This will include the basic principles of tagging and classification, attribute status tracking, and developing information models throughout the project lifecycle. This will ensure alignment with engineering practices. It shall not assign responsibility for individual data elements; this shall be defined in the Project Execution Plan (PEP) or other project-specific frameworks, not this standard. The standard will provide the modelling conventions, structural logic and standardised procedures necessary to ensure consistency across systems, stakeholders and disciplines.

This document defines requirements based on the **need** for consistent, seamless data management throughout the asset life cycle and the discipline. Based on these needs, requirements are defined and rationales provided where suitable, as are explanations of verification activities. The demand is defined at different levels. This approach follows the ISO/IEC/IEEE Standards 15288 and 29149.

Level of demand	**Expression**	**Explanation**
Requirement	'shall'	These requirements are mandatory to fulfil the needs
Recommendation	'should'	These recommendations are useful to fulfil the needs
Options	'may'	These options can be chosen to support the fulfilment of the need

[2] According to digital maturity model(acatech)

Table 1: Definitions

1.2 Scope

The recommendations contained in this document apply to process development, capital projects and ongoing operations in the process industries, particularly chemical, pharmaceutical and petrochemical plants. The recommendations are relevant to both batch and continuous processes, as well as greenfield developments and brownfield modifications.

The scope encompasses the entire asset lifecycle: from the initial study stage, including study (FEL1) and conceptual design (FEL2), through basic engineering (FEL3) and detailed engineering, to construction, commissioning, and long-term operation, maintenance and change management (MOC). The document also supports related processes such as planning and visualisation, regulatory compliance and qualification, structured documentation and handover, and continuous performance monitoring.

1.3 Definitions

The terminology and structure follow internationally recognised standards, including:

- ISO 55000 for asset management.
- ISO 19650 for information management using Building Information Modelling (BIM).
- ISO 10209 for technical vocabulary.
- IEC-ISO 81346 for structuring principles.
- ISO 15926 for lifecycle data integration and semantic modelling.
- ISO 15288 for systems engineering.

A central concept in this context is the digital twin: a structured, model-based representation of a process plant's behaviour, topology and operating state (see chapter 4.1). This model supports the integration of data from multiple tools and disciplines, remaining consistent throughout the lifecycle by using common classes, structures, attributes and tagging.

Managing information digitally requires more effort than handling analogue documents. As the value of information management arises from integrating information across the asset life cycle and between disciplines. Digital information management should prioritise these areas. Information outside this scope can continue to be managed using traditional documents.

Traditional engineering practices in the process industry are typically structured around sequential workflows. Information is developed in isolated stages, often within discipline-specific tools and formats. Project teams exchange process flow diagrams (PFDs), piping and instrumentation diagrams (P&IDs), tag or physical equipment lists and datasheets through manual handover, which introduces inefficiencies and the potential for inconsistency.

This fragmented approach often results in redundant data entry, discrepancies between documents, increased effort for coordination and oversight effort, and frequent rework during construction. In operations, the documentation landscape becomes fragmented and difficult to maintain, which impedes optimisation and change management.

Integrated information management, by contrast, connects tools, disciplines and stakeholders through a shared, object-oriented model. This not only improves data quality and reliability across phases, but also facilitates automation, reuse, and alignment of information from the earliest design studies through to operational excellence. Benefits include:

Classical Engineering	Integrated Engineering
Sequential workflows	Parallel workflows
Redundant document copies	Single source of truth
Manual consistency checks	Automated data validation
Multiple data inputs	Centralised data access
High construction rework	Low rework rates

Table 1. Comparison of Classical Engineering and Integrated Engineering

Practical applications of 'digital engineering' have proven savings in engineering and technical support of operations of 10 to 20%[3].

1.4 Document Status and Disclaimer

This document sets out best practice and is not a normative standard. It has been prepared by the DEXPI[4] consortium and its affiliated partners. While the methodology aligns with international standards (ISO, IEC), DEXPI cannot guarantee the completeness or accuracy of the models. Use of this document is entirely at the user's own risk. Organisations must determine whether and how the methodologies described align with their own project requirements, standards and regulatory obligations to ensure compliance and applicability.

1.5 Reader's Guide: How to Use This Document

This best practice document is structured to reflect the flow of information and engineering logic across the asset lifecycle. To help readers navigate the content, the following orientation is provided:

Chapter 1 introduces the topic, describes the motivation, objectives, and scope of integrated information management in the process industry.

Chapter 2 outlines the fundamental concepts of asset lifecycle and information management, including the role of the digital twin.

Chapter 3 presents the typical project phases and associated information requirements that form the temporal backbone for data maturity.

Chapter 4 provides a detailed overview of information models and industry standards. It introduces key modelling approaches (e.g. DEXPI, CFIHOS, FL3DMS), as well as structuring principles like tagging and breakdown structures.

Chapter 5 focuses on the application of information management across the lifecycle, from engineering and construction to operations and change management. It also addresses cross-disciplinary data collaboration.

[3] Results based on 3 industrial projects with investment between 10 and 70 M€

[4] DEXPI e.V.: Data Exchange in Process Industry, registered association

Chapters 6 explains how discipline-specific information is integrated into the process and plant information model.

Chapters 7 to 10 provide additional supporting material including examples, abbreviations, glossary entries, and references for further reading.

2 Fundamentals of Asset Lifecycle Management in Process Industry

2.1 Basic Process Definitions and Standard Framework

2.1.1 Basic Business Processes

Digitalisation and information management reveal the complexity and structural diversity of the process industry. To manage this effectively, it is helpful to distinguish between the industry's two main business processes [1, 2,], see Fig. 1. A more detailed overview is given in the NIST.IR.8107.

- The supply chain, which is responsible for delivering products to customers.
- The asset lifecycle, which is responsible for developing, building and operating plants.

The process industry is still highly asset-intensive. Many new products require new production facilities to be designed and constructed in order to enable efficient, large-scale, continuous manufacturing. Therefore, proper management of the asset lifecycle is critical to operational and business success. This comprises considering both capital expenditure (CAPEX) as well as operational costs (OPEX). By contrast, production systems in discrete manufacturing tend to be more flexible and easier to adapt to new product lines.

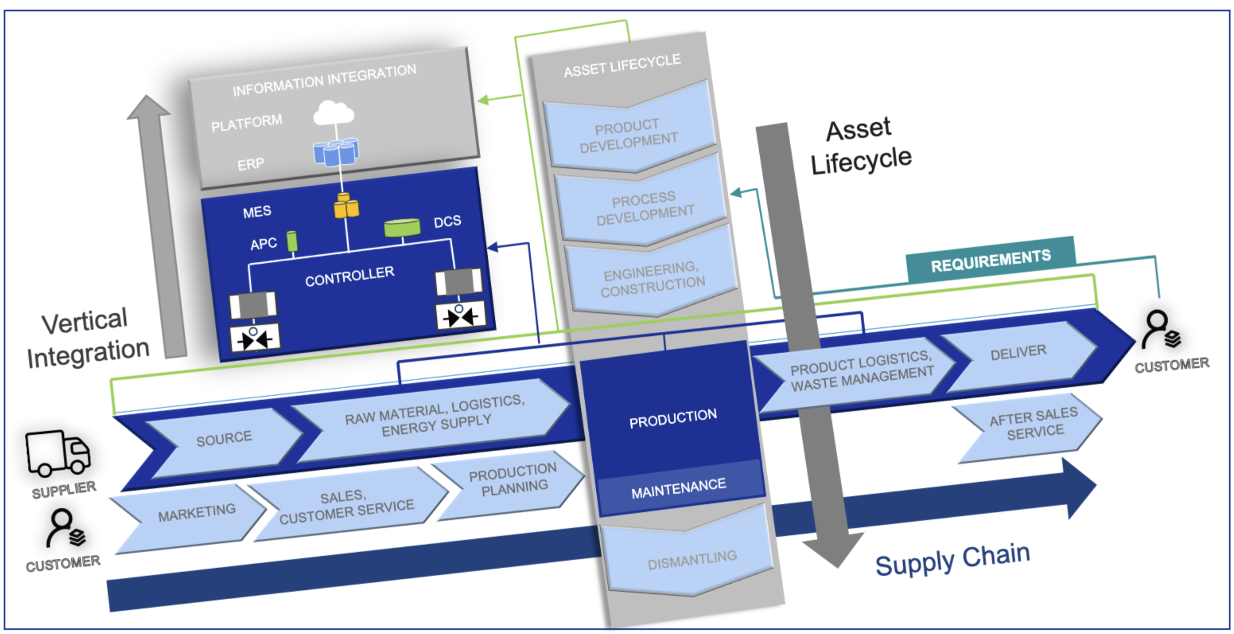


Figure 1. Relevant business processes in the process industry. Source: DEXPI.

Managing data in the supply chain, particularly in production, requires vertical information integration to ensure information can flow bidirectionally between the shop floor and enterprise levels define in IEC 62264 as 'automation pyramide'.

2.1.2 Asset Management, ISO 55000

The general principles of asset management are defined in ISO 55000, which is based on PAS 55:2008. This standard introduces asset management as a discipline and sets out principles for creating value through the effective management of enterprise assets.

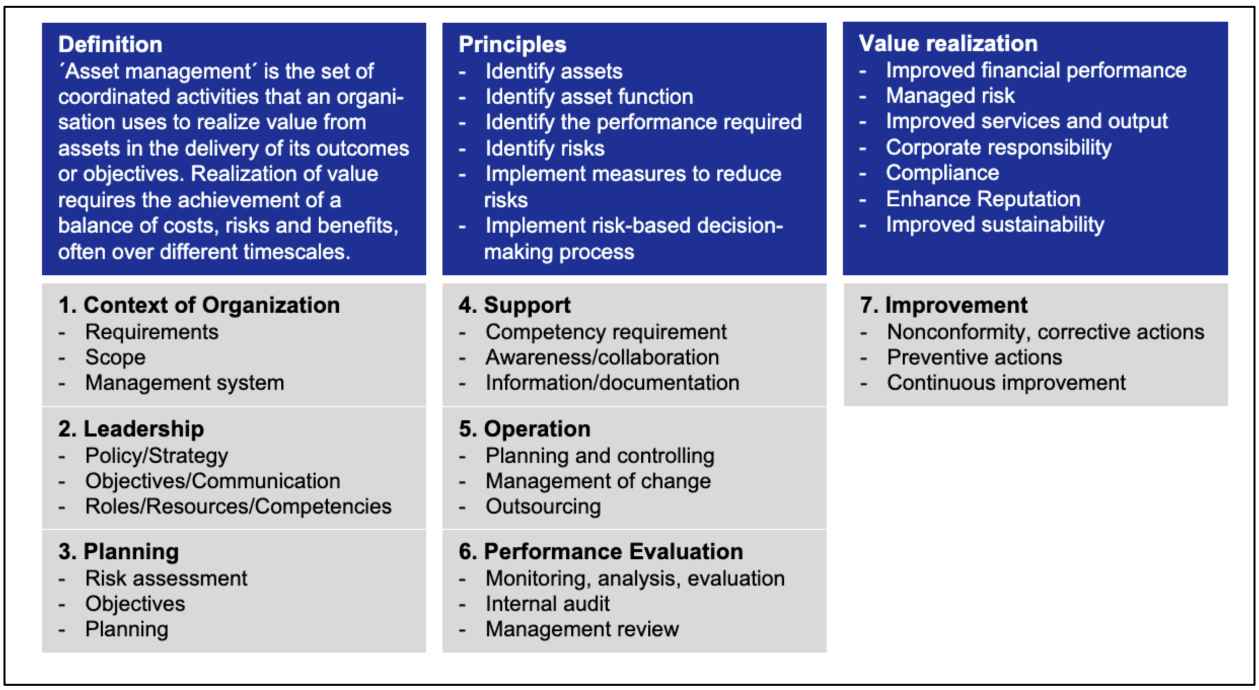


Figure 2. Asset Management defined in ISO 55000. Source: ISO 55000.

Information models realise basic principles:

- Identify assets (tagging)
- Identify asset function
- Identify performance required

and by doing this, support risk management and value realisation (see Fig. 2).

Effective control and governance of assets by organisations is essential for realising value through managing risk and opportunity, in order to achieve the desired balance of cost, risk and performance. The regulatory and legislative environment in which organisations operate is becoming increasingly challenging.

Integrating the fundamentals of asset management and the supporting asset management system introduced in this International Standard into an organisation's broader governance and risk framework of an organisation can contribute tangible benefits and leverage opportunities.

Asset management translates an organisation's objectives into asset-related decisions, plans and activities, using a risk-based approach.

In capital projects, information is generated during the design, development and construction of the plant. The types of models used, and the level of information they provide, depend heavily on the current phase of the asset lifecycle and the relevant data requirements. This phased approach mirrors the logic of Building Information Modelling (BIM).

2.1.3 Organisation and digitisation of information about buildings and civil engineering works – ISO 19650

Since process plants also require civil, structural and architectural engineering as well as facility management, it is useful and logical to align with the ISO 19650 framework governing BIM practices. ISO 19650 defines organisation and digitisation of information about buildings and civil engineering works, including building information modelling (BIM), and Information management using BIM.

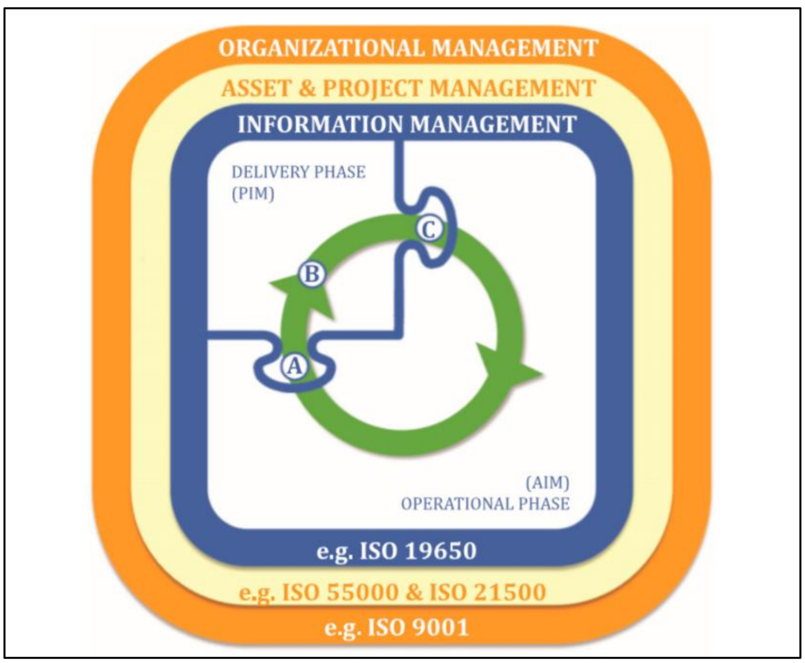


Figure 3. Information framework according to ISO 19650. Source: ISO 19650.

ISO 19650 distinguishes between three domains:

- Organisation (strategic requirements and asset policies).
- Project management (the delivery of capital works).
- Assets (operational use and maintenance).

Accordingly, it defines multiple types of information requirements.

- OIR: Organisational Information Requirements
- PIR: Project Information Requirements
- AIR: Asset Information Requirements
- EIR: Exchange Information Requirements.

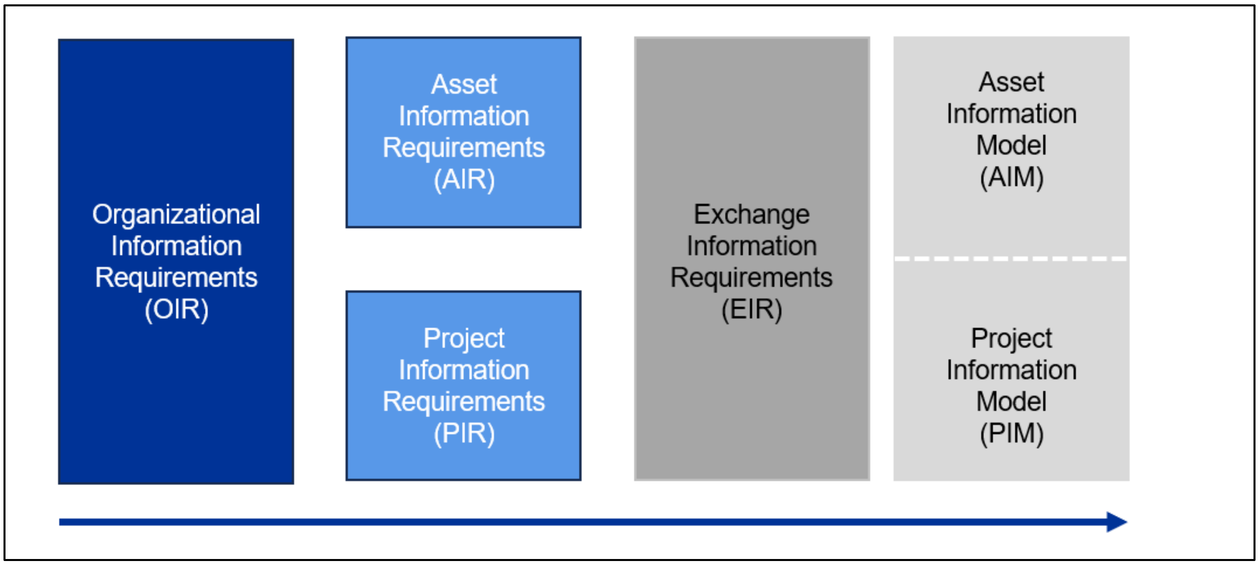


Figure 4. Key principles of the ISO 19650 series regarding information. Source: ISO 19650.

This document focuses particularly on the interaction between project management and asset modelling, as their interdependence directly affects data continuity and digital integration. Effective implementation of integrated data management requires an understanding of the structure of the capital project process.

2.1.4 Systems and Software Engineering – System Life Cycle Processes – ISO 15288

Systems engineering is a holistic, interdisciplinary field of engineering and engineering management that focuses on how to design, integrate, and manage complex systems throughout their life cycles from initial concept to decommissioning. It ensures that all aspects of a system, including technical and non-technical elements, are integrated and function together effectively to meet specific needs and requirements. At its core, systems engineering utilises systems thinking principles to organise this body of knowledge. The individual outcome of these efforts is an **engineered system which** can be defined as a combination of components that work in synergy to collectively perform a useful function.

The basic definitions of the systems life cycle processes are given in the systems engineering approach see Figure 5. In principle ISO 15288 follows the approach shown in Figure 5;

however, this standard deals with technical information management and focusses on technical process and their interaction with project management.

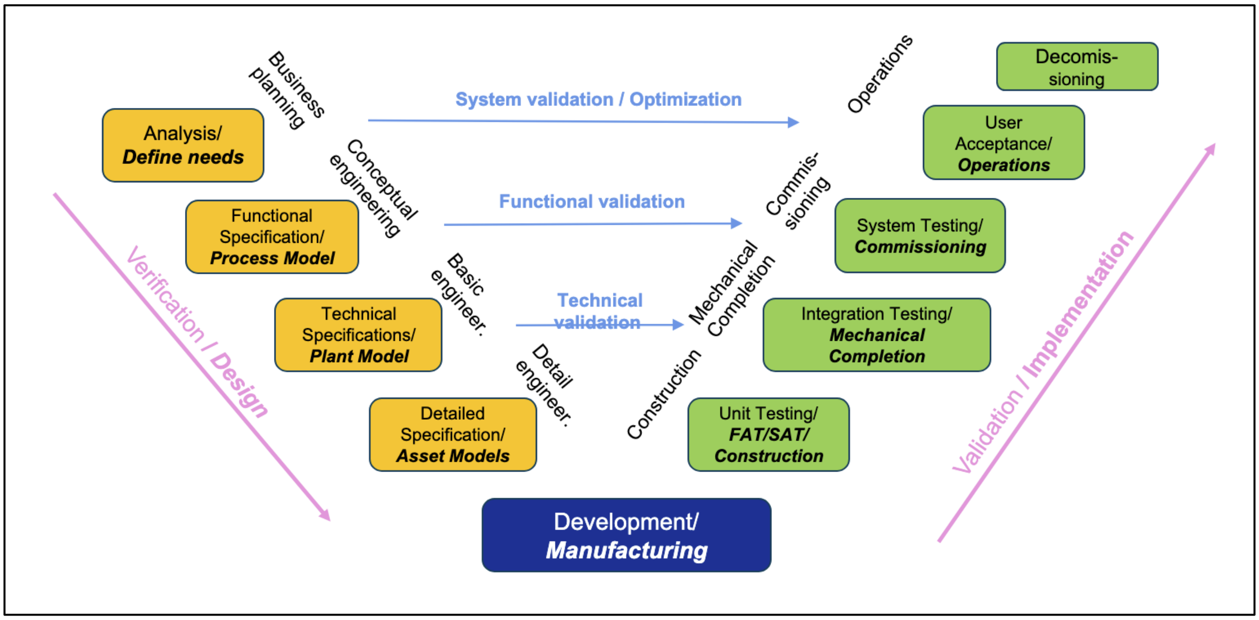


Figure 5. System Engineering Processes of asset lifecycle. Source: DEXPI

2.1.5 The CEN ORCHID ROADMAP

Developed in 2009/2010 the Orchid Roadmap dealt with standardising information across the engineering supply chain to solve the 'interoperability problem' [30].
The Orchid Roadmap is based on a USPI roadmap developed in 2002. The objectives of the ORCHID Roadmap Direction and Framework for lifecycle information management are:

1. To define the major future steps that the process industry is expected to take in the development and implementation of lifecycle information standards to achieve the vision of the common process industries.

