



## Validation over digital twinning

Deliverable No: D6.2

Work package: WP6

Official delivery date: 30.06.2026

Actual delivery date: 01.07.2026 (v1), 14.10.2026 (v2)

Dissemination level: Public



Co-funded by  
the European Union

Project: 101136119 | HORIZON-CL5-2023-D3-01 | [www.twineu.net](http://www.twineu.net)

## Disclaimer

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them.

| Document Authors                       |                                |
|----------------------------------------|--------------------------------|
| Daniele Porcu (ENEL)                   | Francesco Messano (Terna)      |
| Maria Serena Teramo (Terna)            | Micaela Tigre (Terna)          |
| Marco Proietto (ENEL)                  | Marco Sportillo (ENEL)         |
| Gian Lorenzo Giuliattini Burbui (ENEL) | Benedetto Giuseppe Risi (ENEL) |
| Benedetta Serangeli (EDI)              | Ewelina Adamczyk (EDI)         |

| Version | Date       | Author(s) | Notes                                           |
|---------|------------|-----------|-------------------------------------------------|
| 0.1     | 01/03/2025 | D. Porcu  | first draft                                     |
| 0.2     | 30/06/2025 | (all)     | interim draft                                   |
| 0.3     | 01/03/2026 | (all)     | 3 <sup>rd</sup> internal draft                  |
| 0.4     | 08/05/2026 | (all)     | Version clean for review                        |
| 0.5     | 22/06/2026 | D. Porcu  | First review addressed                          |
| 0.6     |            | D. Porcu  | Improved image quality, second review addressed |
| 1.0     | 01/07/2026 | D. Porcu  | First submission                                |
| 1.1     | 23/09/2026 | D. Porcu  | Addressing peer review comments                 |
| 2.0     | 14/10/2026 | D. Porcu  | Final version                                   |

|                                            |                                                                           |
|--------------------------------------------|---------------------------------------------------------------------------|
| <b>Responsible Partner</b>                 | ENEL                                                                      |
| <b>Checked by WP leader</b>                | Daniele Porcu (ENEL), 30/06/2026 (v1),<br>14/10/2026 (v2)                 |
| <b>Verified by the appointed Reviewers</b> | May Myat Thwe (TU Delft), 18/05/2026<br>Lucas Saludjian (RTE), 29/06/2026 |
| <b>Approved by Project Coordinator</b>     | Padraic McKeever (Fraunhofer), 01/07/2026 (v1),<br>14/10/2026 (v2)        |

# Table of Contents

|                                                                 |    |
|-----------------------------------------------------------------|----|
| Executive Summary .....                                         | 6  |
| 1 Introduction .....                                            | 7  |
| 1.1 Task 6.2 .....                                              | 8  |
| 1.2 Objectives of the Work Reported in this Deliverable .....   | 9  |
| 1.3 Outline of the Deliverable .....                            | 9  |
| 2 BIM methodology in energy grids .....                         | 10 |
| 2.1 Designing a TSO and DSO transforming station .....          | 11 |
| 2.2 The Design Validation Use Case .....                        | 12 |
| 3 Methodology and implementation pathway.....                   | 14 |
| 3.1 Proposed solution.....                                      | 14 |
| 3.1.1 Data Dictionary.....                                      | 15 |
| 3.1.2 Rules engine .....                                        | 15 |
| 3.1.3 Validation tool .....                                     | 16 |
| 3.2 TSO Implementation.....                                     | 17 |
| 3.3 DSO Implementation .....                                    | 19 |
| 3.4 Reference KPIs and validation .....                         | 20 |
| 3.4.1 KPI assessment methodology adopted in the TSO pilot ..... | 21 |
| 4 Pilots results and scalability.....                           | 24 |
| 4.1 TSO results.....                                            | 24 |
| 4.1.1 Example - TSO results.....                                | 25 |
| 4.2 TSO Scalability assessment.....                             | 28 |
| 4.3 DSO results .....                                           | 30 |
| 4.3.1 Example - DSO results .....                               | 31 |
| 4.4 DSO Scalability assessment .....                            | 34 |
| 4.5 Transversal Results: Immersive Reality Integration .....    | 35 |
| 5 Conclusions.....                                              | 37 |
| References .....                                                | 39 |