2. To define who is expected to take action to realise these steps.

ORCHID provides a maturity model that can help companies visualise their progress in information management and identify potential bottlenecks. Digitisation programmes improve the quality of information by digitalising it using international standards.

The purpose of the CEN WS ORCHID Roadmap is to provide a consensus on the main steps forward in information management within the supply chain of process industries. It provides three parts:

1. A model to assess information management maturity of companies and industry.
2. Guidance on implementation of standards by learning from use cases.
3. An overview of the relevant international standards in an agreed classification.

2.2 The 'Classical' Engineering Approach

The classical engineering process is divided into distinct phases and disciplines, with defined interfaces at which information is exchanged, usually in the form of documents or spreadsheets (see Figure 6).

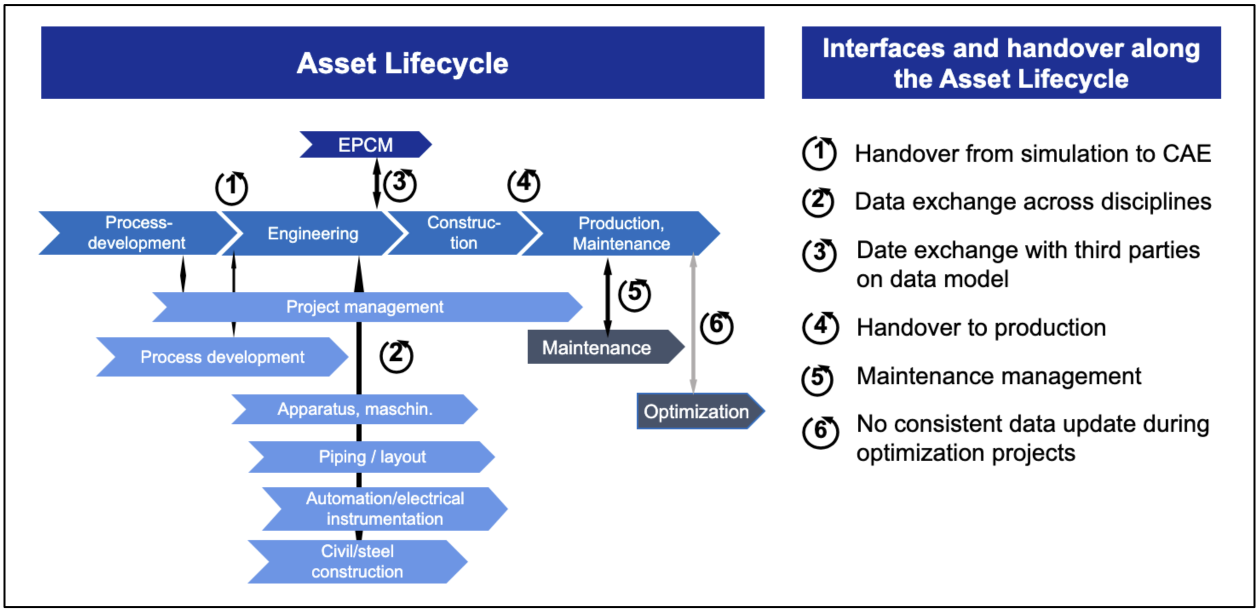


Figure 6. Classical Engineering Process. Source: DEXPI.

This sequential, discipline-isolated approach is still common practice. According to digital maturity models, it corresponds to digital levels 0 or 1[1)]. Some digital maturity models have been developed. The model referred to here is the acatech maturity level definition [31]. Another maturity model has been developed in the CEN Orchid project.

Each discipline generally uses its own set of tools, requiring manual or semi-automated data transfer across interfaces. These handovers create inefficiencies and delays and are a primary source of inconsistency and error in project documentation.

Tracking status and resolving discrepancies in such settings requires considerable project management effort.

One particularly challenging and time-consuming step is the handover from engineering to operations. This is because operational teams typically do not use intelligent CAE tools, but instead work with ERP systems, maintenance platforms and spare parts databases. Each of these systems requires different data structures and formats.

Given the long lifespan of process facilities, ongoing maintenance, optimisation and modification (e.g. during shutdowns or turnarounds) are essential. These changes are managed via a

Management of Change (MOC) process, which can become highly complex and inefficient if plant data is distributed across multiple drawings and unstructured databases.

2.3 Basic Concepts of Integrated ALC Information Management

The transition from document/drawing-based engineering to integrated engineering requires the use of a digital twin. This is typically accomplished via a central database or multiple integrated databases that support all disciplines and lifecycle phases (see Figure 7).

In general, a **digital twin** is a scalable, interoperable and sustainable digital representation of an intended or actual real-world physical asset, product, system, or process (a *physical twin*) that spans its entire lifecycle from design and construction to operation and demolition. It serves as a digital counterpart of it for purposes such as simulation, integration, testing, operations, monitoring, and maintenance.

The digital twin in the process industry is a model-based representation of a physical production facility including its behaviour and operation (see chapter 4 for details).

The process and plant model (CAE-model) of the digital twin is developed incrementally, evolving from a basic functional model in FEL1 to a fully validated and operational model. All disciplines contribute to a shared object model, enabling consistent reuse and traceability throughout the asset lifecycle.

In addition to the central database, an information model is required. This provides the semantic structure and modelling logic to ensure that data is:

- interoperable
- consistently structured
- machine-readable

This includes:

- object identification and classification
- class definitions and relationships
- attribute definition and status tracking

All engineering data that must be handed over during the asset life cycle or between disciplines, including process parameters, apparatus and machines, piping and instrumentation, and automation specifications Is stored in the integrated process and structural model. When information is stored in the common database, changes are reflected at the object level rather than in documents. The information management system applies version control to the data within the information model to ensure data integrity and traceability.

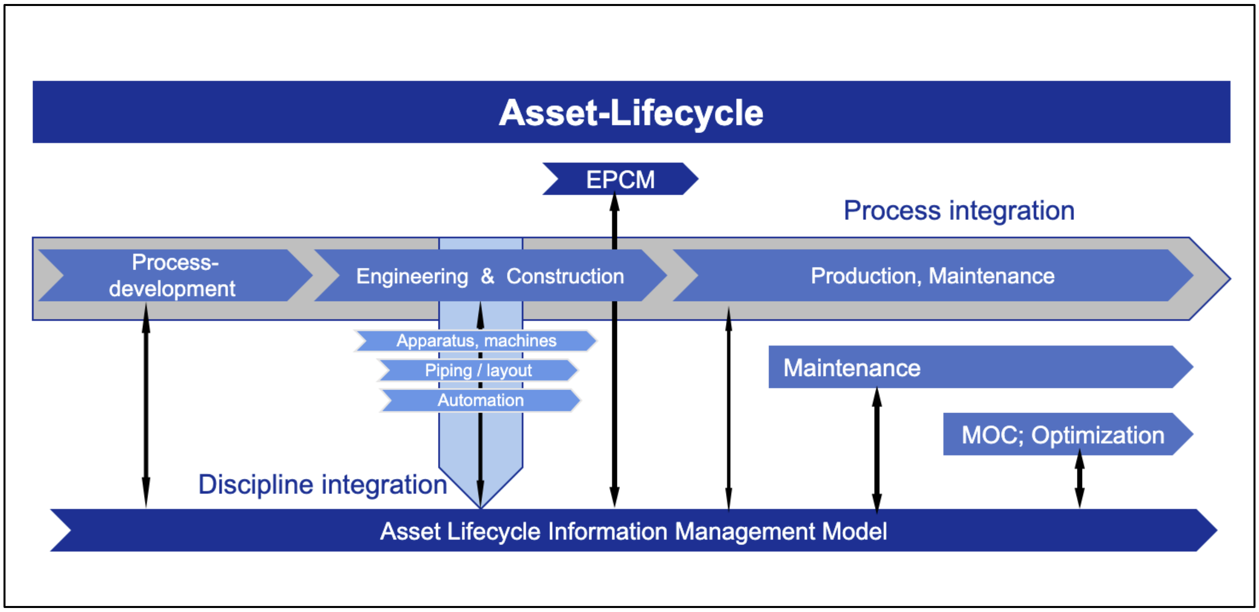


Figure 7. Integrated Asset Lifecycle Information Management (simplified). Source: DEXPI.

2.4 Benefits of Integrated ALC Information Management

Those familiar with the challenges of document-centric engineering, will see the obvious advantages of integrated information management:

- Reduced effort and manual labour across all phases and stakeholders.
- Automatic generation of consistent drawings and tag lists from a shared model.
- Efficiency gains through reuse of typical assemblies or functional modules.
- Higher data quality and consistency, minimising construction rework.
- Reduced engineering effort through model reuse and version control.
- Improved interoperability via vendor-neutral information models.
- Greater flexibility in choosing and changing IT tools and CAE platforms.
- Semantic models are the basis of any AI application.

Perhaps most importantly of all, integrated engineering improves construction quality. It eliminates inconsistent and duplicate data. Experience shows that fully digital engineering projects result in construction rework accounting for only a few percent – a significant improvement compared to conventional approaches.

3 Project Phases and Information Requirements

3.1 Project Phases

Capital projects in the process industry are typically executed following a structured approach known as front-end loading (FEL) and execution. This approach enables well-founded decision-making, precise scope definition, and efficient alignment between technical and business objectives throughout the project lifecycle (see Figure 8).

This approach divides the project into four defined phases:

FEL Phase	Focus	Main Outputs
FEL1	Feasibility and Concept Study	Block Flow Diagram (BFD), strategic options
FEL2	Conceptual Engineering	Process model, Process Flow Diagram (PFD), simulation results, first HAZOP
FEL3	Basic Engineering	Plant model Piping & Instrumentation Diagram (P&ID), layout, interface design
Execution	Detail Engineering	Complete 3D model, procurement and construction documents

Table 2. FEL Phases and their main outputs.

Each FEL phase builds upon the previous one, increasing both the scope definition and the maturity of engineering data. The content of the model, drawing outputs and attribute accuracy progress accordingly.

In FEL1, the project scope is explored and evaluated. Key business goals are defined, process options are simulated, and a basic model of the process is developed.

In FEL2, a conceptual process model incorporating unit operations, safety considerations (e.g. hazard identification), and an initial automation concept is established.

FEL3 produces the plant model with detailed tag and layout specifications, interface definitions and documentation required for CAPEX estimation and investment decisions. Multiple disciplines are involved at this stage, including:

- Process engineering
- Mechanical and rotating equipment
- Electrical and instrumentation (E&I)
- Civil, structural and architectural (CSA) design.

A HAZOP analysis is typically conducted at this stage to identify and mitigate any residual risks. The investment decision is typically based on the outcomes of FEL3 and supported by a CAPEX estimate with an accuracy of ±10%.

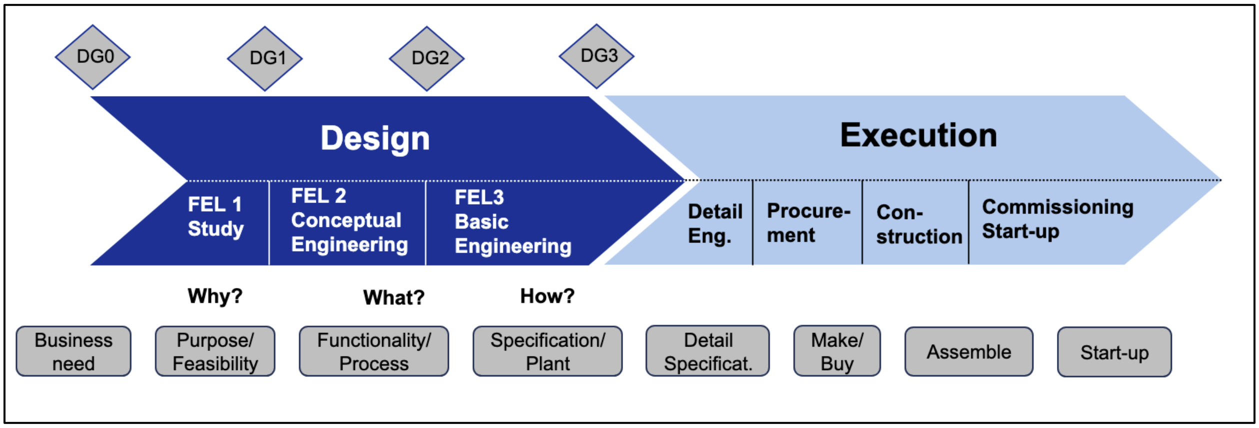


Figure 8. Project schedule for investment projects. Source: DEXPI.

During the execution phase, detailed specifications are finalised to be able to manufacture and buy the equipment, procurement is initiated, and construction is carried out. The engineering model is completed in full detail and becomes the basis for fabrication and installation. After construction the plant model has to be updated as build.

The handover to the commissioning team typically marks the mechanical completion milestone, at which point they conduct:

- Cold commissioning: system checks with utilities (water games).
- Hot commissioning: process start-up with product.
- Performance testing: verification of production capacity and quality.

Once performance acceptance criteria have been met, the plant is handed over to operations.

Although they represent a small proportion of the total engineering effort, it is important to note that FEL1 and FEL2 have the greatest impact on project success and capital expenditure.

The project may also include some long lead items, for which some details and purchasing must be completed during FEL3.

Although there are differences in terminology and roles between industrial sectors (e.g. oil and gas versus chemicals), project structures can be aligned, as shown in Figure 9.

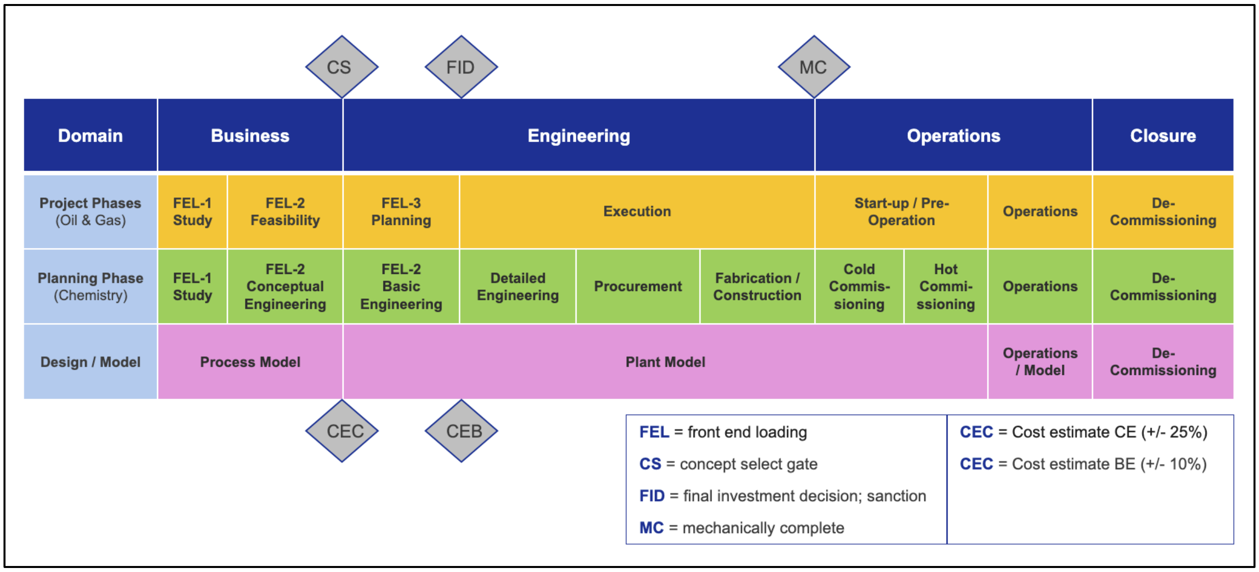


Figure 9. Project execution phases. Source: DEXPI.

Pharmaceutical sector projects follow comparable FEL phases, but additional GMP qualification steps are required:

GMP Phase	Corresponding Project Phase
GMP1	Following conceptual engineering (FEL2)
GMP2	End of basic engineering (FEL3)
GMP3/Design Qualification (DQ)	Following detail engineering
GMP4/Installation Qualification (IQ)	During mechanical completion
Operational Qualification (OQ)	Commissioning phase
Performance Qualification (PQ)	End of commissioning
Validation	During routine operation

Table 3. GMP qualification steps and FEL phases in pharma projects.

3.2 Organisational and Project Information Requirements

At the start of an investment project the following information requirements shall be defined in accordance with ISO 19650 (see chapter 2.1.3):

- Organisational Information Requirements (OIR)
- Project Information Requirements (PIR)
- Asset Information Requirements (AIR)

OIRs relate to strategic decision-making. They should reflect what the asset owner or operator needs to know to manage their portfolio effectively. OIRs are highly dependent on stakeholders and are usually long-term.

More relevant to the interaction with asset information are project information requirements (PIRs). The core of the PIR is the User Requirement Specification (URS), which defines relevant expectations for:

- Capacity and throughput
- Product quality
- Raw material types and utility needs
- Availability and site-specific conditions.

Additional elements of the PIR include:

- Project communication workflows and stakeholder interaction.
- Meeting structures, reporting cycles and milestone reviews.
- Required document types per phase
- Tooling environment (e.g. simulation software, CAE tools, cloud platforms).

Security and confidentiality should be considered from the outset. Areas involving sensitive intellectual property (IP) should be identified via risk assessment and protected using a project-specific know-how protection concept.

The project organisation should define clear roles and responsibilities, including:

- Project Responsible of the facility owner
- Project Manager
- Process Engineer
- Discipline leads (e.g. for E&I, piping and CSA).
- EPC/EPCM partners and third parties.

3.3 Project Metadata

Project metadata is key to information traceability. It uniquely identifies the project itself, its context and its administrative attributes.

To ensure comprehensive identification and management of project information, the system should include the following metadata elements:

- Product/process name
- Plant hierarchy: Enterprise – Site – Industrial Complex – Process Plant – Plant Section (cf. ISO 10209)
- Asset owner/client: Company, division and business unit
- Site/location name

- Project title (unique identifier).
- Project number
- Responsible organisation
- Project Manager (Name)
- Revision number/status

This metadata must be managed within a controlled system to ensure data integrity and traceability. The metadata shall be linked to all models, documents and handover packages to clearly identifying the models/documents, their responsibilities and their status.

3.4 Project Execution Plan

In order to fulfil both the technical requirements and the information needs of a project, a Project Execution Plan (PEP) should be created. It should address:

- project objectives, scope and definition.
- Stakeholders and interaction with OIR.
- Project organisation: roles and responsibilities.
- The delivery model (e.g. EPC, EPCM).
- Project schedule and governance.
- Risk management and mitigation.
- Communication structure and escalation paths.

Regarding information, the PEP should specify how, why, when and by whom information modelling and exchange will be conducted. It should clearly specify:

- the content and format of the required information.
- the level of information needed (LOIN) for each object type or discipline.
- the tools and formats used (e.g. DEXPI, XML, PDF or IFC).
- validation and review processes.

The PEP is the central control document for both engineering delivery and digital collaboration.

4 Information Models and Standards

4.1 Business Process Oriented Data Models and Digital Twin

As shown in Figure 1, digitisation and the necessary information models should support the main business processes. Therefore, it makes sense to structure them according to the business processes of the industry [1]. To this end, business process models have been defined for the process industry [1, 2], covering the core business processes of the supply chain, asset lifecycle, and production (see Figure 10).

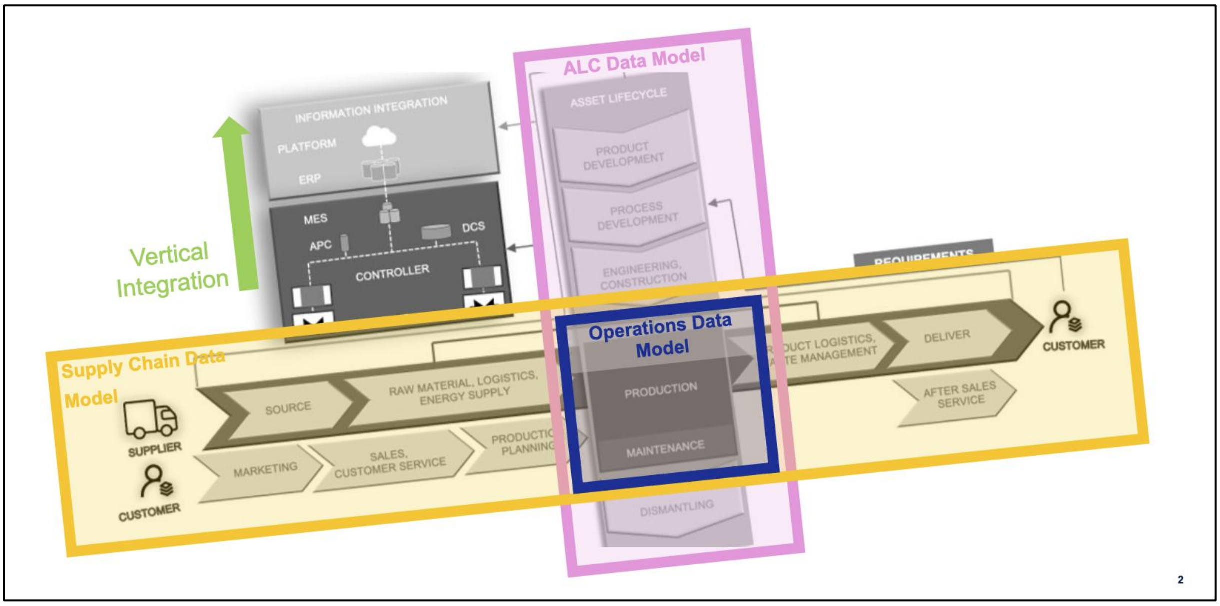


Figure 10. Business-oriented data models in the process industry. Source: DEXPI.

The asset lifecycle and the supply chain overlap in operations. Therefore, a separate data model should be defined for operations. This model should be based on the process and plant model, since these this information defines the plant structure and sources of information. The process and plant data are time-independent (if the assets are not modified), whereas production planning data and operating data, such as measurements, change continuously over time.

The supply chain model (Figure 10, yellow segment) is largely linear and is driven by ERP and logistics systems. In contrast, the operations domain requires tight vertical integration, linking field-level automation systems to enterprise-level tools. Although high levels of automation have been achieved, particularly in plant operations, the integration of engineering data is still evolving.

Operations share elements of both the asset lifecycle and the supply chain. Therefore, a dedicated operations model is required, based on stable process and plant data, but which is also extended by time-dependent data such as production plans, setpoints, and real-time measurements.

The **Digital Twin concept**, introduced in Chapter 2, for process industry covers the following elements and their interaction:

1. Simulation model (behaviour model) – for process design and optimisation.
2. Process/plant model (CAE model, 2D/3D): for representing functional requirements, assets and layouts.
3. Operations model: for measurement, scheduling data, set points, etc.

The operations model is used for time-dependent production data such as set points, measured values, alarms, and maintenance.

When integrated, these three model types form the digital foundation for design, plant operation and optimisation (see Figure 11). Specific use cases and tool classes are addressed in later sections.

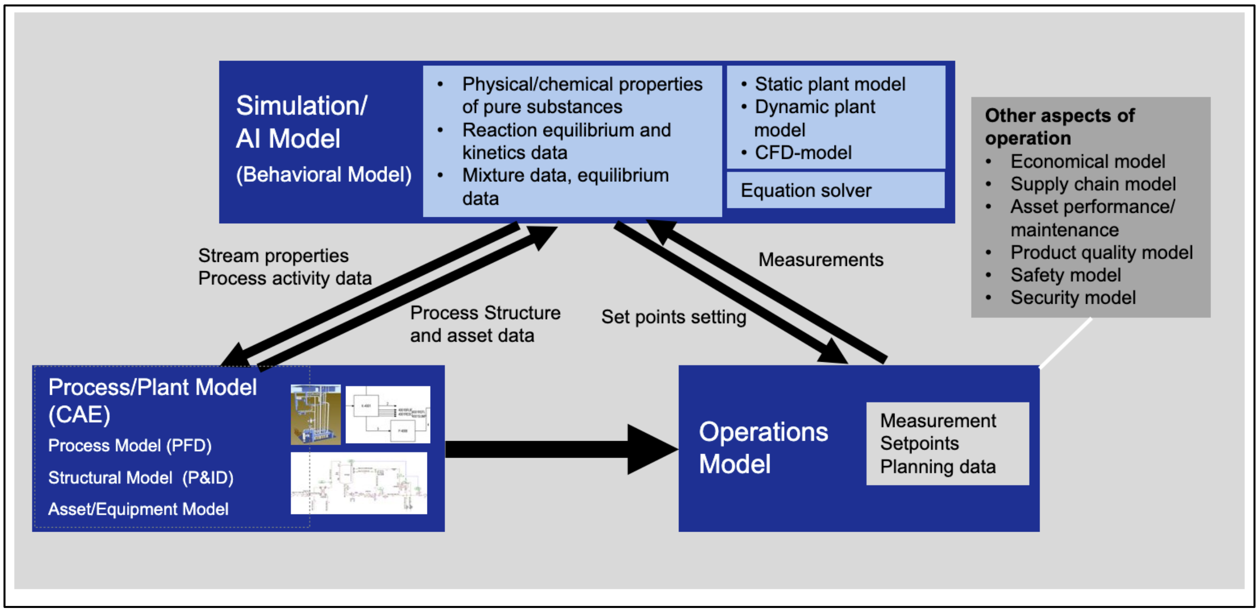


Figure 11. Digital twin of a process/plant in the process industry. Source: DEXPI/NAMUR [2,12]

According to current practice, the **simulation model** (behavioural model) consists of:

- A steady-state simulation model, that describes the physical and chemical properties of the material components, their reactions, and their separation behaviour.
- A dynamic model, which reproduces the temporal behaviour of the plant; and
- A fluid-dynamic model, which describes the processes in individual apparatuses in detail.

Modern simulation tools can calculate steady-state and dynamic processes. Models of 'data analytics and artificial intelligence are also used to predict and optimise plant behaviour.

Today, simulation models are mainly used for the following tasks (see [4]).

- Process design and layout (mostly steady-state simulation).
- Apparatus dimensioning (static).
- Virtual Plant Simulator (dynamic).
- Process optimisation (mostly static).
- Advanced Process Control (dynamic).

An **operational model** is required to operate and control the production process. This comprises a human-machine interface (HMI), automation/process control, alarm management, safety, security and maintenance. The operational model should consider the target variables, planned values, setpoints and measured data of the process in a time-dependent manner. However, other aspects that may also be considered include plant safety with alarm and switching values, security and maintenance. The complexity involved explains why standardised, integrated operational models are not yet available. The MTP (Module Type Package) is an initial attempt at creating a standardised operating model for modular systems (see VDI/VDE/NAMUR 2658). It is intended to cover aspects such as the process HMI, control, alarm management, safety and security, and maintenance.

In the process industry, there is no separate 'product model' for the product to be produced: Rather, the simulation and process models contain product data because the interaction between process and product is very intensive in this industry.

Standardised information models and IT tools that support cross-disciplinary data processing and the seamless management of data throughout its life cycle, from process development to operations, should be used. The corresponding definitions should be agreed upon in the early stages based on the standards defined in the following chapters.

The following section will cover the Process/Plant and Asset Model, which forms the basis of computer-aided engineering throughout the entire life cycle.

4.2 Fundamentals of Asset Lifecycle Information Models

To design and operate a plant efficiently, the CAE-based asset lifecycle model must accurately represent the following:

- Metadata.
- The physical and chemical production processes and utility data.
- The physical structure of the facility.
- The specifications of the objects and properties of installed physical equipment.

In order to digitalise engineering and procurement processes, the vendor product types should be treated as a separate object with their own data sets.

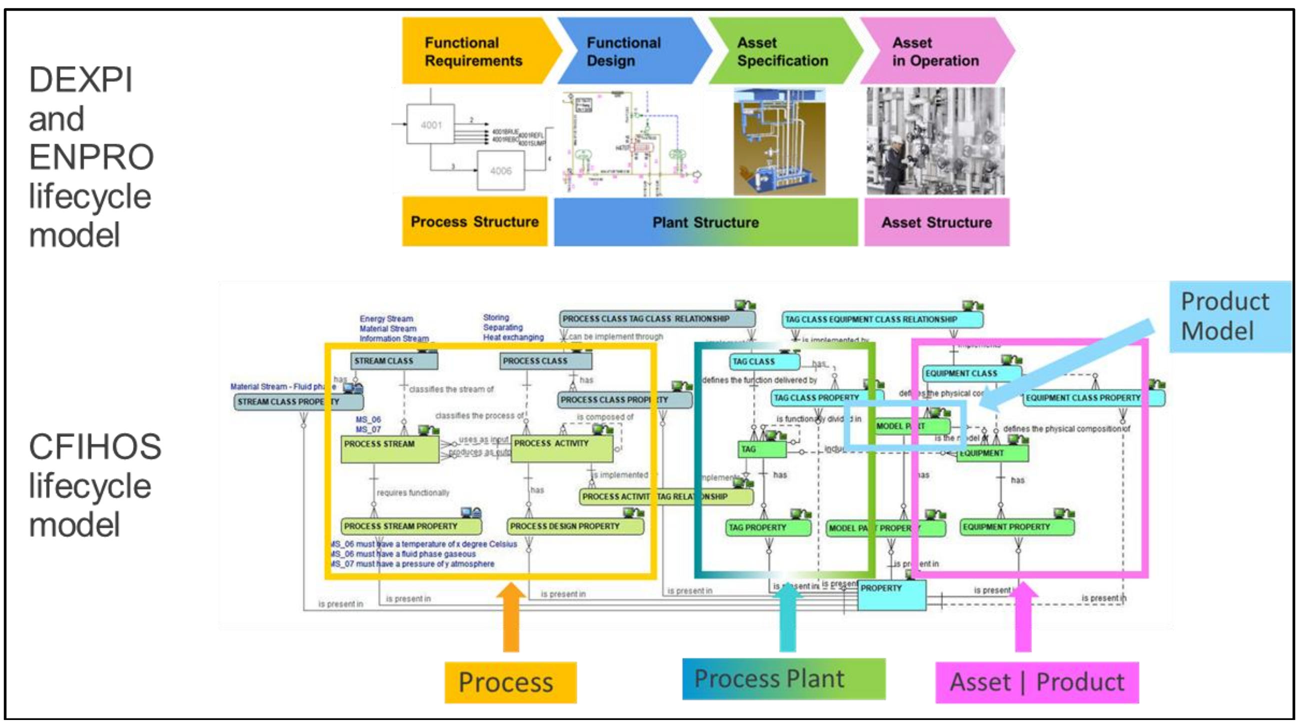
This information model definition enables effective handling of data across project phases and supports the reuse, comparison, and version control of data. A basic overview from a systems engineering perspective is provided in [3].

Process, plant and tag (i.e. individual asset specification) models are developed and maintained by various industry associations and standardisation bodies that work on lifecycle models for the process industry. In order to manage the objects in the database, they must have unique identifiers. Considerable alignment efforts have recently taken place to establish a shared understanding of asset lifecycle modelling requirements. The key contributors include:

- ISO 15926: Lifecycle data integration.
- IEC 62424/61987/61360: instrumentation modelling.
- IOGP JIP33/36 (CFIHOS)[5]: handover and procurement data structures.
- USPI/FL3DMS: 3D plant model configuration.
- CII (Construction Industry Institute): Advanced work packages.
- DEXPI e.V.[6]: standardised process and plant models.

These models divide the asset lifecycle into the following main aspects (see Figure 12):

- Functional requirements/process model.
- Functional design/plant model.
- Asset specification as an object/tag in the plant model.
- Vendor product/type models.
- Assets in operation (physical, installed equipment).



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5 „International Oil and Gas Producers' - see https://www.jip36-cfihos.org

6 „Data Exchange in the Process Industry' - see https://dexpi.org

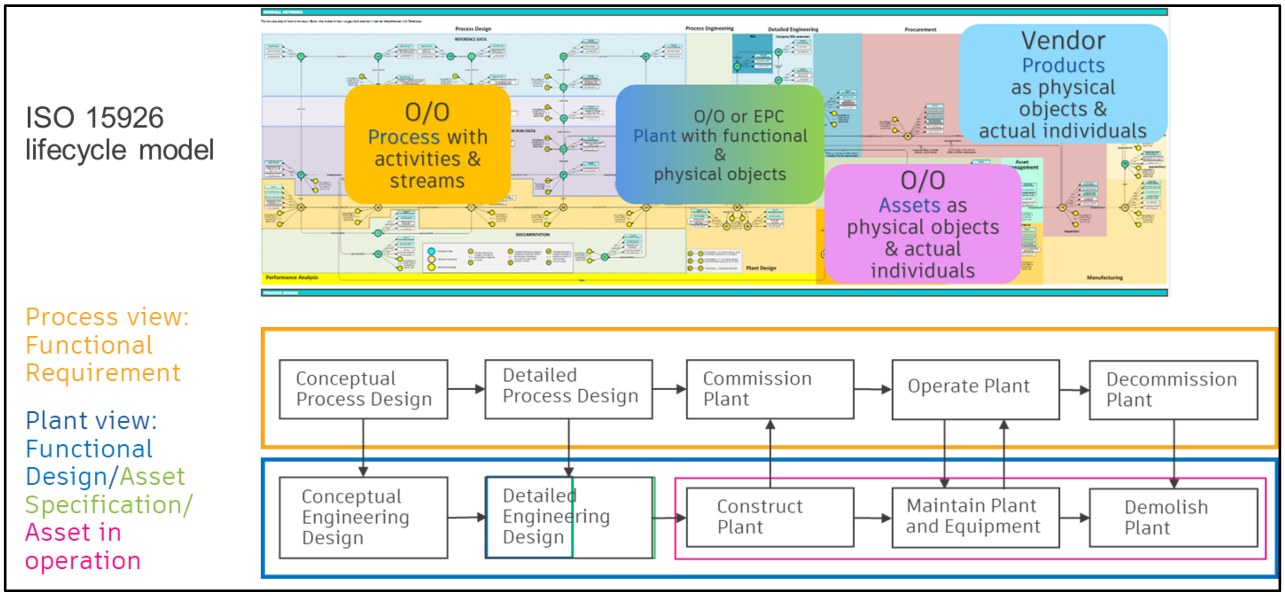

Figure 12. a and b: A common understanding of the asset lifecycle in the process industry. Source: DEXPI/CFIHOS.

Functional requirements define what the chemical/physical process should achieve and are typically represented by unit operations and streams. Historically, chemical processes were visualised by using block flow diagrams (BFDs) and process flow diagrams (PFDs).

The functional design, i.e. the plant structure and initial tag specification, is covered by the plant model. This is traditionally visualised using a piping and instrumentation diagram (P&ID) and a 3D model. Historically, specifications were often managed using paper-based or spreadsheet-based specification sheets.

In order to implement fully digital engineering, it is essential to distinguish between the following:

- The tag specification (e.g. functional location in SAP) and
- physical equipment (asset in operation).

These should have distinct identifiers and different data in the engineering process. For example, the process team may define a functional requirement for a 9 bar pressure increase based on simulation results. The plant designer then increases the design pressure to 10 bar due to the location and hight of the pump. The mechanical engineer defines an upper limit of 15 bar design pressure to assure that, under all circumstances, 10 bar is achieved during operation. However, the vendor may provide a pump with a 20 bar head due to the type of pump available, which would require additional control measures, such as pressure regulation.

Another reason for this distinction is the maintenance process. Even though the functional requirements remain unchanged, the physical pump may need to be replaced or modified over time. Any differences in the performance of the modified or newly installed pump must be reflected in the equipment model.

In the process industry, the asset lifecycle model typically covers the disciplines, **process engineering**, **apparatus and machines** (rotating equipment), **piping**, and **electrical and instrumentation (E&I)**. However, the information model shall not cover civil, structural and architectural (CSA) elements, such as walls and steel structures and often HVAC systems as these are addressed through Building Information Modelling (BIM). During project execution, the process and BIM models must be aligned to detect clashes between process equipment and structural elements.

4.3 Plant and Asset Models in Process Industry

4.3.1 Overview of Plant and Asset Models

Several standardisation organisations are actively involved in defining and developing information models for functional objects (tag) and equipment in the process industry. These models support the consistent management of engineering data throughout the plant lifecycle, from process design and specification to procurement, construction and operation.

The following initiatives and standards are relevant and also cover the 'core standards' defined by the CII (see below):

- **ISO 15926:2004** – Data integration, exchange and handover between IT systems.
- **ISO/IEC 81346** – Structuring principles regarding the aspects function, product and locations.
- **ISO 19650** — Organisation and digitisation of information about buildings and civil engineering works, including building information modelling (BIM) – Part 2: Delivery phase of the assets.
- **ISO 16739** — Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries.
- ISO 14224:2016 - Petroleum, petrochemical and natural gas industries — Collection and exchange of reliability and maintenance data for equipment.
- **IEC 61987** – Asset specification, particularly for instrumentation.
- **IEC 61360 / CDD** – Common Data Dictionary for classifying components.
- **IOGP JIP36 / CFIHOS** – Information handover specification (e.g. for EPC(M) contractors).
- **IOGP JIP33** – Equipment specification for procurement[7].
- **USPI / FL3DMS** – 3D model standard for facility lifecycle coordination.
- **DEXPI e.V.** – exchange standards for process and P&ID data.
- **IDO & PLM POSC.**
- **CII** – AWP; Advanced Work Packaging.
- **MIMOSA ISDD, Industry Standards Datasheet Definition.**
- **ECLASS** – a classification system for products and services.

[7] „International Oil and Gas Producers' -see https://www.jip36-cfihos.org

- **Digital product passport/Digital Nameplate based on IEC 61406, ISO 59040 and ISO/IEC 15459.**

ISO 15926 is a standard that covers the integration, sharing, exchange and handover of data between computer systems. ISO 15926 provides the basic definitions and standards. It has developed a generic data model and a reference data library for process plants. These can be used to represent lifecycle information about technical installations and their components.

Part 2 for the data model and Part 4 with the Core reference data for process plants including oil and gas production facilities are the most important parts of ISO 15926. Part 4 edition 3 was published in 2024. Industry specifications such as CFIHOS, DEXPI and FL3DMS use Part 4 as a central reference data library.

ISO IEC 81346 is also referenced. ISO/IEC 81346 is an international standard that provides a framework for structuring and referencing industrial systems, installations, and equipment. Part 1 introduces the concept of aspects, particularly those relating to

- function,
- plant
- product and
- location.

While this view is quite helpful, the alignment of the ISO 81346 with the other standards is still under discussion. If the aspects are used as follows, meaning full alignment is achieved with the other standards:

- Function: Functional requirement, process model/activities.
- Plant: Asset specification.
- Product: vendor production.
- Installed: Physical equipment.
- Location: Locational structure.

This structuring concept is important for the entire process industry.

For automation purposes, IEC 61987 and **IEC 61360-4/CDD** (see chapter 6.4) are relevant, as they define classes and attributes for measuring instruments, measuring instrument components, final control elements, infrastructure devices and analysers.

ISO 14224:2016 covers the collection and exchange of reliability and maintenance data for installed physical equipment in the petroleum, petrochemical and natural gas industries. The standard was last reviewed and confirmed in 2022. ISO 14224:2016 provides a comprehensive basis for the collection of reliability and maintenance (RM) data in a standardised format for equipment in all facilities and operations within the petroleum, natural gas and petrochemical industries throughout the operational lifecycle of equipment. It describes data collection principles and associated terms and definitions that constitute a 'reliability language' that can be useful for communicating operational experience.

Beyond guiding the operational phase, ISO 14224 also influences the design of data structures in the engineering phase. Two key concepts are central to this: the boundary concept, which defines which components are included in a fully tagged equipment object, and the maintainable item concept, which determines the level of decomposition required for maintenance purposes.

CFIHOS

The Capital Facilities Information HandOver Specification (CFIHOS) is an international standard developed to improve the way information is created, structured, exchanged, and handed over across the lifecycle of capital facilities — from engineering and construction through to operations and maintenance. It was initiated by major owner/operators, EPC contractors, and equipment suppliers in the oil and gas and energy sectors to address the long-standing challenges such as inconsistent data formats, incomplete handovers, and poor information interoperability between project participants.

The primary purpose of CFIHOS is to define a common, standardised, and interoperable framework for managing asset information. This ensures that data generated during project execution can be easily transferred, understood, and reused by all stakeholders — regardless of the tools, systems, or organisations involved.

By using CFIHOS, organisations can significantly improve the quality, consistency, and accessibility of information throughout the asset lifecycle, supporting more efficient handovers, enhancing operational readiness, and ensuring long-term information sustainability. CFIHOS enables organisations to create a standardised, digital information environment that supports the generation of accurate, consistent, and reusable data throughout the entire asset lifecycle.

In essence, CFIHOS provides the foundation for efficient, transparent, and sustainable information management across capital facility projects and operations.

<u>Key Objectives</u> of the standard are:

<u>Standardise information exchange</u>**:** Establish a common language, structure, and set of definitions for asset data and documentation to improve communication and reduce errors among project stakeholders.

<u>Enhance data quality and consistency</u>**:** Ensure that information is complete, validated, and structured in a consistent manner across all project phases to reduce rework and ambiguity.

<u>Enable efficient handover and operations readiness</u>**:** Define what information must be delivered, when it must be delivered, and in what format, to enable data to flow efficiently from design and construction to operations systems.

<u>Support lifecycle data management</u>**:** Enable the reuse of engineering data throughout the facility's lifecycle, supporting maintenance, modifications, and digital twin development.

Promote interoperability and system integration**:** Facilitate the seamless exchange of data between various software tools and platforms by using open, standardised data definitions and structures.

Reduce costs and risks**:** Minimise project delays, data re-entry, and interface issues by improving automation and standardising handover requirements.

Ensure long-term information sustainability**:** Preserve the integrity and usability of data throughout the asset's lifetime, independent of specific software vendors or formats.

Key deliverables and their functions are:
CFIHOS is composed of several core deliverables, each serving a distinct function within the overall information management framework:

Data model**:** This defines the overall structure and relationships between information objects (e.g., physical equipment, documents, systems, and tags). It provides a logical framework for how asset data should be organised and linked throughout its lifecycle.

Data dictionary**:** Provides detailed definitions and attributes for each class or entity in the data model. This ensures a consistent understanding of what each data element represents, how it is named, and how it should be used.

Reference Data Library (RDL): Contains standardised terminology, codes, and reference values used across industries. It ensures consistency and interoperability by defining common vocabularies for equipment types, properties, and document classifications.

Specification document**:** This outlines the overall CFIHOS framework, principles, and requirements for implementing the standard. It serves as the main reference document describing how the various components work together.

Scope and procedures document**:** It defines the boundaries, rules, and processes for applying CFIHOS within projects. It details the roles and responsibilities involved in creating, managing, and handing over information as well as the workflow.