## List of Figures

|                                                                                                                                 |    |
|---------------------------------------------------------------------------------------------------------------------------------|----|
| Figure 1: Building blocks and formats.....                                                                                      | 14 |
| Figure 2: Example of rule described into a snippet of ids file (machine-readable representation) .....                          | 16 |
| Figure 3: Example of rule defined through platform-native configuration (user-oriented representation of validation logic)..... | 16 |
| Figure 4: Example of report of validation via IfcOpenShell with Blender and Bonsai plugin .....                                 | 17 |
| Figure 5: High-level validation workflow within the TSO validation process .....                                                | 18 |
| Figure 6: Validation maturity assessment based on rule readiness, model readiness and validation performance. ....              | 23 |
| Figure 7: Synthesis of key achievements, KPI highlights and insights derived from the validation pilot. ....                    | 23 |
| Figure 8: Example of Product Breakdown Structure adopted in the TSO pilot .....                                                 | 25 |
| Figure 9: Structure of property sets adopted in the TSO pilot to support validation activities .....                            | 26 |
| Figure 10: Examples of validation rule families identified and implemented in the TSO pilot .....                               | 26 |
| Figure 11 - BIM model development process extract.....                                                                          | 27 |
| Figure 12 - Example of validation structured outcomes generated in the TSO pilot. ....                                          | 28 |
| Figure 13 -Asset-data-model-driven scalability path of the validation framework .....                                           | 29 |
| Figure 14 - IFC model overview of the primary substation .....                                                                  | 31 |
| Figure 15: Validation process.....                                                                                              | 32 |
| Figure 16: Example of attributes from the data dictionary, which can be translated into rules.....                              | 32 |
| Figure 17: Example of creating a text rule .....                                                                                | 33 |
| Figure 18: Example of a report generated by the validator.....                                                                  | 33 |

## List of Tables

|                                                                                                              |    |
|--------------------------------------------------------------------------------------------------------------|----|
| Table 1: Key performance indicators (UC ID EACL-IT-01) .....                                                 | 20 |
| Table 2: Key performance indicators (UC ID EACL-IT-02) .....                                                 | 20 |
| Table 3: Key performance indicators (UC ID EACL-IT-03) .....                                                 | 21 |
| Table 4: KPI IDs, validation maturity dimension, and percentage results for the three assessment dates ..... | 22 |

## List of Abbreviations and Acronyms

| Acronym  | Meaning                            |
|----------|------------------------------------|
| BCF      | BIM Collaboration Format           |
| BIM      | Building Information Model         |
| bSDD     | building SMART Data Dictionary     |
| CDE      | Common Data Environment            |
| CIM      | Common Information Model           |
| DSO      | Distribution System Operator       |
| GIS      | Geographic Information System      |
| HV/MV/LV | High/Medium/Low Voltage            |
| IDS      | Information Delivery Specification |
| IFC      | Industry Foundation Classes        |
| LOIN     | Level of Information Need          |
| PBS      | Product Breakdown Structure        |
| POC      | Proof of Concept                   |
| Pset     | Property Set                       |
| TSO      | Transmission System Operator       |

## Executive Summary

While in the construction industry, the **Building Information Modelling (BIM)** methodology is widely used for the full lifecycle management of a built asset—from the early planning stages to the final operational phase—the energy industry is still in the process of fully transitioning toward its comprehensive adoption. The design phase currently represents the critical entry point for this transformation. It represents the transition toward a new methodology for managing grid assets throughout their lifecycle.

The adoption of BIM in the design phase is particularly complex for power stations compared to traditional civil buildings. While an airport or a theatre may be a unique, stand-alone project, electrical substations are characterized by a high degree of **serialization and standardization**. However, their complexity is amplified by their interdisciplinary nature, where civil works, electromechanical systems, and strict regulatory safety norms must coexist. Furthermore, the design of these infrastructures is often delegated to an **external supply chain**, creating a challenge for System Operators (SOs) who must verify that external professionals comply with technical prescriptions. The introduction of a vast number of properties makes manual validation an inefficient and error-prone process.

To address these challenges, **Terna Rete Italia (TSO)** and **Enel Grids/E-Distribuzione (DSO)** have jointly implemented an automated validation framework. Despite different object taxonomies, both operators identified the need for a common, standards-aligned methodology based on **OpenBIM** to ensure interoperability. The **Information Delivery Specification (IDS)** was selected as the most suitable solution for defining machine-readable requirements—including objects, properties, and values—within an IFC model. This allows a Rules Engine to perform systematic checks, transforming the process from subjective manual review into an objective, automated workflow that significantly reduces "time-to-validation". Beyond reducing validation effort, the proposed approach creates value across several business domains of TSOs and DSOs. In the short term, it supports faster design approvals, improved coordination with external designers, and higher consistency of project deliverables. It also establishes the information foundation required for future asset lifecycle management and Digital Twin applications supporting planning, operation, and infrastructure evolution.

However, the implementation highlights that the energy sector remains in an **intermediate phase**. While other industries have achieved "total integration" where objects possess functional intelligence—such as automated volume recalculations—the energy industry is currently focused on perfecting the **Physical Digital Twin**: a detailed 3D representation enriched with technical metadata. A significant gap remains in achieving a dedicated data domain that bridges physical 3D representations and **electrical functional logic**. For example, the industry lacks an automated correspondence between the 3D model and the **single-line diagram (SLD)**. Furthermore, challenges persist regarding the automation of specific electrical checks, such as the dynamic calculation of **clearances** between live and non-live parts, which vary according to voltage levels and environmental conditions.

Ultimately, this work establishes the essential bedrock for a future **Functional Digital Twin**. By prioritizing data governance and standardized rules within a **Common Data Environment (CDE)**—which currently provides sufficient intrinsic interconnection for validation without the immediate need for external connectors—the project provides a scalable roadmap for total BIM adoption. The next frontier will be the integration of functional electrical intelligence to support the full lifecycle of the European energy grid.

# 1 Introduction

BIM could be defined as the use of a shared digital representation of a built asset to facilitate design, construction, and operation processes to form a reliable basis for decisions, covering all assets' life phases [1]. Those phases are generally identified in Planning, Design, Build and Operate.

For example, let's imagine the **Planning** phase of a large and complex construction like a new theatre. Various disciplines must provide contents for modelling the initial plan, with a certain degree of approximation, accounting for all existing **constraints**, such as underground utilities, distances from other structures, and environmental factors (e.g. water bodies or vegetation). In this phase, different professionals can access the design platform simultaneously and cooperatively, maintaining mutual awareness of other colleagues' requirements and project's evolution. Once finalized, the planning project is submitted to the local and national authorities for approval.

In the **Design** phase, all the involved experts cooperate for provide detailed executive plans, allowing for **clash detection** and the verification of coherence across all elements – structural, technological and aesthetic as well as the validation of the characteristics that distinguish them. The aim of this phase is to anticipate inconsistencies or issues as early as possible. Indeed, the earlier a need for change is identified, the lower the associated cost. Each object within the design not only includes its exact 3D geometry but also the data for all materials required for its construction (for instance, the specific quantities of bricks, concrete, plaster, insulation, and paint for a wall) . The main outputs of this phase include disciplinary 3D models, the 3D federated model, executive drawings (floorplans, sections and technical service plans) and the **Bill of Materials (BoM)**.

Once the design phase is concluded, the **Build** phase begins. This is the most critical stage, where changes become significantly more expensive and increase the risk of **exceeding** the overall budget. BIM supports the simulation of any modification, calculating the impact on both execution time and the cost (often referred to as 4D and 5D BIM). By associating duration and costs with each building component, this methodology provides a progressive simulation of construction phases and expenditure forecasts, allowing a better cashflow management. Moreover, by simulating these phases, operative planning – including supply chain logistics, material storage, site management and safety - can be optimized and anticipated to prevent major disruptions.

After construction is completed, the theatre enters in **Operate** phase. Here the model functions as “Digital Twin” for facility management, supporting computerized heating and cooling systems by utilizing data on the thermal transmittance of walls and ceilings or managing the flow of people within the physical space. In the energy sector, equivalent future applications may include support for asset maintenance planning, project modification management, engineering change tracking, and the progressive integration of operational information. While these capabilities are not yet fully mature within electrical BIM environments, the development of structured and validated information models represents an essential prerequisite for their future adoption.

While this methodology is widely adopted in the construction industry for complex infrastructures, the **electric energy industry** seems still transitioning to fully encompass the BIM approach. In Italy, local regulations for public tenders now obliges System Operators to provide BIM-based designs during the authorization phase. Consequently, the first mandatory step is implementing BIM within the design phase.

The primary difference between a theatre, an airport or a metro tunnel and an **electric power substation** is that the former are unique “stand-alone” projects, while the latter can be considered

**serialized projects.** A significant challenge for industrial plants is that the designer is often an external party – either a contracted designer or an energy producer (in Italy, each energy producer is allowed to provide the designs for the System Operators’ infrastructure). Despite their a general expertise, these external professionals might not be fully aware of the specific technical prescriptions or constraints of such complex grid infrastructure. Furthermore, as BIM introduces a significant complexity due to the high number of properties (parameters) required for each object, the validation process becomes complicated and time-consuming for the System Operator.

## 1.1 Task 6.2

The Design Validation will encompass both the civil and the technical designing phases to verify the completeness and coherence of all information requirements – a task that is particularly complex and time-consuming for electric power plants, stations, and lines. This tool will support both technical supervisors of the System Operators and contractors in verifying the accuracy of project deliverables. The objective is to prevent unforeseen errors and cost overruns during the execution phase, while also ensuring the accuracy of the **As-Built model** so that it can be used by system operators as a **Digital Twin** of the infrastructure.

The study is focused on two specific use cases:

1. **TSO (Transmission System Operator):** Validating a transmission station design developed by an external producer, where the TSO is responsible for verifying compliance with technical requirements, standards and constraints.
2. **DSO (Distribution System Operator):** Validating the HV/MV substation design created by a contracted designer.