Implementation guide for principal (Owner/Operator): Provides detailed guidance for owners and operators on how to specify CFIHOS requirements in contracts, manage information deliverables, and ensure data compliance from contractors.

Implementation guide for contractor: Offers practical instructions for EPCs, suppliers, and service providers on how to prepare and deliver information in accordance with CFIHOS requirements.

CFIHOS contract scenario templates: These provide ready-to-use contract clauses and examples showing how CFIHOS requirements can be embedded in project contracts and information exchange agreements.

The **USPI** association is a formal Non Profit Association created in 1997 which is open to all companies world wide being a part of or serving the Process and Power Industry. In practice this means: plant owners, contractors, suppliers, software vendors, mgt consultancies and training institutes. USPI started the CFIHOS activities and handed it over to IOGP but is also developing its own standards for 3D modelling (FL3DMS) [7, 8] and tagging.

The **Construction Industry Institute (CII),** based at The University of Texas at Austin, is a non-profit consortium comprising more than 130 owner, engineering-contractor, and supplier firms from both the public and private sectors. The group aims to enhance the business effectiveness and sustainability of the capital facility life cycle through research, related initiatives and industry alliances. As the name indicates the focus of the work is on detail engineering and construction. However, there are also best practices referring to other sections of the asset lifecycle, for example 'CII Best Practices Guide Improving Project Performance' [22] or 'Front End Planning' which are in line with the definitions in this document.

DEXPI e.V. (Data Exchange in Process Industry) is an international standardisation organisation that aims to improve data exchange between software tools throughout the life cycle of process plants.

The 'DEXPI Process Model' [9] is an information model representing the information contained in a process flow diagram. It describes metadata, activities, units, material flows and instrumentation, as they are usually defined in process planning.

The 'DEXPI Plant Model' [10] is an information model representing the information contained in a 'Piping and Instrumentation Diagram'. It describes the 2D plant structure/topology, metadata, apparatus/machinery, piping, instrumentation, symbols, and labels, as well as some engineering content (see Chapter 4 for details). DEXPI models are based on international standards such as ISO 15926 and ISO10628 as far as possible. The process and the plant model have been integrated in the DEXPI 2.0 standards, which covers structural information of a plant over the lifecycle and most of the information handled from FEL 1-3.

Since process and plant aspects are relevant throughout the asset lifecycle, the relevant process and plant information must be updated throughout the asset lifecycle to enable process optimisation and safety evaluations, including updates to process flow diagrams (PFDs) and piping and instrumentation diagrams (P&IDs). During the basic engineering phase, only the most relevant asset specifications should be defined and represented in the P&ID (DEXPI plant model), such as the diameter of a column, to ensure accurate and efficient design processes.

ECLASS is a global reference data standard for the classification and unambiguous description of vendor products and services. It provides a database used by over 4,000 companies for engineering and procurement [11].

The CII Construction Industry Institute has chartered **Research Team 415 (RT-415), ' International Data Standards, Landscape and Guideline for Capital Projects Industry '**, to improve how organisations and projects can leverage data standards in industrial construction. The results are published in [21]. The research team found that, while data standards are available to support projects, no central body of knowledge regarding standards exists. RT-415 also found that the standards governing the creation, formats, and exchange of data for capital projects and handover to operations are numerous and complicated. In addition, the standards landscape is challenging for executing or developing digital project delivery plans. These conditions are a true barrier to the value that implementing data standards can bring to projects. They also reduce the benefits that broader efforts in digitisation can provide.

In response to these challenges, RT-415 reviewed 143 data standards and categorised them as core, niche, supporting, and foundational as they relate to capital projects execution. It identified 14 core and 17 niche standards that are primarily used for project data capture and exchange. The **above-mentioned standards are core standards**. The other two categories, supporting and foundational standards, are also important and are in use for their specific functions.

To help industry practitioners select applicable data standards, RT-415 developed metadata to describe the standards which are project phase, function and use cases. All three dimensions are considered in this document.

In addition to creating the four data standard categories and the tool, the research team developed a set of 15 'critical success factors' in organisational, contractual, and technical areas.

Usage of standards along the asset lifecycle:
While DEXPI standards focus on the structural information defined in the early phases of engineering (Front End Loading, FEL1 to 3), oil and gas information models focus more on execution and detailed asset specifications for exchange with the EPC(M) contractor during detailed engineering (JIP36) and procurement (JIP33). Figure 13 illustrates the usage of the standards.

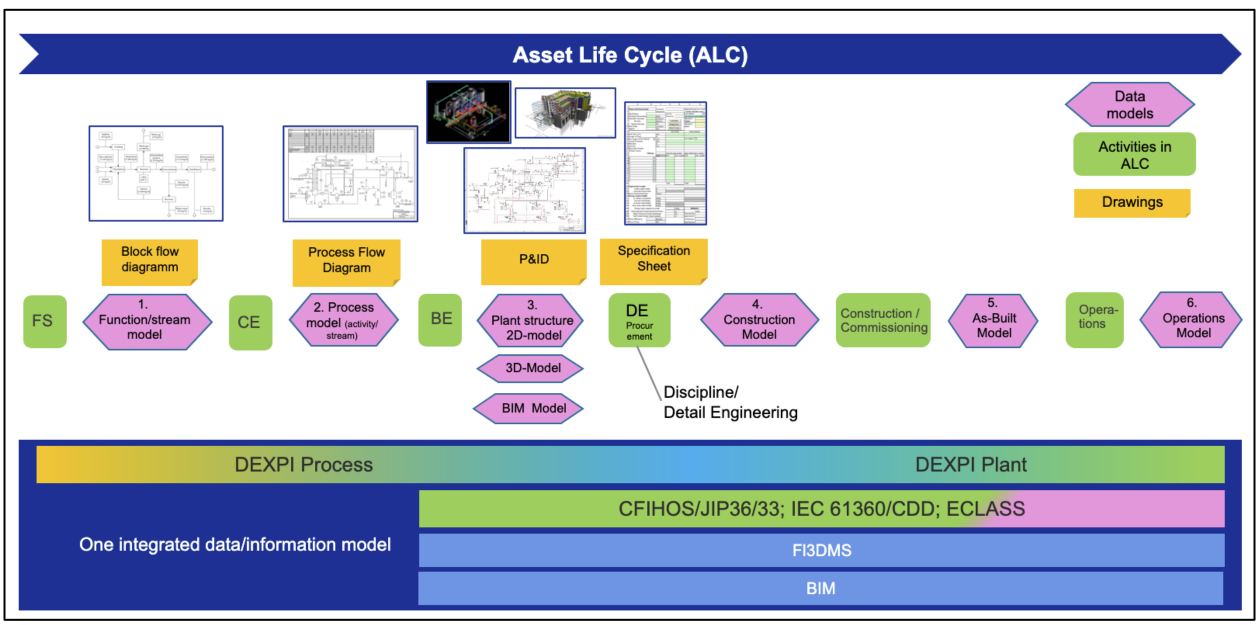

Figure 13. Information models in the asset life cycle – process, plant, asset models. Source: DEXPI.

4.3.2 DEXPI Process and Plant Models

4.3.2.1 DEXPI Process Model

The DEXPI process data model is shown in Figure 14. This illustrates the primary classes within the model and their relationships. The model comprises:

- Process steps and unit operations (activities)
    - All the itemised activities (process steps and unit operations) required to run the process, along with their respective classes.
    - The name of each activity, to explain its function (e.g. Distillation 1).
    - Process step details and characteristic design values of process units.
- Streams
    - Numbering of all streams.
    - All material streams entering and leaving the unit, as well as between activities, are shown as main flow lines according to ISO 10628, with process data such as pressure, temperature and mass flow.
    - The electrical and thermal energy flow exchanged with the process steps.
    - Designate all fluids and solids entering or leaving the process, as well as sources and sinks.
- All required basic process controls.

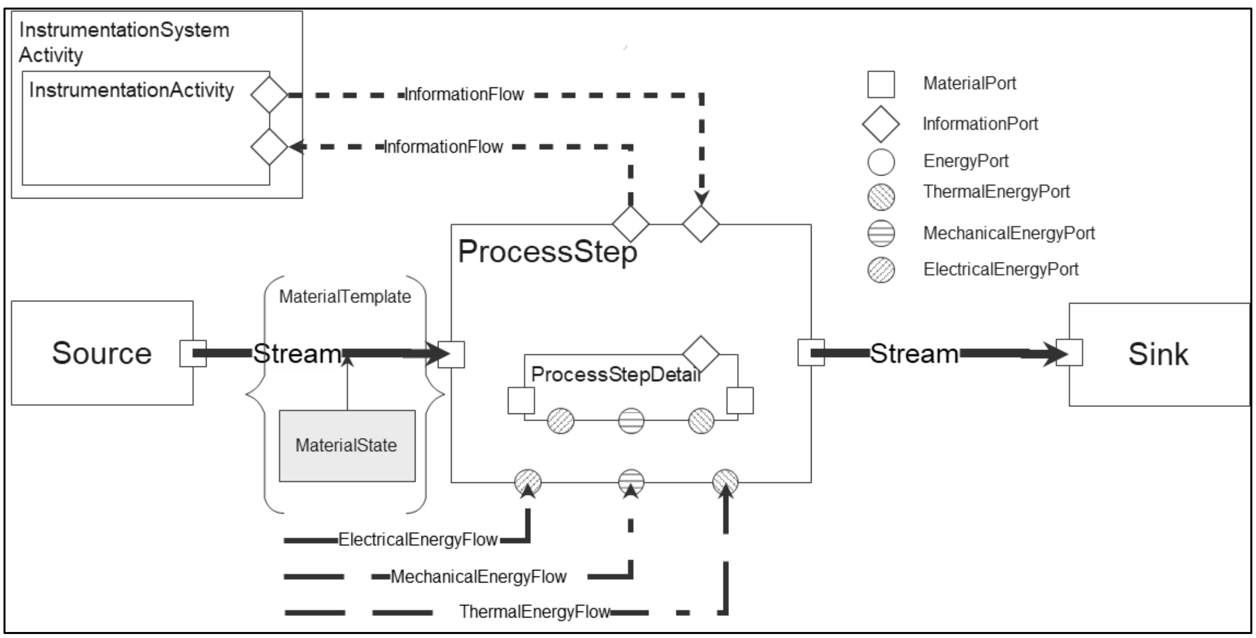

Figure 14. The classes in the DEXPI process model. Source: DEXPI

The DEXPI process defines a hierarchical taxonomy of process steps, and unit operations. Based on existing standards and taxonomies, it can represent processes in most process facilities. For details of the model, please refer to references [3, 5].

4.3.2.2 The DEXPI plant model (P&ID representation).

The DEXPI plant model in DEXPI 2.0 (former DEXPI Standard 1.4) was developed to facilitate the exchange of information between software tools in the form of a P&ID. Digitising the piping and instrumentation diagram creates a machine-readable plant topology, serving as a central information model for basic engineering. The elements shown in DEXPI Standard 2.0 plant model are presented in Figure 15 [6, 7]. The DEXPI Plant Information Model describes the plant's structure and topology, i.e. the interaction between objects, such as the connection between a pipe and an apparatus.

DEXPI is based on international standards wherever possible:

- Plant structure: ISO 10209.
- Apparatus/machines: ISO 10628.
- Piping: ISO 10628.
- Instrumentation: IEC 62424/61987.
- Reference data library: ISO 15926, Part 4.

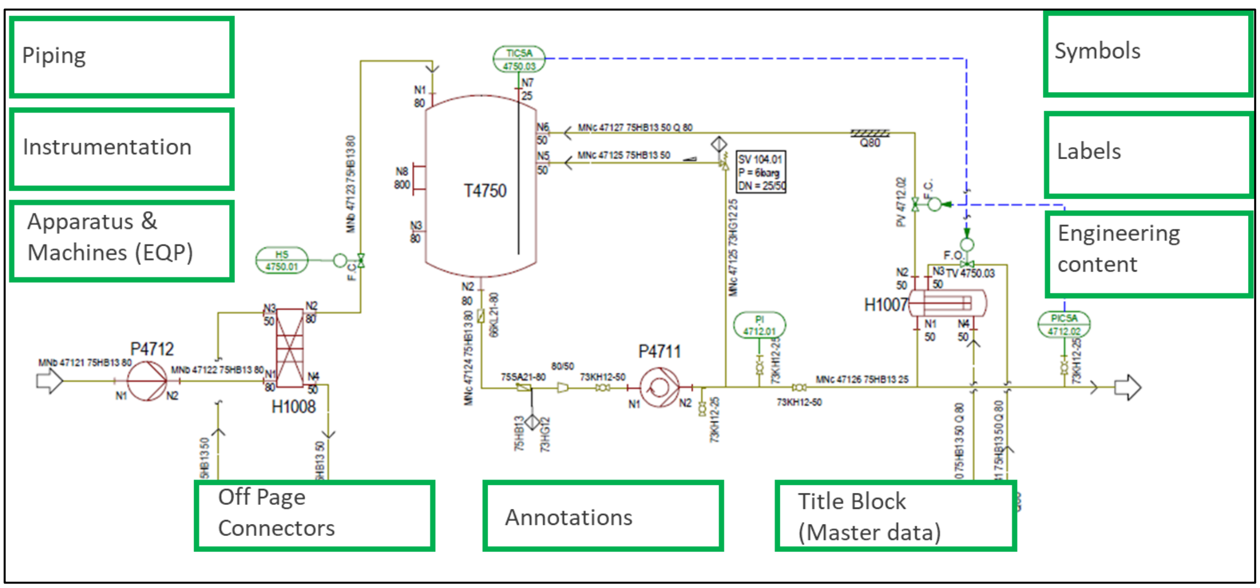

Figure 15. Content of DEXPI Plant Information Model 2.0. Source: DEXPI.

4.3.3 Asset Handover Specification - CFIHOS/JIP36

The Capital Facilities Information Handover Specification (CFIHOS) is an industry-wide initiative that aims to standardise the exchange of information between stakeholders involved in the construction, operation and maintenance of industrial facilities. As part of the IOGP JIP36 project, the specification aims to establish a common language for structured handover throughout the asset lifecycle.

Initially, CFIHOS focused on the handover of structured data and documents from EPC(M) contractors to asset owners/operators at the end of a project. However, the long-term goal, however, is to provide a unified information model that supports the entire lifecycle, from vendor data acquisition to decommissioning.

At the core of CFIHOS is the Reference Data Library (RDL), which is closely linked to ISO 15926, part 4. This provides a standardised vocabulary and classification system for functional objects, documents, disciplines, and attributes. The CFIHOS RDL includes:

- A list of classes for tags and physical equipment, defining what the asset should do and what it is.
- A list of properties, including technical characteristics, measures and metadata.
- Requirements by class: which attributes and documents are required for a given class.
- Standard coding systems to support integration into digital workflows.
- A list of document types for each lifecycle stage.
- A list of disciplines, such as mechanical, electrical and instrumentation (E&I) and process engineering.

Currently, CFIHOS focuses on structured data and documents rather than graphical or geometric data. However, future extensions are planned to include design tools and support for the procurement of spare parts, as well as inspection and test requirements as well as commissioning check sheets, work packaging, configuration management and payment processing.

4.3.4 3D Model FL3DMS

The Facility Lifecycle 3D Model Standard (FL3DMS) [7] is an industry standard providing a specification that standardises how 3D models are configured and their content. It also specifies what is to be handed over to optimise the return on investment in a 3D model.

Standardising the 3D Model generates additional benefits:

- Consistent tagging, data exchange between 2D and 3D model, avoid redundant data.
- Automated routing of pipes and cables.
- Automatic generation of layout drawings.
- Integrated 2D and 3D HAZOP information.
- Integrated 2D and 3D information for automated definition of construction work packages.
- Reduce effort of data exchange with EPM(m).
- Integrated 2d and 3D information for operating processes such as MOC.

FL3DMS is being developed collaboratively by principal companies (owners/operators), EPC contractors, software providers, service providers and equipment suppliers (including subcontractors and/or packaged unit suppliers) as a practical standard.
This document specifies the requirements for:

- Requirements for 3D model content, objects and object classes.
- Accuracy of the objects, including their relationships with and references to disciplines.
- 3D model configurations.
- Its representation method.
- 3D model deliveries and
- As-built concepts.

From the perspective of 3D model content, it includes both tagged and non-tagged objects. The included elements are generic, regardless of the application area.

Users of this specification are assumed to be familiar with the terminology used within it that is related to the project- and application. One example is obstruction areas, which are commonly used in 3D model development.

In the FL3DMS project, data quality is categorised as either 'logically correct' (properly connected) or 'physically correct' (correct sizes and orientation). Tolerances are defined.

4.3.5 CII Work Packaging

In 2015, CII officially designated AWP (Advanced Work Packaging) as a CII Best Practice. CII currently defines AWP as, 'The overall process flow of all the detailed work packages including construction, engineering, and installation work packages' (CII 2020). CII's Body of Knowledge that pertains to AWP indicates that it is a planned and executable process that exists from the inception to the final construction execution of a project. Several research teams within CII have investigated various aspects of AWP for capital projects:

- The integration of the supply chain with AWP practices (RT-363).
- Supply chain integration of materials planning and work packaging (RT-344).
- The value quantified in integrating supply components to front end planning efforts (RT-272).
- Making the case for AWP as a standard practice (RT-319).
- AWP 'Digital Threads' to enable supply chain visibility on capital projects (RT-TC-03).

CII AWP defines a data model structure, which is an extension of the functional breakdown structure, see below. It also defines a minimum set of requirements from a 'constructability' point of view (see Figure 16).

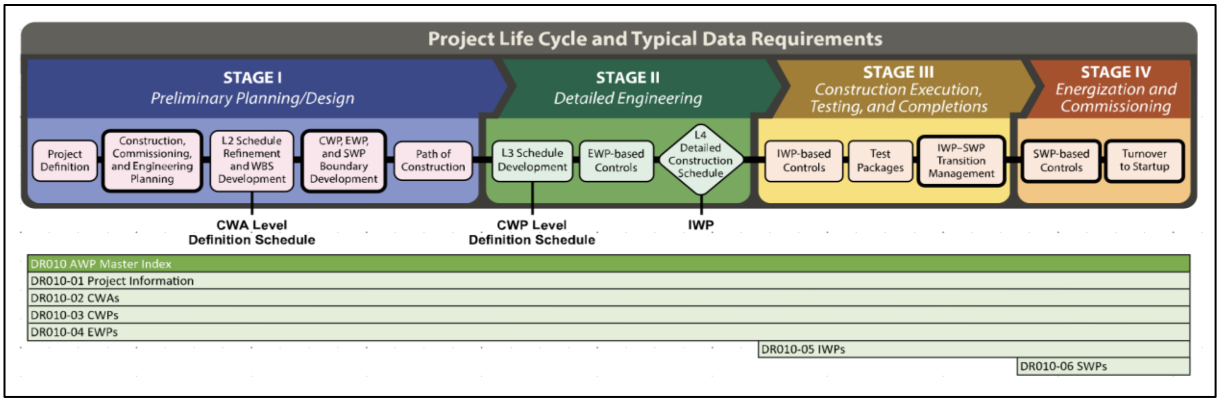

Figure 16. CII Advanced Work Packing Data Requirements. Source: DEXPI.

For the front-end loading the standard requires basic project information and a list of unique construction work areas (CWAs) within a given project. It also requires the definitions of the Project's construction work package (CWPs) and a list of unique engineering work packages (EWPs) within a given project.

The Advanced Work Packaging (AWP) data requirements outline the minimum requirements for data object attributes including format, structure, and description. By specifying the minimum data requirements communication is clarified, the quality of data is improved, and data integrity and integration can be realised.

4.3.6 Semantic Data modelling

Semantic data modelling extends traditional data modelling by giving every class, property, and relationship not only a structure, but also a defined meaning that is both human- and machine-readable. This semantic meaning enables consistent interpretation across systems and facilitates advanced reasoning.

Ontologies provide the conceptual framework for semantic data models. An ontology is a computable representation of knowledge within a domain. The Resource Description Framework (RDF) and Ontology Web Language (OWL) are foundational W3C specifications for defining these models. The Industrial Data Ontology (IDO), developed by the PCA community, is a W3C OWL ontology designed to cover all phases of the life cycle of industrial assets and processes. It is currently being developed into ISO 23726-3.

While OWL, RDF, and IDO can be applied in many industries, process industry models require domain-specific Reference Data Libraries (RDLs) such as ISO 15926-4 to ensure unique, standardised definitions for classes and properties.

Semantic data models deliver several key benefits: they ensure semantic consistency across systems, support automated reasoning (i.e. software can infer new facts), enable efficient data integration, and provide a solid foundation for AI-driven applications. Further benefits can be obtained by using ontologies to support reasoning about data in a knowledge graph.

The knowledge e. g. about a plant using semantic approaches can be stored in RDF triple stores and the complete information network can be visualised using graphic tools.

Complex process systems have a natural graph structure. Therefore, knowledge graphs are a promising way of organising information about process systems. A knowledge graph is a data representation consisting of nodes that are connected by edges. Both the nodes and the edges can be categorised using a set of reference data. A knowledge graph is serialised using the Resource Description format (RDF) https://www.w3.org/TR/rdf11-primer/, which defines triples. A triple consists of a subject (node), predicate (relationship) and object (either a node or literal value).

Several initiatives have already implemented prototypes and use cases based on OWL, RDF, and IDO. To maximise interoperability, a shared approach to these concepts is essential. The Arrowhead Flexible Production Value Network (fPVN) project is developing modelling patterns for using IDO to connect major standardised data models and reference data libraries such as DEXPI, CFIHOS, PCA reference data, ISO 15926, and ISO 10303. These results will be significant for advancing digitalisation in the process industry.

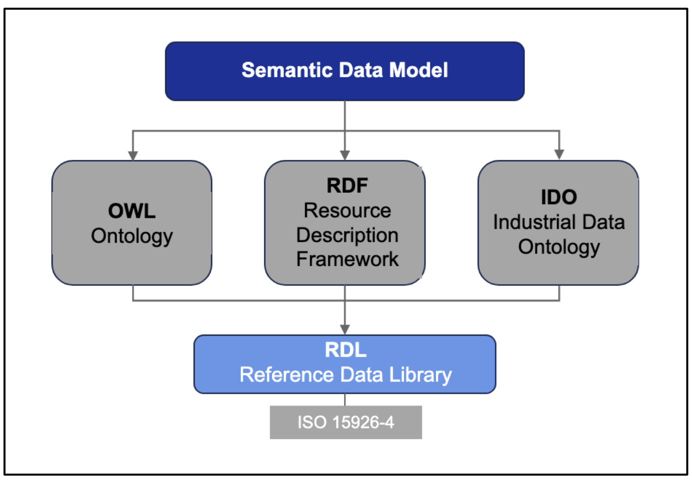

Figure 17. Semantic Data Modelling. Source: DEXPI.

4.3.7 MIMOSA

MIMOSA is a not-for-profit industry trade association dedicated to developing and encouraging the adoption of open, supplier-neutral IT and IM standards enabling interoperability and digital transformation for asset lifecycle management across plants, platforms and facilities. MIMOSA standards support key functional and interoperability requirements of critical infrastructure management on a cross-sector basis, addressing the highly heterogeneous and interdependent nature of critical infrastructure. MIMOSA standards and specifications enable digital twins to be defined and maintained on a supplier-neutral basis, while also using those digital twins to provide context for big data (IIOT and other sensor-related data) and Analytics. Mutually beneficial collaboration with other industry associations provides a pragmatic basis for Industrial Digital Transformation based on the Open Industrial Interoperability Ecosystem (OIIE).

MIMOSA CCOM (**Common Conceptual Object Model**) serves as an information model for the exchange of asset lifecycle information. Its core mission is to facilitate standards-based interoperability between systems: providing an XML model that allows systems to electronically exchange data. However, the object model is not aligned with CFIHOS or DEXPI.

The Industry Standard Datasheet Definition (ISDD) project will capture existing Industry Standard Datasheets (ISDs) as machine-interpretable business objects that are then fully re-usable, mappable and extensible. The effort will capture high-value properties from existing, high-value ISDs published by reputable industry associations including API, ASME, IEC, ISA, ISO, NORSOK and PIP.

MIMOSA is hosting an OIIE Joint Working Group to initiate the work to add RESTful Services (with a RESTful API) to the existing MIMOSA and OpenO&M specifications which are based on SOAP and XML Schema and used as the basis for the **Open Industrial Interoperability Ecosystem (OIIE).** The OIIE OGI Pilot also serves as the testbed supporting ISO TC 184/WG 6 in the development of emerging standard ISO 18101 'Automation systems and integration — Oil and gas interoperability'. This standard provides requirements, specifications and guidance for an architecture of a supplier-neutral industrial digital ecosystem. It includes a standardised connectivity and services architecture, and a standardised use case architecture with methods to specify atomically re-usable scenarios and events, which can be used to specify the characteristics of standardised industry use cases.

4.3.8 Digital Product Passport (DPP)/Digital Nameplate

In the EU, all installed products (physical equipment) used in a facility must fulfil the requirements of the Ecodesign for Sustainable Products Regulation (ESPR) and the Digital Product Passports (DPP).

There is a distinction between type of identification depending on the product type whether it is defined as Type/Batch or Item (Serial Number). More complex products in a facility are defined by the vendor at serial number level. And in that case the product needs to be traceable, and its lifecycle handled in the 'digital twin' (procurement, maintenance, and storage systems) from the procurement process through the lifecycle until the end of its life, when it is refurbished or sent to recycling.

4.4 Alignment of Information Models

Extensive work was undertaken to align the information models. To coordinate the various organisations, bilateral interaction took place. Beginning at the Achema 2022 an annual PIDMIC (Process Industry Data Model Integration Congress) was organised. The main fields of harmonisation are:

- a common view on asset lifecycle methodology.
- common modelling rules.
- common evaluation of the standards, which should be used.
- The creation of a complete map of information models covering the entire lifecycle and the different disciplines.
- Alignment between the different standards.

Some important results have been compiled in recent years, e.g.:

- The setup of the CFIHOS-CII AWP-USPI FI3DMS-DEXPI plant alignment table based on ISO 15926 Part 4.
- The extension of the CFIHOS-DEXPI plant alignment table with the FL3DMS specification.
- Alignment between the NAMUR recommendation 159 and DEXPI plant.
- Setup of the DEXPI Process specification.
- Setup of an IDTA Asset Administration Shell sub model for DEXPI plant.

4.5 Breakdown Structures and Tagging

To manage asset lifecycle information management effectively, it is essential to use standardised information models and IT tools that support cross-disciplinary data processing and the seamless flow of information throughout all lifecycle phases, from process development to operations.

Since most industry information models are designed with a degree of flexibility, a project-specific configuration step is required. This ensures that the data structures are properly adapted to the specific needs and scope of the project. These definitions should be agreed upon early in the project lifecycle.

A **functional plant structure** with the associated tagging must be defined in order to structure the assets, to assign information to different levels of the structure, to group information, to modularise and reuse information (see DEXPI, ISO 15926, CFIHOS/JIP 36 and IEC 81346) Since locational structure generally does not match with the functional structure a location structure must be introduced to complement the functional structure and structure location oriented information. A cost structure should be implemented in the information model to allocate costs.

Structure Type	Source Standard / Specification
Functional plant structure	DEXPI P&ID Specification 2.0, [10]
Tag and equipment classes	DEXPI P&ID Specification 2.0, [10]; ISO 15926 part 4;
Location structure	IEC 81346
Cost structure (CAPEX)	ISO 19008

Table 4. Structure types and source standards

Each object in the process and plant models must be **tagged** with a unique identifier to ensure accurate tracking and management within the information model. The information model shall not handle objects without unique identifiers. DEXPI proposes the use of different functional structures to identify units in the process model and tags/functional locations in the plant model.

Figure 18 shows the logical data model representation of the CFIHOS data model structure [8], indicating the location of TAG and (physical) EQUIPMENT objects. These objects are coloured to indicate their classification: blue indicates a *specified* physical object; yellow indicates a functional plant aspect; red indicates a location aspect; and green indicates a *supplied* physical object.

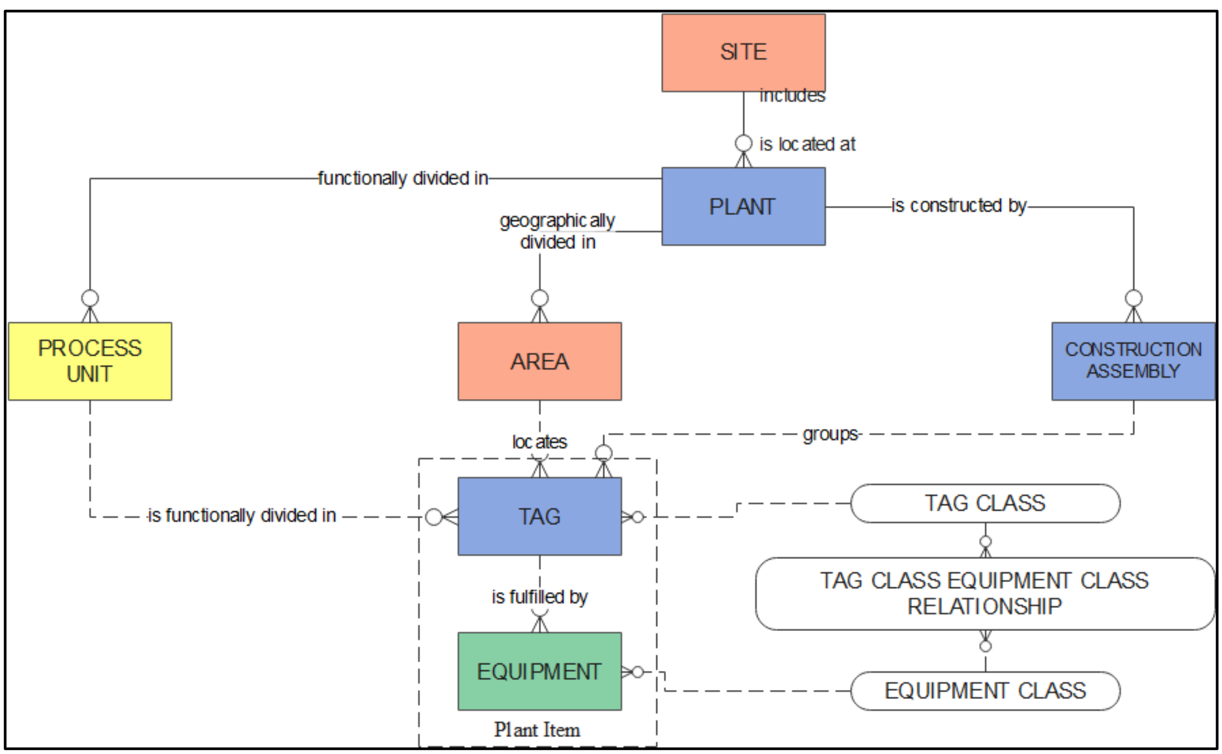

Figure 18. Part of the CFIHOS data model. Source: CFIHOS.

The problem with this structure is that it mixes functional aspects with the location structure. Best practice recommends building a functional structure according to ISO 10209 (see Figure 19) and defining a separate, independent location structure.

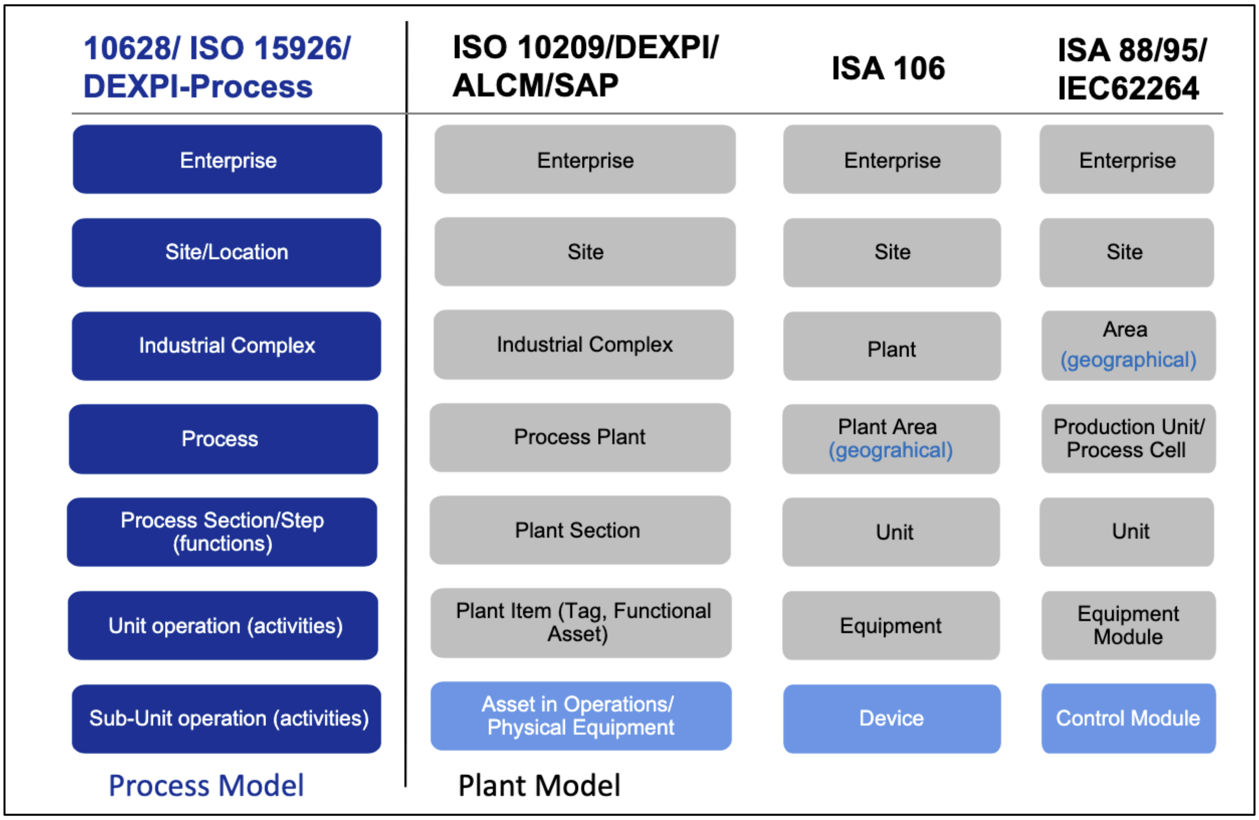

Figure 19. Comparison of Functional structures. Source: DEXPI.

Besides 'functional structure' and 'locational structure' a '**cost structure**' is defined to plan, allocate and control the capital expenditure.

The ISO 19008 standard for the oil & gas industry defines three dimensions to allocate the cost:

- Functional structure
- Standard activity breakdown
- Resources

In the chemical Industry, costs (CAPEX) are usually tracked on the one hand on the functional structure an on the other hand a combination of activities and resources mixed in cost groups.

100	Main equipment, apparatus, machines
200	Piping material
300	Process control and instrumentation devices/material
400	Electrical material
500	Civil structure and architectural
600	Insulation, corrosion protection
700	Installation, construction
800	Miscellaneous and services (safety experts, permitting)
900	Engineering

Table 5. Typical cost groups in the Chemical Industry. Source: DEXPI.

In addition to these structures, the information model should be able to group objects in order to represent functional relationships. For example, it should be possible to show that objects form a module, or that a group of objects is handled in a design or operational process like

- hazard studies and risk analysis
- constructability analysis
- inspection loops
- corrosion loops, etc.

4.6 Levels of the Data Model (Level of Information)

Although the data model is continuously developed in digital engineering, experience of introducing 'integrated engineering' shows that is helpful to align data model development with engineering phases and relate it to documents/diagrams from traditional engineering. This also helps to align BIM engineering work with process engineering.
The status of the data model achieved during the planning stage is indicated by status numbers and represented by output drawings (PFD, P&ID), which have issue numbers related to the model's status.

Design/Model focus		Process Design/Model			Plant Design/Model							Operations/ Model	De-Commissioning
Planning Phase		Study	Conceptual Engineering		Basic Engineering			Detail Eng.	Procure-ment	Construc-tion	Commis-sioning	Operations	De-Commissioning
Model level	Levels/revision	1	2.1	2.2	3.1	3.2	3.3	4.1	4.2	4.3	5	6.x	
Diagramm issues	Block Diagram	1		2			3			4	5	6	
	Process Flow Sheet		1	2			3			4	5	6.x	
	Piping & Instrumentation	(1)		(2)	3.1	3.2	3.3	4.1	4.2	4.3	5	6.x	
	3D-Drawing	(1)		(2)			3	4.1	4.2	4.3	5	6.x	
BIM	Level of information			100			200	300		400		500	

Table 6. Planning phases, model levels and diagram revisions. Source: DEXPI.

In general, it is useful to distinguish between the level of information (LOI) and the level of graphics, especially when it comes to 3D representations. Certain levels of information are defined for BIM. These can easily be matched to the project phases of a process engineering project:

- Level 100: Conceptual representations and studies (end of conceptual engineering).
- Level 200: Information on the dimensions and sizes of relevant components, and their relationships with each other (end of basic engineering).
- Level 300: Basis for implementation, providing tender-ready information and specifications (end of detail planning).
- Level 400: Production-ready execution planning (end of construction).
- Level 500: As-built documentation of the executed element (as-built).

4.7 Status of Attributes

In order to manage data within the engineering process and asset lifecycle, the status of information, particularly attributes and parameters, should be defined, given that the quality and reliability of data evolve throughout the engineering process. The following status definitions are proposed:

- Draft: initial, estimated or preliminary value.
- Checked: the attribute is provided by the attribute owner and checked by the data user or process owner (four-eyes principle).
- Released:
  - For design: the attribute is released by the attribute owner for use in the engineering process by other disciplines. Attributes may be changed and adapted in the design process.
  - For procurement: the attribute is released by the attribute owner as the final value for use in the procurement process.

Qualifiers for parameters have been defined in IEC61360-7 but are still under discussion.

4.8 Use Cases for Information Models

Vendor-independent information models can be used either to configure CAE tools or as an exchange format for exchanging process, plant and asset information between CAE systems and other systems/models (e.g. simulation models), thus avoiding the need for individual interface design. If the CAE system uses standardised information models internally, mapping to get the standardised format is avoided.

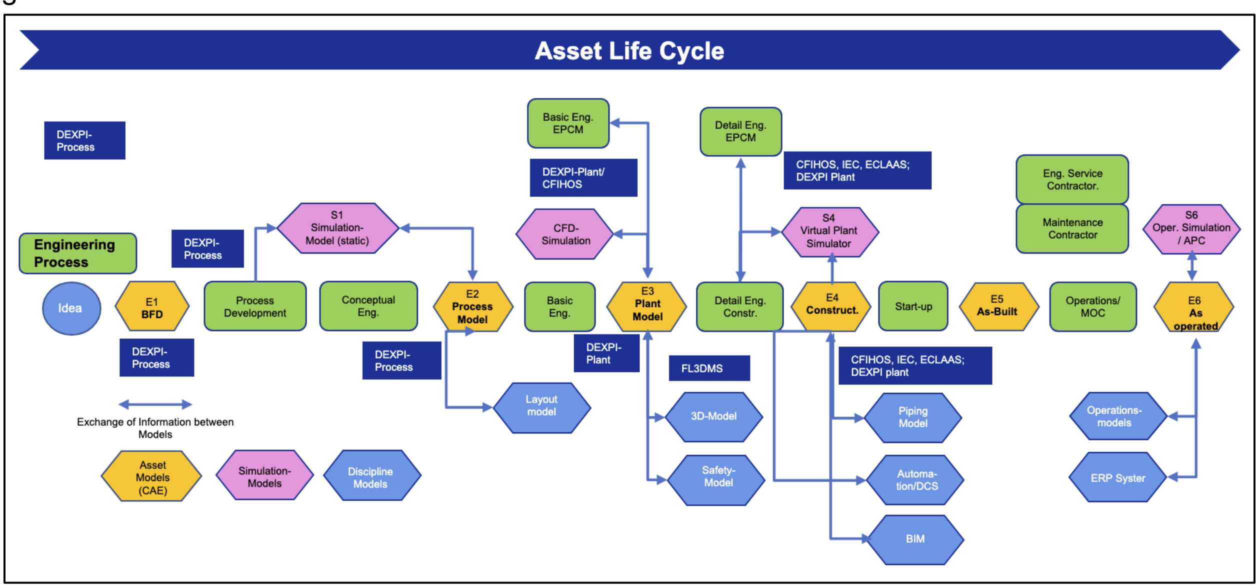

Figure 20. Use cases for vendor-independent, standardised information models. Source: DEXPI.

Figure 20 illustrates the possible uses of vendor-independent data models in the asset life cycle. Details will be explained in the next section.

5 Asset Lifecycle Data Management

5.1 ALC Data Handling and Model Levels

The development of capital projects in the process industry typically follows the Front-End Loading (FEL) methodology, which is structured into four main phases, as described in Chapter 3 and shown in Table 2. Each phase is associated with increasing information maturity, both in terms of data completeness and model reliability. Accordingly, different levels of information (LOI, see Section 4.6) introduced by BIM and document status are applied to support decision-making, procurement, and construction.

The following table outlines how model content and document outputs evolve across the FEL phases. It also links each phase to typical drawing types (PFD, P&ID and 3D models) and the expected LOI:

Phase	Model Content	Typical Output	LOI-Level	Purpose
FEL1	Process idea, functional blocks, material flows	Block Flow Diagram (BFD)	**LOI 100**	Feasibility, business case
FEL2	process design, process unit, mass & energy balance initial specs	Process Flow Diagram (PFD), URS	**LOI 200**	Simulation, automation concept, HAZIP
FEL3	Plant structure, basic tag layout, interfaces	Piping & Instrumentation Diagram (P&ID)	**LOI 300**	Basic design, HAZOP, cost estimation
Detail Eng.	Full specification, procurement data	3D model, detail drawings, datasheets	**LOI 400**	Execution, fabrication
Construction	As-built verification	Validated 3D and P&ID model	**LOI 500**	Hand-over to operations, maintenance

Table 7. Engineering Phases and levels of information. Source: DEXPI.

5.2 FEL1: Study Phase/Process Simulation (Data Model Level 1)

The development of a process, plant or entire facility begins with a basic overview of the process, with the process steps and material flows represented graphically in a block flow diagram. This information can be digitally represented in a DEXPI process model (see Section 6.2).

At its most basic level, the data model provides a simplified, synoptic view of the units within the complex under review.

- Function blocks/process steps
  - All basic function blocks illustrate the overall process or facility (e.g. a reaction or a separation process).

- Names of the function blocks to explain their function (e.g. reaction or separation).
- Streams:
  - All streams entering or leaving the unit or passing between the blocks are represented as lines.
  - Designation of all fluids and solids entering or leaving the process.
  - Design the total mass flows for all material streams entering and leaving the process, as well as the mass flow of the most relevant components.

Process steps are represented by rectangles connected by lines.

The block flow diagram, which shows the segmentation of an industrial process into steps and unit operations, is particularly important because it enables process flow diagrams and P&IDs to be assigned to the relevant section of the plant.

A simulation model of the process is typically developed for process design.

The simulation model requires physical and chemical data as well as unit operation models.

- Physical/chemical properties of pure substances.
- Reaction equilibrium and kinetics data.
- Mixture data and equilibrium data.
- Unit operation models.

The outcome of the simulation is:

- Mass and energy balances for all relevant substances
- Stream information: Mass flow, mass flow of the material components, pressure, temperature, density, vapor fraction, solid fraction, etc.
- Relevant design parameters of the process units

At the beginning of the conceptual engineering phase, the stream and unit operation information to be handed over to the CAE tools should be defined.

5.3 FEL2: Conceptual Engineering

5.3.1 Scope and Activities

The goal of conceptual engineering according to systems engineering and asset lifecycle (see figure 12) is to define the “functional specification”, to ensure that business needs defined in FEL1 will be fulfilled. This is realized by defining the process, units and streams. While in FEL1 the process steps are defined on high level in FEL2 the process steps have to be defined on unit operation level [3]. In the conceptual engineering the all major cost-relevant definitions and decisions should be made during this project phase to achieve CAPEX accuracy within +/- 25%. The process concept should be developed based on requirements relating to the customer, the site, plant safety, the authorities, utilities, and waste management.

Engineering work is based on proper project definitions (user requirement specifications). Conceptual engineering includes, among other things, the following measures/activities:

- Project organisation and execution concept.
- Block flow diagram.
- Creation of process model/flowcharts and process descriptions.
- Mass and energy balances and material properties.
- Requirements for environmental protection, plant safety risk identification (HAZID), explosion protection, health protection, emission limits and official permits.
- Boundary conditions for logistics, packing types and sizes, utilities and waste management.
- Design of unit operations and preliminary process data sheets.
- Preliminary automation concept.
- Preliminary concept for electrical power supply and preliminary list of electrical consumers.
- Site evaluation and selection; interfaces to infrastructure and site.
- Layout concept.
- Requirements for the building and technical building services.
- Know-how protection concept.
- Schedule.
- Cost (CAPEX) estimation based on unit operation costs[8] using the factor method.
- Conceptual engineering report.

5.3.2 Process model content (process flow diagram)

As conceptual engineering focuses on the processes, a process data model shall be developed to represent each process, including all process-specific and safety-relevant information.

- This includes all itemised process steps/unit operations (activities) required to run the process, as well as the main flow lines.
- The designation of all fluids and solids entering or leaving the process.
- Material streams containing relevant process design data, such as pressure, temperature and mass flow. These may also contain mass or molecular concentrations, etc.
- Energy streams with relevant data.
- Information streams.
- Characteristic design values of unit operations, e.g. the number of required plates for a distillation unit, or the required convective heat flow (balance value) for process units such as heat exchangers and furnaces, in W, kW or MW.
- All required process controls, including protective devices relevant to running the process.
- Safety measure that are required from a process engineering viewpoint.
- Identification marking of emission sources.

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[8] Since the cost factors are based on apparatus/machines of realised plants experience of the relation of unit operation costs and apparatus/machines costs is required or first P&IDs with cost estimation of apparatus/machines have to be developed

5.3.3 Data models used in conceptual engineering.

The DEXPI process data model covers the full scope of process model content, as defined in Chapter 4.3.2. The process model standardises the interface between the simulation and engineering databases.

5.3.4 Stages reached in conceptual engineering (model levels)

The different statuses of the data model reached during planning are indicated by the data model revision number and diagram issue numbers. The related process flow diagrams are edited in various issues that reflect the different stages with consecutive issue numbers.

5.3.4.1 Data model level 2.1, PFD issue no. 1

This version of the data model typically represents the output of the simulation model in the CAE system, including stream information and unit operations (also referred to as 'activities') with their design parameters for conceptual engineering.

5.3.4.2 Data model level 2.2, PFD issue no. 2

This level of the process model (PFD) represent the outcome of the conceptual engineering process by describing the processes, unit operations, streams, and basic automation. This issue forms the basis for initial work on P&ID diagrams.

It includes all process steps with their identification markings and connections, partly with main control loops and possibly a general material balance. Within issue no. 2, the process undergoes technical development and improvement. The process flow diagram is supplemented with the automation and safety functions which are required from a process engineering viewpoint.

5.4 FEL3: Basic Engineering

5.4.1 Basic Engineering – Scope and Activities

The goal of basic engineering is to define the technical concept and all the boundary conditions regarding official approval, infrastructure, plant operation and plant and product logistics, in preparation for the detailed design. It also involves defining the time schedule and preparing a cost estimation of ±10%. The investment decision is typically made after basic engineering.

During this stage, the focus shifts from a process-based view (process steps/unit operations, streams) to a plant-based view. This involves considering apparatus and machines, piping and the detailed automation concept – in other words, the specification of the physical assets that fulfil the functions defined by the process model. Engineering contractors are often involved in basic engineering, particularly in the oil and gas industry.

The following activities are carried out in basic engineering, generating the associated information:

- Expanding the project team and definition of the organisational procedures (update project execution plan).

- First plant model (first version of P&ID) based on process description and process diagrams with apparatuses/machines, piping and instrumentation.
- Final process data sheets and technical specifications for apparatus and machinery.
- Definition of package units for example for infrastructure (chillers) or subsea equipment.
- Basic design of piping and piping specifications (valves, flanges, gaskets).
- Defining measurements, instruments automation concepts, interlocks and PLC/DCS concept.
- Electrical consumer list / emergency power list, power supply concept.
- 3D model with main piping lines inside and outside the plant, media list, pipe classes and valve selection list, piping lines list.
- Site plan with pipe rack concept and piping connections, connection to the infrastructure and roads and underground piping.
- Building layout, preliminary static calculation for process plants, warehouses, tank farms, plant buildings, control room, electrical supply, offices and social rooms and laboratory, concept for technical building services (HVAC) and active and passive fire protection
- Process safety concept (Hazard and operability study, HAZOP).
- Preparation of environmental protection and safety, operations, maintenance and logistic concept.
- Preparation of approval documents, permitting engineering.
- Update project execution plan for Detail Engineering, Procurement, construction and Start-up concept.
- Obtain quotations for the main equipment and Obtain quotations for design work and/or EPCM services.
- Cost estimation +/-10% based on material take-off in all disciplines and quotes for most expensive objects.
- Project documentation, basic engineering package.

5.4.2 Plant Model Content (P&I diagram)

The focus of basic engineering is to provide a complete representation of the plant structure and tags shown in the P&I diagram. This supports the management of interactions between the disciplines. By the end of the basic planning stage, the Level 3 data model, and accordingly issue 3 of the P&ID, should contain the following information:

5.4.2.1 Apparatus/Machines:

- All itemised apparatus and machines, including driving motors and installed backup equipment including their design temperature and pressure.
- All nozzles and manholes on itemised tags and identification markings.
- Type of insulation, including sound insulation.
- Characteristic data for apparatus and machines (except for drive motors).
- Special requirements placed on the plant structure (e. g. outgoing lines in a downward direction, minimum distances).

- Limits for the explosion zone classification of product rooms.

5.4.2.2 Piping

- Identification markings for piping lines and pipe classes.
- Identification marking of valves and representation of valves.
- Nominal diameters of valves that differ from nominal pipe diameters.
- Identifiers of non-standard parts.
- Slope and direction of piping.
- Type of insulation and coating system, if different from the standard defined for the selected pipe class.
- Dimensions required from a process engineering viewpoint
- Length of Spillways and immersion depth, including all necessary dimensions of related process apparatus and machines. Vent holes that are submerged inside process specified equipment.
- Design temperatures and pressures (on piping) if they deviate from standard levels.
- Represent intersecting piping lines with broken lines at the intersection point.
- Safety fittings/valves.
- Normal position of valves (normally open or normally closed) if this information contributes to the understanding of the valve's operational function
- Locked position of valves.

5.4.2.3 Electrical & Instrumentation

- Representation of E&I devices, including protective devices.
- Single line diagrams.
- Supply limits (e.g. for E&I and piping components provided by equipment and machine suppliers).
- Transitions from existing to new plant assets.
- Identification marking of flow-through type E&I components with a sealing function (optional for open/close valves).
- The normal position of valves (normally open or normally closed) provided this information contributes to understanding the operational function of the valve.
- Position of the actuators in the event of an auxiliary power failure.

5.4.3 Data Models used in Basic Engineering

The DEXPI plant model is used to represent the plant topology (P&ID).

In Basic Engineering, the assets are specified in detail to ensure the functionality of the plant objects and to define their dimensions, layout and initial 3D model. The data models for assets, classes and attributes are provided by the CFIHOS/JIP36 standard or alternatively ECLASS.

Once the plant has been defined in the structural model (P&ID), its dimensions and the spatial arrangement of the specified equipment are defined. A two-dimensional plant layout is usually developed to define the base area of the plant and the location of the units. To define the three-dimensional arrangement of the plant objects, a 3D model is developed.

To avoid redundant data handling and ambiguity, the functional plant structure of the plant model (P&ID) should be used for the 3D model. In addition to the plant model, the 3D model contains the geometric information of the plant model.

To standardise the requirements for 3D models and ensure interoperability, USPI has developed the FL3DMS standard [8, 9].

Based on the P&IDs and 3D model we need to produce a cost estimate according to ISO 19008 and a carbon footprint.

5.4.4 Stages in Basic Engineering – Model Levels

The information contained in the plant model and P&ID diagrams will gradually evolve and mature as project engineering activities continue.

Responsibilities for preparing and distributing information and documents within the project team, to customers and to the site are to be defined at the kick-off meeting.

The project manager (PM) will prepare a detailed time schedule considering the times required for design, procurement, construction and installation, start-up, official approval, provision of raw and auxiliary materials, and shutdowns for tie-in work.

5.4.4.1 Data model level 3.1, P&ID Issue no. 3.1:

The project manager/project engineer (PM/PE) will draft **the data model/P&ID diagram,** data model level 2, **based on the process model** (process flow diagram), layout plans, and existing technical specifications, manufacturers' documentation and electrical and instrumentation lists.

5.4.4.2 Data model level 3.2, P&ID Issue no. 3.2:

Feedback on the specifications for apparatus and machines, as well as feedback from vendors is introduced in the plant model.

The next step is to consider the requirements for tightness, media compatibility, and process technology specifications in the piping design, when preparing the pipe classes and valve selection and specifying the piping lines, including the nominal diameter, pipe class (nominal pressure, material, and sealing strip), fluid conveyed, upper and lower levels of design pressure and temperature This involves assigning a pipe number and identification marking to the valves, selecting the insulation types and thicknesses, and specifying the heating systems.

All E&I functions should be entered (e.g. indicating and recording instruments, alarms, switches, interlocks and controls). Commissioning and start-up requirements should also be considered (e.g. normal start-up, rinsing/pickling).

The result of this phase is P&ID issue 3.2 and tag specifications.

5.4.4.3 Data model level 3.3 and P&ID Issue no. 3.3 and PFD issue no. 3.

Plant safety concepts (HAZOP) are defined at this stage. This procedure is based on the plant model/P&ID and requires data from the process model (mass flow, temperature, pressure etc.). The plant model/P&ID is updated based on the mitigation measures decided upon for the safety risks. Feedback is received from discussions on the design of apparatus/machines, the numbering of E&I functions, the process engineering numbering of safety valves and explosion zone limits in the product room, the identification marking of protective E&I functions and the entry of the identifier of the associated unit.

All subsequent engineering-related additions based on the specifications should be included in Issue No. 3 of the plant model/P&ID diagram.

The process model, issue no. 3 of the PFD, should be updated if relevant changes to the process are defined in the basic engineering specifications. The release of issue No. 3.3 of the plant model (P&ID) together with the cost estimate (+/-10%) marks approval for detailed engineering and construction.

5.5 Detail Engineering

5.5.1 Scope, Activities and Content of Detail Engineering

The goal of detailed engineering is to specify the objects of a plant in such detail that they can be manufactured, procured, installed, and commissioned enabling the plant to be operated safely, produce the desired quantity and quality, and remain within the project budget. Detailed design is mainly characterised by the further specification of plant objects. The objective is to obtain the technical specifications needed to place orders and assign construction and installation work. In addition to good engineering practice, requirements relating to operation, maintenance, spare parts management, life cycle costs and operational experience must be considered.

Depending on the execution concept, external design companies should be assigned early so that they can start planning on time. If EPCM contractors are used, the mobilisation time for EPCM personnel and the transfer times for the project team should be factored in.

The main activities during the detailed design and the associated key documents include the following:

- Using a 3D model as a central planning tool for all disciplines.
- Updating P&I diagrams based on vendor feedback.
- Final technical specifications and manufacturer drawings for apparatus and machinery.
- Final technical specifications for package units.
- Piping list, Valve list.
- Stress calculation of piping lines.
- Isometric and support drawings.
- Technical specifications for safety valves and special parts.
- Instrument list.
- Technical specifications for instrumentation objects.
- Logic diagrams.
- Electrical consumer list.
- Technical specifications for electrical devices.

- Layout plans.
- Site plan.
- Construction drawings (substructure, foundations, steel construction, architecture, building services, etc.).
- Operation manuals, operating instructions and training plans.
- Maintenance concept and spare parts.
- Project controlling and change management.
- Schedule and progress control.
- Order execution and contractor assignment.
- Authority engineering.
- Installation concepts/studies.
- Construction site and contractor management.
- Start-up and commissioning concepts.
- Preparation of plant documentation.
- Procurement.

5.5.2 Information Models used in Detail Engineering

The CFIHOS data model can be used for detailed engineering and handover to contractors.

CFIHOS/JIP36 is an asset model that allows the exchange of data associated with tags and equipment classes. To cover the full set of information, the plant model (which defines tag interactions) and the tag model (which defines the tag data) shall be used in combination. Tag classes have been aligned between CFIHOS and DEXPI.

The most important tool for interaction between disciplines in detail engineering is the 3D model standard (FL3DMS) [7].

5.5.3 Stages in Detail Engineering – Model Levels

The data model is further detailed in the detail engineering process. This stage involves Vendors, engineering companies, and construction companies. Throughout the planning process, it is crucial that the technical information remains consistent. In this respect, the plant model level 3.3, and consequently the representation of the model in the P&I diagrams and the 3D model, are of key importance.

The entire scope of the project's process technology must be fully represented in P&I diagrams (process plant, energy supply and external piping). As planning progresses, these are successively modified to reflect changes in status (e.g. the inclusion of manufacturer's information). The interfaces and boundary limits of the site should also be considered in the plant model.

- Process model/flowcharts are revised based on P&IDs released for installation if required. They shall be provided to the PO for start-up.
- The entire project scope should be visible in the 3D model.

- All disciplines map their current planning status onto the model and continue to develop it. The model should be checked regularly by all disciplines. Official review meetings are held with the PO, PM, all disciplines, the installation manager and representatives from the plant at specific milestones (usually at planning statuses of 30%, 60% and 90% model review). Aspects of occupational safety, operability and maintenance must be considered. Ventilation ducts, cable trays, firefighting equipment and all other installations may also be shown in the 3D model. All statutory and local regulations shall be followed, including requirements for escape routes and tank farm regulations.

5.5.3.1 Plant model: Level 4.1/P&ID, Issue no. 4.1; 3D model: Level 4.1 (30%)

The 30% planning stage is reached when all layout-relevant aspects are finalised, and, regarding the processing plant, when the building structure, all critical apparatus and machinery and piping lines are implemented. After the 30% model has been discussed, CSA Engineering will prepare the main static calculations and the piling and foundation drawings.

5.5.3.2 Plant model level 4.2/P&ID Issue no. 4.2: 3D Model 4.2 (60%)

Feedback received from the discussion of technical specifications, interaction with utilities and product supply / disposal at the battery limits; connections for steam, rinsing liquid, purge gas, seal gas, and other utilities for small consumers, (Bubbling-through measurement devices, analysers, building services equipment, mechanical seals, utility stations) in the utility flow diagram; entry of the insulation thickness from the list of piping lines; designation of nonstandard piping components; designation of all flow diagrams in the address boxes.

At the 60% model review, all information from manufacturers about apparatus & machines should have been included in the model and large piping lines and all process piping lines should have been designed. Based on this, the CSA department can then carry out detailed planning for the steel construction.

5.5.3.3 Plant model level 4.3/P&ID issue no. 4.3; 3D model 4.3 (90%); PFD issue no. 4

Following the release of issue no. 4, the project team confirms that it has considered the feedback received from the safety issues discussion and/or the safety analysis and from work on the P&I diagrams:

Connection, review, and/or adoption of P&I diagrams prepared by outside contractors (analysis devices, compressors, pumps, agitators, etc.); check for compliance with the conditions requested by the supplier (layout, utilities, etc.); corrections resulting from the piping system network planning phase (e. g. disposal of sacks). This status should represent the as-build status at mechanical completion of the plant for commissioning.

Before the 90% model review, all piping lines and in-line instrumentation devices should be shown in the model. At this point, all relevant planning documents will be released for construction and installation. At the end of the 90% model review and when the comments have been implemented, the piping engineering department is able to prepare the isometric drawings for the piping and the support drawings. Before the isometric drawings are prepared, the stress calculations for the piping should be completed and documented.

Instrumentation specifies the instrument types that will be used in the project. Based on the requirements of the PR, the specifications and configuration for the process control system are prepared.

The electrical discipline is responsible for designing the electrical infrastructure and all electrical installations (e.g., communications systems).

Package units are complete functional units consisting of several components across several disciplines.

The specification should be manufacturer-neutral. Battery limit conditions for process and occupational safety, instrumentation, piping and CSA engineering, etc. should be defined and integrated into the general concepts of the plant (DCS, standard devices, plant philosophy, layout, etc.). Requirements for the official authority documentation and certificates should be considered as well (e.g., CE mark in the EU).

5.5.4 Procurement and Type/Physical Equipment Data

The project procurement team should be involved in ordering assets (in the broadest sense) and external services/companies.

Immediately after the detailed design has been approved, the sourcing strategy for the timely and cost-effective procurement of assets should be finalised. If a Project Procurement Manager (PPM) has been appointed for the project, he is responsible for coordinating the procurement activities.

Once the technical specifications have been defined (including requirements for documentation and testing), procurement activities can begin. Quotations should be compared from a commercial perspective and, from a technical perspective too. Based on the technical and commercial bid comparison, the buyer will decide on the winning vendor in consultation with others and prepare the purchase requisition.

During order processing, the requestor is responsible for:

- Clarification of technical issues.
- Vendor model and drawing control and release.
- Implementing supplier information into the plant model.
- Procurement of spare parts.
- Carrying out/arranging inspections at the manufacturer’s premises.

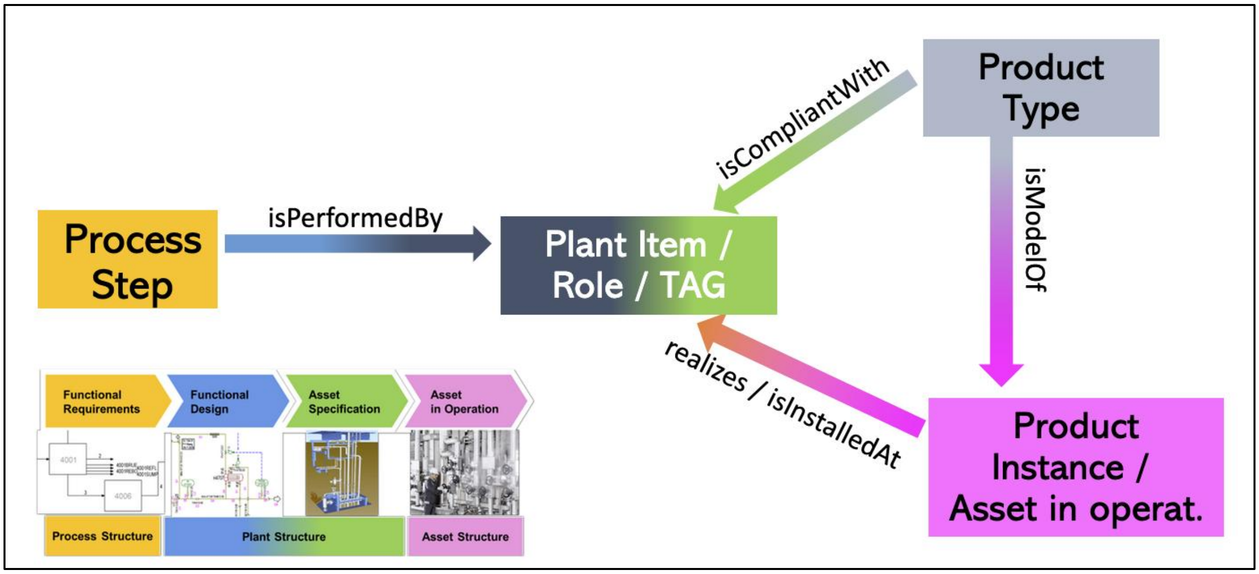

Figure 21. Procurement – Interaction between plant object specification, product/type, instance/asset in operation/equipment. Source: DEXPI.

During the procurement process, it is essential to distinguish between the specifications of the plant objects (tag), and the data of the product type and the data of the delivered equipment (assets in operation), as illustrated in Figure 21. During the procurement process, the specifications are handed over to the vendor, who then proposes products that fulfil the specifications. Alternatively, the buyer can select a product type from a catalogue, which is then configured according to the application´s specific needs by either the vendor or the user. This is a common practice for all disciplines but particularly for automation equipment.

Once a product has been selected in the RFQ process and is ready to be purchased, the delivery of the product must also be carried out via a digital information transaction. The vendor needs to provide the DPP data and minimum the DPP identifier link. The full DPP data set during the handover, the asset owner could be forced to download the DPP data after the delivery. DPP data must then be uploaded into the data model of the production facility.

5.6 Construction and Commissioning of the Plant.

5.6.1 Construction – Scope and Activities

The construction phase can be divided into the following activities: construction of temporary facilities; groundwork; erection of buildings; installation of apparatus & machines, piping and installation of E&I facilities. Construction will only be described here to the extent that it is relevant for information management.

To define the work packages the CII Advanced Work Packaging Information model should be used.

The entire construction site is organised, monitored and coordinated by the overall construction manager. The overall construction manager is responsible for the organisation of the entire construction site.

A construction manager is typically assigned to monitor all construction activities, including steel construction, fire protection, and technical building services (HVAC).

Qualified discipline supervisors may be assigned to monitor the installation of apparatus and machines, piping, insulation and E&I installations. They are responsible for monitoring the progress of installations in their area of expertise and ensuring that installation work is carried out professionally, including updating the plant model and documentation.

The overall construction manager, the CSA construction manager and the discipline supervisors coordinate construction and installation activities with contractors. They ensure that work is carried out in accordance with scope descriptions and technical documents. Any deviation from the detailed engineering design shall be fed back to the planning engineers, who will then update the plant model accordingly (P&ID, asset/tag specification, 3D models and physical equipment data).

5.6.2 Mechanical Completion, Safety-related Approval and Handover

While the construction and installation work is in progress, the overall construction manager and the discipline supervisor, supported by the discipline lead engineer, carry out inspections to ensure proper installation and functionality.

The mechanical completion milestone is reached when the entire project has been fully installed in accordance with the applicable plant model and technical documents, and when any remaining items have been documented in a punch list. Before mechanical completion, pressure and leak tests shall be carried out and documented on physical equipment and piping systems, and loop checks of control equipment and rotary directions of electric drives must have been carried out and documented where possible. Official acceptance inspections by the relevant authorities should also have been carried out if required.

As part of the mechanical completion and safety inspection of the plant, occupational safety aspects are also inspected, in addition to the completion of the project. The project manager (PM) then hands the project over to the person responsible for commissioning and start-up. This process shall be documented using a 'Plant Handover Report' form, for example.

5.6.3 Project Documentation at Mechanical Completion

The final plant model and updated detailed design documents are compiled in the project documentation. These documents describe the functions and technical facilities at the time of mechanical completion.

The data model will be updated to reflect any changes made during construction:

- Process Model/PFD.

- Plant model/P&ID.
- Plant object/tag specification/specification sheets.
- Assets in operation (physical equipment) data with DPP.
- 3D model.

This documentation will be handed over to the operator upon mechanical completion, so that it can be used as a basis for employee training and start-up preparation purposes.

5.6.4 Commissioning – scope and activities

Commissioning involves checking all process functions, typically first with the use of water. As part of start-up production tests, performance tests and emission measurements are carried out, and technical changes are made according to the customer's specifications if necessary.

In a second step the plant is started up using raw material and the production rate is increased.

Typically, a 72h performance test is run to prove that the plant can produce at the design rate.

The successful completion of the agreed performance tests and handover to the operator by the commissioning representative should be documented.

Once commissioning is complete, the system is handed over to the operator and enters production mode. Responsibility for safety and the environment then transfers to the plant manager.

5.6.5 Data Model Level 5 (Commissioning, PFD/P&I Diagram/3D Model)

The data model (see Section 4.6) and associated documents must be updated to reflect changes to the plant (e.g. apparatus/machines, piping, automation and CSA, etc.) and the commissioning process to represent the 'as-built' situation.

With the release of issue no. 5 of the process model/PFD and issue no. 5 of the plant model/P&ID, the project team will confirm that the documentation reflects the 'as-built' situation. This status is then transferred to the CAE systems used for operations (e.g. the maintenance system).

Physical equipment will have a unique identifier, which, in most cases, will be at an individual level. The identifier on the product QR code or RFID/NFC tag can be scanned using a smart device to access the digital twin for approval / comments or other actions.

5.7 Operations

5.7.1 Scope and Activities

5.7.1.1 Normal Operations

The core production processes and activities are:

- Operations

- Production planning.
- Logistics (internal and external).
- Managing processes and process control.
- Process Safety.
- Quality management.
- HR management (onboarding, training).

- Integrity management of the assets and maintenance
  - Plant safety.
  - Reliability.
  - Optimum performance.
- Management of Change (MOC).

While integrity management and maintenance focusses on the plant assets, operation focusses on the supply chain (see Fig. 1).

All of these processes are managed using process or asset health data, which is measured and stored by sensors and the DCS (see Figure 1, 'Vertical Integration'). This data is linked to the tag of the measuring system to identify them. Additional data, such as 'plan data', is used during operations to operate the plant within the permitted range (see Figure 22). Examples of this data include the daily production rates, maximum and minimum values, and thresholds.

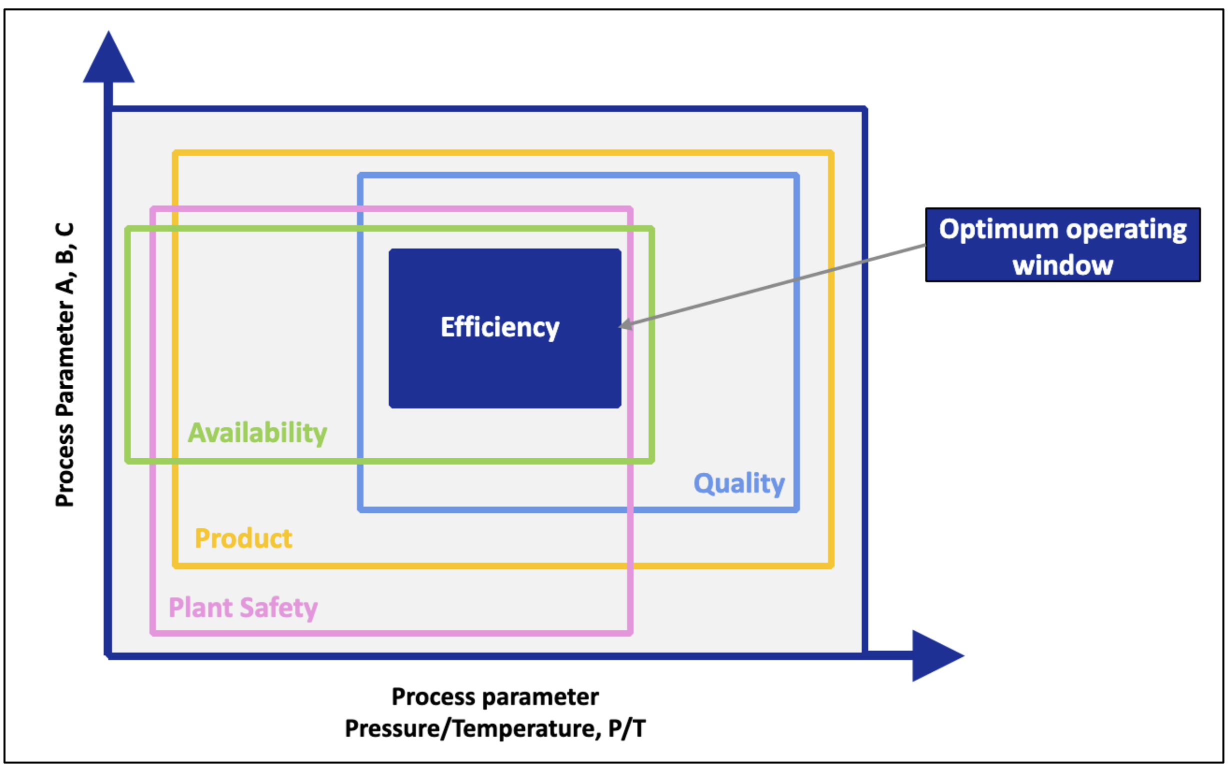

Figure 22. Integrity operating window of production. Source: DEXPI.

All operational data is linked to the plant objects (tags or functional locations); therefore, the asset information should not be stored in every operational subsystem but rather be linked to the integrated engineering database via the vendor-independent information model shown in the standard (see Figure 23). All operational processes rely on asset data; for example, mass balancing and achieving the production rate rely on the proper specification and maintenance of sensors in the field.

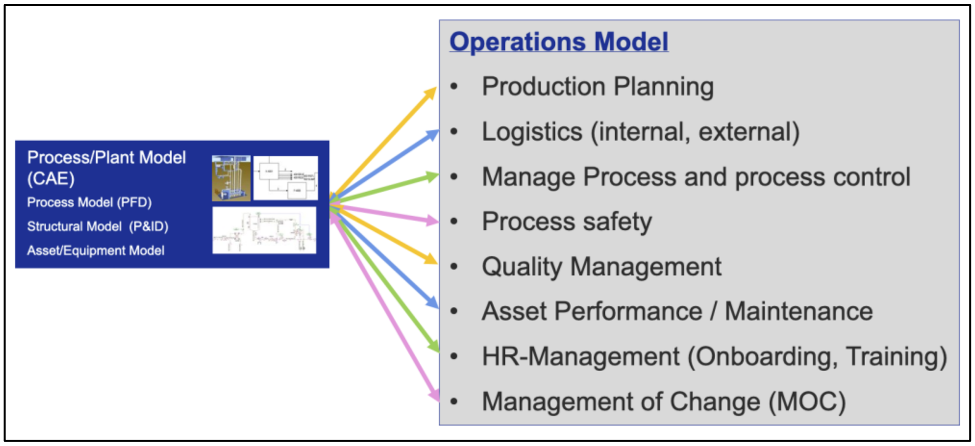

Figure 23. Interaction between asset information and operations information models. Source: DEXPI.

5.7.1.2 Integrity management and Maintenance

The purpose of maintenance is to ensure the availability of assets, or to repair physical equipment in the event of failure, restoring its functionality (as detailed in ISO 14224). Maintenance only deals with assets in operation (physical equipment) and their associated data. The asset specification does not change during the maintenance process. If equipment has been repaired or replaced, maintenance must ensure that the new equipment meets the existing asset specification. If the specification changes, an MOC (see 4.8.3) must be initiated.

Maintenance subprocesses are:

- Preventive and predictive maintenance.
- Corrective maintenance.
- Spare part management.
- Contractor management.
- Shutdown/turnaround management (maintenance and MOC).

During maintenance, it's important that the unique identifier of the equipment is updated if an equipment is replaced while for example the "old" equipment is send to the workshop for repair and then to storage or of it is not reparable, sending it to recycling.

5.7.1.3 Management of Change

If you wish to modify something in the plant, for example to optimise the process, you must follow a structured process similar to the engineering process.

- Modify the process model/PFD (if required).
- Run a HAZOP analysis if the change generates risks.
- Modify plant models, plant object specifications and discipline specifications.
- Modify or buy and install physical equipment.
- Commission and operate the physical equipment.

During these processes, the process model (PFD), plant model/specification (P&ID) and plant object specification will change. Any new equipment must fulfil these specifications.

5.7.2 Information Models used in Operation

In principle the complete documentation, data model and documents handed over to the operator upon mechanical completion, is required to operate the plant safely and efficiently, particularly

- Process Model/PFD.
- Plant model/P&ID.
- Asset specification/specification sheets.
- Assets in operation/equipment data.
- 3D model.

Practical experience reveals that operations struggle to use the engineering tools to keep the information models up to date, since CAE tools are not that simple to use. Therefore, information models are very often not maintained in operations, and operations fall back to a low level of digitalisation, dealing with drawings and Excel lists.

This results in the typical issues associated with low-level integrated information management:

- Master data are handled in different systems and do not match.
- No as-build documentation available.
- Errors due to inconsistent data or incorrect (handy) data transfer.
- …..

There are two ways to overcome this dilemma. The first solution is to simplify and configure your CAE tools in a way that the operation plant manager and plant engineers can use them. The other possibility is to establish a strong technical support team on site or in the region that operates close to operations and can handle the engineering CAE tools.

5.7.3 Data models used in operation processes

As mentioned above, operations focus on production, the supply chain, process safety and quality. Therefore, the major data model is the process model (PFD), which provides information on process conditions and limitations.

Integrity and maintenance are focus on the asset. Therefore, their major data model is the plant model (P&ID), which includes asset specifications and physical equipment data.

The most complex operational procedure is the management of change. In principle, the MOC covers all phases of an engineering process, albeit with limited scope: Idea generation (FEL1/feasibility study); process modification (FEL2/conceptual engineering); plant design (FEL3/basic engineering); construction and commissioning including risk evaluation and safety concepts. Even if an MOC usually has a limited scope the overall effort over the lifetime of a plant is huge. There the usage of the information model in operations would create a significant contribution to run operations more efficient and with higher quality.

6 Interaction of Disciplines

6.1 Process Engineering, Simulation

Process engineering (FEL2) usually starts with a static simulation of the process (see Chapter 5.1). Process engineering is the leading discipline in conceptual engineering. The DEXPI process model can be used to standardise the content of the process model (PFD) and the interfaces between the CAE process model and the simulation, since the DEXPI process also follows the CAPE-OPEN standard.

The simulation and process models should be updated in FEL3 and subsequent steps if relevant changes to the process are made.

In basic and detail engineering, CFD simulation is primarily employed to simulate fluid dynamics and scale up apparatus. To simulate the dynamic behaviour of the plant for process control design, 'dynamic models' are required. These models can also be used for 'virtual plant simulators' for operator training. Static and dynamic simulation models are used to optimise operations.

6.2 Apparatus and Machines

In the plant model, apparatus and machines should be represented. The DEXPI plant model provides more than 150 classes for the most common apparatus and machines, including their components in the 'package equipment'. These classes are aligned with the 167 CFIHOS tag classes within a shared taxonomy. However, DEXPI only provides a limited number of attributes. Only the information shown on the P&ID is included. CFIHOS provides a list of attributes, which are allocated to the classes. JIP33 provides specifications for procurement.

ECLAAS provides a full set of apparatus and machine classes, each with a complete set of attributes. However, these are not aligned with the ISO/DEXPI/CFIHOS classes. Therefore, there is no harmonized international standard available for the detailed specifications of apparatus and machines.

6.3 Piping

Models for piping plant objects/tags (e.g. valves, flanges and compensators) are defined in the DEXPI plant model 'Package Piping'. The 81 DEXPI classes are harmonised with the 97 tag piping classes of CFIHOS. There is a European standard for piping specification, EN 13480.

The American Society of Mechanical Engineers (ASME) piping standards, specifically the B31 series, provide guidelines for the design, materials, fabrication, assembly, erection, examination, inspection and testing of various types of piping systems. These standards are also used for international projects..

Detailed piping specifications are provided by Process Industry Practices (PIP).

6.4 Automation

6.4.1 Overview of Automation Engineering and Interfaces

To carry out the activities of the Process Control Technology (PCT) within the engineering process, information is exchanged with other disciplines. PCT comprises all technical systems required for the measurement, control, regulation and automation of a process plant, including sensors, actuators, control logic and related instrumentation. In Figure 24, yellow arrows represent information derived from the functional requirements of the process. Blue arrows represent information that comes from the plant design. Some information comes from both sources. For instance, the requirement to heat trace material flows originates from the functional requirements, whereas the length of the pipes is derived from the plant design model.

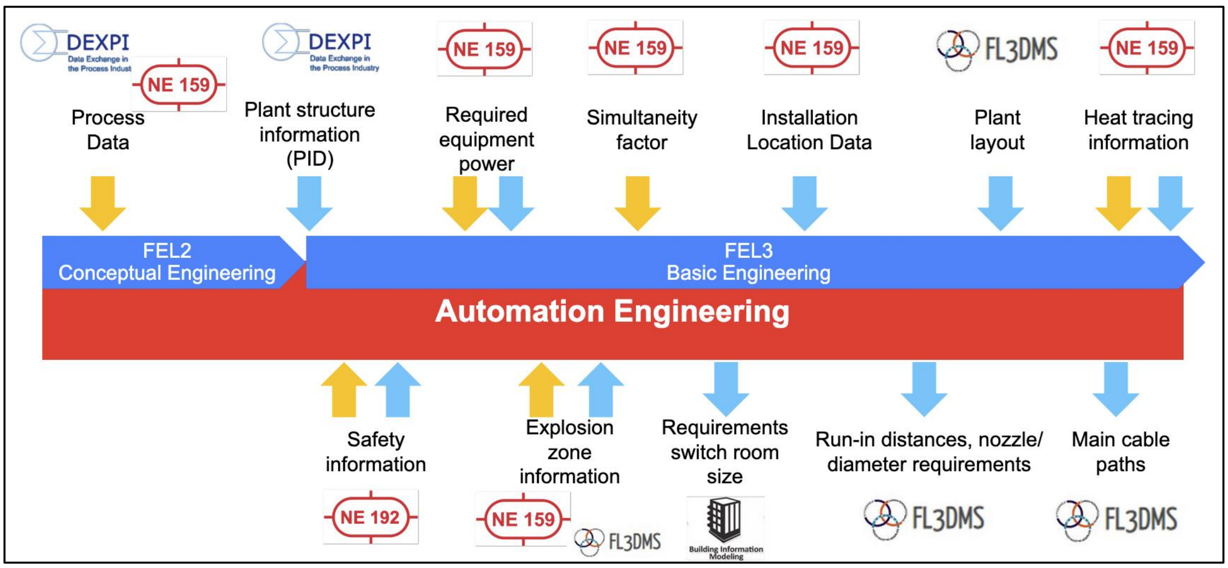

Figure 24. *Figure 23 shows the interfaces of automation engineering. Source: NAMUR.*

In addition to the organisations mentioned previously, the NAMUR association is working on the digitalisation of automation engineering and the integration of information models in cooperation with DEXPI, CFIHOS and USPI.

NAMUR is an international association of users of automation technology, focusing on the process industry. The integration of automation technology into the DEXPI standards was developed in collaboration with NAMUR [12]. A key document describing the planning of PCTs for automated plants in the process industry is the NAMUR Worksheet NA 35.

6.4.1.1 Process Control Technology in FEL1 to 3

During the initial project phases including basic engineering, the PCT focuses on concepts relating to power supply and automation, cost estimation, and the associated creation of quantity structures. Technical clarifications, such as the selection of measurement principles, are also carried out. The work in the individual phases is detailed as follows:

In the first phase (FEL1), the PCT's project goals are defined, interfaces with other departments are clarified, and the requirements and prerequisites are determined. The rough cost estimate is typically presented as a percentage of the project's total costs.

In the conceptual engineering phase (FEL2), the automation concept is developed, from which the initial requirements for the field and automation components can be derived. The same is done for the electrical energy supply. The cost estimate is refined. By the end of FEL2, the operational philosophy will have been defined, specifying the needs for control rooms and equipment rooms.

During the first two project phases, the effort required for the PCT is minimal. During basic engineering (FEL3), however, this increases. The necessary PCT functions (PCT tasks in accordance with IEC 62424 [11]) are inserted into the P&I diagram and provided with process data. Based on this, measurement principles are defined, and potential device manufacturers (for instrumentation devices, valves, electrical devices and control systems) are identified. To specify the automation system, requirement specifications are created alongside quantity structures. Similarly, specifications for assembly are drawn up, as well as strategies for procurement and execution. Furthermore, the PCT participates in safety discussions, prepares safety requirement specifications and specifies the electrical power supply. The automation domain integrates the main cable paths into the 3D model.

6.4.1.2 PCT in Detail Engineering

The results developed in Basic Engineering (FEL3) are specified in Detail Engineering and prepared for ordering and construction. As a rule, this process does not require any new information. Instead, existing information becomes more concrete.

- Assumptions made during basic engineering can be replaced with information from supplier documentation.
- The safety talks are finalised so that the requirements derived from them can be determined.
- The system model has been finalised, meaning the length of piping and cable tracks, and the installation locations (e.g. for field distributors) have also been finalised.

In addition, documents for installation and commissioning are prepared, including site and circuit diagrams, as well as specifications for tests prior to commissioning, such as explosion protection, functional safety and electrotechnical safety.

Traceability of changes and revision management are even more important than in basic engineering. Experience shows that changes that impact components to be ordered or even components that have been ordered, still occur late in the engineering process.

Information exchange for automation technology can be divided into two categories. Firstly, information models can serve as an interface to other trades [12], and secondly, they can enable the exchange of information within the PCT.

However, PCT engineering is also characterised using different systems and communication between various partners. Typically, hook-ups and various lists are first generated, and these are then often planned in detail by contractors.

Control loops are created from a list of measuring points with assigned typical hardware due to the hardware planning of field devices. This process also requires information about the location of infrastructure components, such as field distributors and remote I/O systems.

Information from the consumer list is then used to plan medium- and low-voltage switchgear.

The input/output (I/O) list forms the basis for control system planning.

6.4.2 Information Models for Automation Engineering

This document-based approach will be replaced by a model-based approach in the future, working in a similar way to the overall process. Several information models already exist that can simplify integrated engineering within the PLT:

NE 100 [15] has given rise to ECLASS [16] and IEC 61987 [17, 18]. These standards provide lists of properties that support order processing. These lists of properties also serve as International Registration Data Identifiers (IRDIs) in other information models, enabling the creation of machine-readable semantics.

NE 150 [19] can be used to model signals from PCE requests. This facilitates close collaboration between hardware planning, and control software creation. Additionally, NE 150 provides a description of a manufacturer-neutral, bidirectional interface between planning/CAE systems and automation systems, ensuring secure data exchange between systems throughout the life cycle and maintaining the digital twin's accuracy.

NAMUR Recommendation **NE 159** [13] describes an information model that can be used to transmit both process and installation location data. It is also possible to model design operating cases, i.e. process data under operating conditions relevant to device design.

NE 191 facilitates the depiction of the electrotechnical structure of a plant. This model shows which terminals on which devices, terminal blocks, cards or consumers are connected to each other via which cables and wires. The NE is thus analogous to DEXPI in the field of automation, however, there is no transport mechanism for the graphical representation included.

NE 192 contains an information model for functional safety. This information model is intended to transmit the information about PLT safety functions defined in the risk analysis (HAZOP, LOPA, ...) to the PLT. Not only does it represent the interface to the safety discussion but can also contain all the information required for preparing Safety Requirement Specifications and PFD calculations in the form of a model.

NE 193 is intended to create an information model for security engineering. This will integrate the topic of security more closely into the overarching engineering process. The retrospective consideration of security that has taken place so far is to be replaced by 'security by design' [20].

The Operating/Device List of Properties (OLOP/DLOP) concept is well accepted for interaction in detail engineering (see Figure 25).

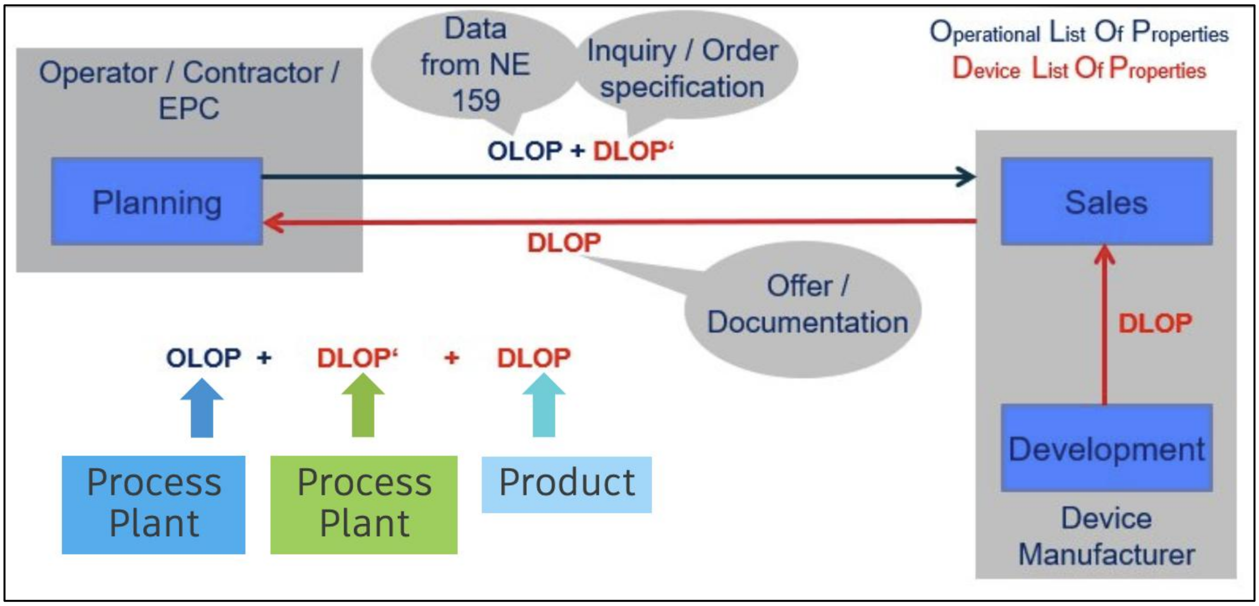

Figure 25. PCT Engineering OLOP and DLOP concept. Source: DEXPI.

During the instrumentation engineering, the engineer uses information from NE 159 to develop the OLOP for the instrument, adding non-functional requirements to the DLOP´, which is a DLOP in inquiry view. The instrumentation device vendor takes the information and looks for a matching device type, sending back the DLOP of the device type. Once the device has been ordered and produced, the vendor sends the DLOP of the device instance. The Asset Administration Shell can be used as a transport mechanism for OLOP and DLOP.

6.4.2.1 Representation of Automation Functions in Information Standards

To represent automation in front-end loading (FEL) 1–3, DEXPI has integrated the following automation functions:

- Process signal generation function (sensing).
- Actuation function.
- Process instrumentation functions.
- Loop function (control).

In the DEXPI process and plant model, automation technology is considered in accordance with the international IEC standards if it is depicted in the flow diagrams (see Figure 26).

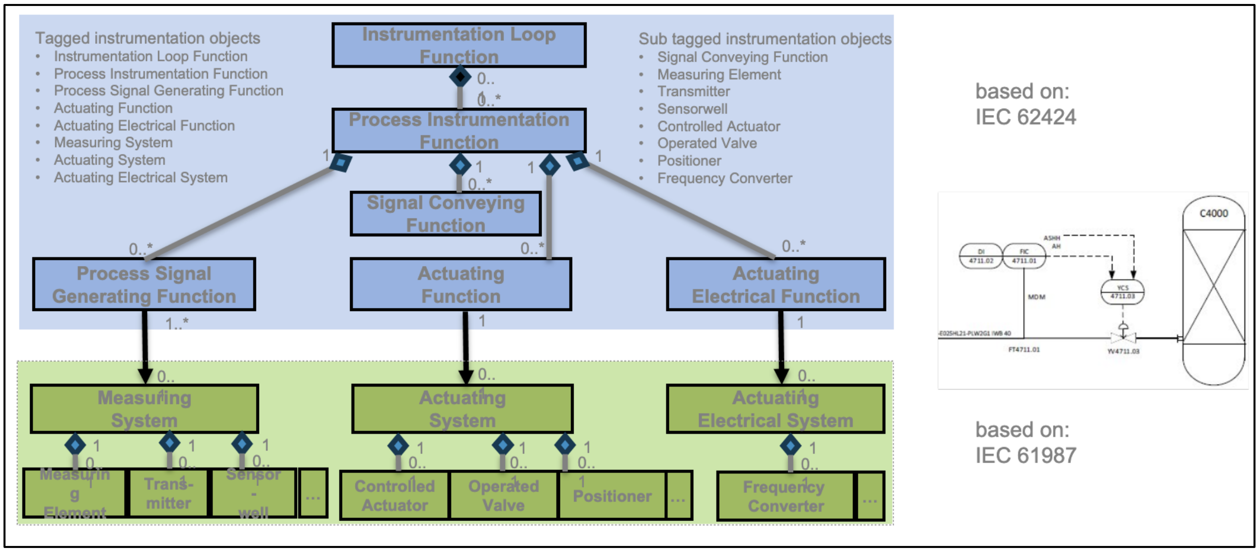

Figure 26. DEXPI automation and instrumentation model

The CFIHOS instrumentation model defines about 200 tag classes. These are physical artefacts that implement the Measuring, Actuating and Electrical Actuating systems. The IEC PAS 63131 introduces the system control diagram which defines the requirements to the control system.

Within the framework of modular plant construction, the Module Type Package, MTP, defines a standardised automation model for operating the plant. DEXPI 2.0 enable the semi-automated transfer of process and plant data into the MTP design. From a user's perspective, implementing a standardised HMI import function for conventional control systems would also be beneficial, as it would enable the use of the workflow there too.

6.5 Civil and Architecture (BIM)

The basis for executing a CSA project is defined in ISO 19650. The basics were presented in Chapter 1. However, the ISO standard does not define project phases in detail.

- Design
- Procurement
- Build
- Operate.

However, the information management process is described in detail in ISO 19650 Part 2, Section 4.1. Throughout the lifecycle of an asset, information flows continuously. The Common Data Environment (CDE) captures, controls, manages and shares this information, which is referred to as 'metadata' in ISO 19650, throughout the lifecycle. See Figure 2: 'Lifecycle information management via a Common Data Environment' – ISO 19650 Part 1.

The level of information needed refers to three main approaches that are not defined in the ISO 19650:

a. Level of geometry: The geometric precision of the elements represented – which parts of the element can be ignored or simplified and while keeping the element functional for BIM uses such as clash detection, an object can be represented as a line, a surface or a solid.
b. Level of information: The semantics to be attached to the object, including properties, material, etc.
c. Level of documentation: The kind of documentation to be associated with the object.

The level of detail can be matched to the phases of a process/plant project (see Table 3).

BIM uses the Industry Foundation Classes (IFC) standard as the information model. IFC is a computer-aided design (CAD) data exchange scheme intended for the description of architectural and construction industry data. It is a platform-neutral, open data schema specification that is not controlled by a single vendor or group of vendors. The object-based data schema was developed by buildingSMART (formerly the International Alliance for Interoperability, IAI) to facilitate interoperability in the architecture, engineering, and construction (AEC) industries. It is also a commonly used collaboration format in building information modelling (BIM)-based projects. The IFC model specification is open and available. It is registered with ISO as an official international standard (ISO 16739-1:2024).

IFC files contain information about a building's geometry, physical properties, materials, spatial relationships and other attributes. Object classes are CSA-oriented. They are designed to support interoperability among different software tools, enabling project stakeholders to share and utilise data across various platforms and applications. So far there is no alignment between the classes and properties of IFC and those of process industry standards such as ISO 15926, CFIHOS and DEXPI. This work needs to be done in future.

7 List of Abbreviations

Abbreviation	Meaning
2D	Two-Dimensional
3D	Three-Dimensional
AIR	Asset Information Requirements
API	Application Programming Interface
BFD	Block Flow Diagram
BIM	Building Information Modelling
CAE	Computer-Aided Engineering
CAPEX	Capital Expenditure
CFIHOS	Capital Facilities Information Handover Specification
CSA	Civil, Structural and Architectural
DCS	Distributed Control System
DEXPI	Data Exchange in the Process Industry
DMS	Document Management System
DPP	Digital Product Passport (Digital Nameplate)
DTDL	Digital Twin Definition Language
E&I	Electrical and Instrumentation
EIR	Exchange Information Requirements
EPC	Engineering, Procurement and Construction
EPCM	Engineering, Procurement, Construction Management
ERP	Enterprise Resource Planning
ESPR	EU regulations according to Ecodesign for Sustainable Products Regulation
FBS	Functional Breakdown Structure
FEL	Front-End Loading
FL3DMS	Facility Lifecycle 3D Model Standard
FMEA	Failure Modes and Effects Analysis
GMP	Good Manufacturing Practice
HAZIP	Hazard Identification Process
HAZOP	Hazard and Operability Study

HMI	Human-Machine Interface
HVAC	Heating, Ventilation and Air Conditioning
IDO	Industrial Dato Ontology
IDTA	Industrial Digital Twin Association
IEC	International Electrotechnical Commission
IOGP	International Association of Oil & Gas Producers
ISO	International Organisation for Standardisation
IT	Information Technology
JIP	Joint Industry Project
KPI	Key Performance Indicator
LOIN	Level of Information Need
MOC	Management of Change
MSR	Mess-, Steuer- und Regelungstechnik (see PCT)
OIR	Organisational Information Requirements
OPEX	Operational Expenditure
OPC UA	Open Platform Communications Unified Architecture
OWL	Ontology Web Language
P&ID	Piping and Instrumentation Diagram
PAS	Publicly Available Specification
PCT	Process Control Technology
PEP	Project Execution Plan
PIR	Project Information Requirements
PFD	Process Flow Diagram
PLC	Programmable Logic Controller
RDL	Reference Data Library
RDF	Resource Description Framework
SIL	Safety Integrity Level
SME	Subject Matter Expert
URS	User Requirements Specification
USPI	Unified Standardisation of Plant Information
XML	Extensible Markup Language

8 Glossary of Terms

Term	Definition
Asset Lifecycle (ALC)	Entire lifespan of a plant asset, from planning and design through construction, operation, maintenance and eventual decommissioning.
BIM (Building Information Modelling)	Digital representation of the physical and functional characteristics of a facility, typically applied to civil, structural and architectural disciplines.
Block Flow Diagram (BFD)	Simple diagram that shows the general process flow and process steps.
CAE (Computer-Aided Engineering)	Use of computer software to aid in engineering analysis tasks, including simulation, validation, and optimisation of products and processes.
CFIHOS (Capital Facilities Information Handover Specification)	Industry initiative aimed at standardising asset information exchange across lifecycle stages and stakeholders.
DEXPI (Data Exchange in the Process Industry)	consortium and standardisation initiative developing data models for the exchange of engineering data in process industry applications.
Digital Twin	Virtual representation of a process or facility that includes simulation models, engineering models, and operational data.
ECLASS	Standardised reference data system used for classification and description of products and services across industries.
Engineering Phase FEL1 to Execution	Phased approach to front-end engineering design: FEL1 – Study, FEL2 – Conceptual design, FEL3 – Basic design, Execution.
Equipment	<chemical and petrochemical industry> single part of a plant (general term) Source: ISO 10209 Note 1: used for planned, specified, ordered, bought and installed objects; this definition is used in this document Note 2: DEXPI Plant uses Equipment only for planned or specified apparatuses or machines, in this document referred as part of 'specified equipment' Note 3: CFIHOS uses Equipment only for all objects of a physical facility, in this document referred as 'physical equipment' Note 4: SAP/PM uses Equipment like CFIHOS: Equipment is an individual, physical object that is maintained as an autonomous unit and tracked over its lifecycle — typically a machine, motor, pump, vehicle, tool, or instrument.

Specified **Equipment**	A specified equipment is an equipment and a specified object
Physical **Equipment**	Used for planned, specified, ordered, bought and installed objects used to perform a functional requirement that forms part of an industrial facility or process plant; synonym 'asset in operation' Note: CFIHOS and ERP systems use the term 'equipment' in this sense
FL3DMS (Facility Lifecycle 3D Model Standard)	Standard for structuring, delivering and managing 3D models across the facility lifecycle.
HAZOP (Hazard and Operability Study)	structured and systematic technique for identifying potential hazards and operational issues in engineering systems.
IEC 61987 / IEC 61360 / IEC 62424	International standards for instrumentation, asset specification and communication data structures.
Information Model	Structured representation of objects, their properties, and their interrelationships to support engineering and operations across the asset lifecycle.
Integrated Engineering	Engineering based on an information model and data base covering the engineering steps from conceptual engineering to detail engineering and the process relevant disciplines process development, apparatus/machines, piping and automation
ISO 15926	Standard for data integration, sharing and handover between computer systems in the process industry.
ISO 19650	Standard for organising and managing information using BIM, particularly during the lifecycle of a built asset.
LOIN (Level of Information Need)	Specifies the required content, level of detail and reliability of data at specific project stages.
MTP (Module Type Package)	Concept for modular automation and standardised integration of modules into process automation systems.
PCT (Process Control Technology)	Encompasses all systems for measuring, controlling, regulating and automating process plants.
PEP (Project Execution Plan)	Central planning document that defines how a capital project will be delivered. It outlines project objectives, roles and responsibilities, schedules, milestones, risk management, communication strategies, and how information will be managed throughout the lifecycle. The PEP also specifies the modelling scope, required Level of Information (LOI), and coordination between stakeholders.
PFD (Process Flow Diagram)	Diagram showing the unit operations and process streams and basic automation function in a process

P&ID (Piping and Instrumentation Diagram)	Detailed diagram showing all piping, instrumentation, and control devices of a process system.
RDL (Reference Data Library)	Structured library of standardised data classes and properties used in information modelling, such as in CFIHOS and ISO 15926.
Simulation Model	Model representing physical and chemical behaviours of processes, often used for design, control, and optimisation.
Tag	Specified object with a unique identifier assigned to object within an engineering model or plant or facility capturing the design requirements Note: In ERP-Systems the term 'functional location' is used
Type	A type object is out of catalogue of types. It represents one object class with a set of parameters that is typical for that class. This set of parameters is preliminary and needs to be confirmed when the actual product is produced and installed. The type is selected based on the assumption that most of the type parameters will not change.
3D Model	Digital three-dimensional representation of plant components used for visualisation, clash detection and asset management.
Process	<process plants and industry> sequence of chemical, physical or biological operations for the conversion, transport or storage of material or energy Source: ISO 10209
Process step	part of a process which is predominantly self-sufficient and consists of one or several unit operations Source: ISO 10209
Unit operation	simplest operation in a process according to the theory of process technology Source: ISO 10209
Facility	A <FACILITY> is a <FunctionalObject> that is capable of <PERFORMING> one or more specific activities or functions, and that usually is a commercial or industrial property Source: ISO 15926 part 4 Note: superclass for Plant and Process Plant
Plant	complete set of technical equipment and facilities for solving a defined technical task Source: ISO 10209

Process Plant	facilities and structures necessary for performing a process Source: ISO 10209
Plant section	part of a process plant that can, at least occasionally, be operated independently Source: ISO 10209 Note: often Process unit is uses as a synonym in the process industry
Component	constituent part of equipment that cannot be physically divided into smaller parts without losing its character Source: ISO 10209
Asset	An <ASSET> is an <PhysicalObject> that is a resource with economic value that an individual, corporation, or country owns or controls with the expectation that it will provide a future benefit. Source: ISO 15926 part 4
Object	<industrial systems> entity treated in a process of development, implementation, usage and disposal Source: ISO 10209 Note: The object may refer to a physical or non-physical thing that possibly exists or not exist.

9 Standards: Referenced Codes and Standards

ISO 5457: Technical product documentation - Sizes and layout of drawing sheets

ISO 7200: Technical product documentation - Data fields in title blocks and document headers

ISO 10209, Technical product documentation — Vocabulary — Terms relating to technical drawings, product definition and related documentation ISO 10303: 'Industrial automation systems and integration - Product data representation and exchange,' it is a standard for the computer-interpretable representation and exchange of industrial product data. The objective is to provide a mechanism capable of describing product data throughout the life cycle of a product, independent of any system. It is also known as STEP or the 'Standard for the Exchange of Product model data.'

ISO 10628: Flow diagrams for process plants - General rules

EN 13480: European standard EN13480 piping

IEC 61360-7: Standard data element types with associated classification scheme - Part 7: Data dictionary of cross-domain concepts (IEC 61360-7:2024)

IEC 63365:2022
Industrial process measurement, control and automation - Digital nameplate

ISO 14224: Maintenance

ISO/IEC/IEEL 15288: Systems and Software Engineering – System Life Cycle Processes

ISO 15926: It is titled: 'Industrial automation systems and integration. Integration of lifecycle data for process plants including oil and gas production facilities.' The purpose of ISO 15926 is to facilitate the integration of data to support production facilities' lifecycle activities and processes. Elements it provides that are relevant for FL3DMS include a conceptual data model for computer representation of technical information about process plants and a Reference Data Library (RDL).

ISO 16016: Technical product documentation - Protection notices for restricting the use of documents and products.

ISO 16739: Industry Foundation Classes - It specifies a conceptual data schema and an exchange file format for Building Information Model (BIM) data. The conceptual schema is defined in EXPRESS data specification language or XML Schema definition language (XSD). Alternative exchange file formats may be used if they conform to the data schemas. It is a platform-neutral, open file format specification that is not controlled by a single vendor or group of vendors.

ISO 19008: Standard cost coding system for oil and gas production and processing facilities

ISO 19650: 'Organisation and digitisation of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling.' The purpose of ISO 19650 is to provide recommendations for a framework to manage information, including exchanging, recording, versioning, and organizing for all actors. An interesting aspect of ISO 19650 is that it includes a lifecycle perspective regarding the detail, granularity, content, and structure of the engineering and design data, including 3D models.

Part 1 provides definitions and principles of information management. Part 2 deals with specific information management related to buildings.

ISO/IEC/IEEE 29148: Requirements engineering

IEC 61987 - IEC/SC 65E - Industrial-process measurement and control - Data structures and elements in process equipment catalogues,

IEC 62424: Representation of process control engineering – Requests in P&I diagrams and data exchange between P&ID tools and PCE-CAE tools

IEC 61360-4 - IEC/SC 3D - Standard data element types with associated classification scheme for electric components - Part 4: IEC reference collection of standard data element types and component classes: 2005,; Common Data Dictionary (CDD - V2.0018.0002) https://cdd.iec.ch/cdd

ASME B31: piping standard
Process industry practices: https://pip.org/practices-new/
ECLASS, https://www.eclass-cdp.com/portal/info.seam,

NA 35: NAMUR Worksheet 35: Engineering and execution of PCT projects in process

NE 100: NAMUR Recommendation 100: Lists of Properties and their Use in Process Control Engineering Workflows

NE 159: NAMUR Recommendation 159: Standardised NAMUR interface for data exchange between CAE systems for Process Design and CAE systems for PCT Hardware

NE 191: NAMUR Recommendation NE 191: Information model for the representation of connected PCT components to standardise the exchange of data throughout the plant life cycle, Edition 2024.

NE 192: NAMUR Recommendation NE 192: Functional Safety Information Model, Edition 2025.

NE 193: NAMUR Recommendation NE 192: An Information Model for Automation Security Engineering; VDI/VDE/NAMUR 2658 1-6 Automation engineering of modular systems in the process industry

NIST.IR.8107: National Institute of Standards and Technology (US)
Current Standards Landscape for Smart Manufacturing Systems
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