The initial phase involved the functional role of a validator: a digital tool that enables the automated validation of a BIM-based design according to a predefined set of model rules.

The validator is conceived as an **automated workflow**, where model data and validation rules are processed in a structured environment to systematically verify compliance and generate structured validation outputs. The process typically involves several actors. Designers and contractors create and submit BIM models according to System Operator requirements. The validation framework then verifies the delivered information against predefined rules. Validation outputs can be used both by the supply chain for self-assessment and by the TSO or DSO during formal project approval activities, creating a continuous feedback loop that improves model quality throughout project development.

The process begins with an initial set of rules that can be subsequently extended to cover all the element of the power station. Being agnostic to specific circuit elements, building blocks, or project phases, these rules can then be expanded to include other grid assets initially outside of the study, such as power lines and MV/LV substations and.

Since both the Italian TSO (Terna) and the DSO (E-Distribuzione) has already begun implementing BIM elements prior the project’s start, a model comparison phase was conducted. This verified that a consistent high-level model was used for designing core components, such as circuit breakers, transformers, and conductors. Once the validator concept was defined and the alignment of ontologies confirmed, the analysis addressed the data model required to describe the validation rules. In this context, validation rules can be structured in machine-readable formats, such as **Information Delivery Specification (IDS)**, or defined directly within the validation environment to enable automated compliance checking.

The two use cases then progressed in parallel through the implementation phase, after which a comparative analysis was conducted to draw the final pilot conclusions.

In the final phase, an internal scalability analysis was performed, to verify the applicability of the approach to different use cases and evaluate the extension of the BIM methodology for all types of managed assets (extended or transformation power stations and power lines) as well as the entire lifecycle of grid elements.

This approach established the foundation for a scalable and repeatable validation process, enabling consistent verification across different projects and stakeholders.

## 1.2 Objectives of the Work Reported in this Deliverable

The objective of the work reported in this deliverable is to describe the activities carried out within the task, focusing on the definition of data models and the implementation of an automated validation process for BIM-based designs.

The report presents a comprehensive description of the data models, and the validation process is duly provided, alongside the results obtained during the project and the final conclusions. These findings highlight the potential of automated validation to significantly improve the consistency, efficiency, and quality of design verification. Furthermore, this deliverable provides an overview of the work carried out, summarizing the adopted approach and outlining key findings to support future development and the scalability of the solution and its integration with transversal tools like immersive reality, while identifying the CDE as the central interconnection for validation purposes.

## 1.3 Outline of the Deliverable

This deliverable is organized to provide a comprehensive overview of the approach, implementation, and results of the automated validation process for BIM-based designs in the energy domain. The document is divided into the following chapters:

- **Chapter 2 – BIM methodology in energy grids:** This chapter introduces the BIM methodology and its application in energy grids, focusing on the validation process and providing a detailed description of the use cases.
- **Chapter 3 – Methodology and implementation pathway:** Details the methodology and the implementation pathway. This chapter describes the common framework adopted by both operators, including the definition of the data dictionary, rule engine, and validation tool. It also specifies the individual implementations for the TSO and DSO.
- **Chapter 4 – Pilots results and scalability:** Showcases the results of the pilots for both the TSO and DSO perspectives. It includes an assessment of the scalability of the solution and explores the potential extension of the approach to additional use cases, including the extension for Immersive Reality.
- **Chapter 5 – Conclusions:** Summarizes the key findings and provides the final remarks of the report.

## 2 BIM methodology in energy grids

The digital transformation of Europe's infrastructure sector is being strongly driven by EU-level initiatives aimed at enhancing efficiency, interoperability, and the modernization of energy networks. The **European Grids Action Plan (COM/2023/757)** [10]—and subsequent initiatives such as the **European Grids Package (COM/2025/1005)** [11]—underscores growing challenges, including grid capacity constraints, delays in project development, and the increasing need for advanced digital tools to improve planning, coordination, data management practices, and overall system resilience for both TSOs and DSOs across Member States.

At the same time, the adoption of BIM across Europe is progressing unevenly. While several countries have already established structured BIM strategies or mandates—particularly through public procurement frameworks and digital construction standards—others remain at earlier stages of maturity. Italy is among the countries that have introduced a robust regulatory framework. Building on the foundations laid by the European Directives 2014/23/EU, 2014/24/EU, and 2014/25/EU [12], and further consolidated in the **Public Contracts Code “Codice degli Appalti” (D.Lgs. 36/2023)** [13], Italy has mandated the use of BIM for public works exceeding beyond a certain cost threshold (to date equal to €2 million) starting from 1 January 2025. This requirement establishes binding obligations for contracting authorities and public operators, including DSOs operating within regulated procurement processes. The present work therefore does not assume that all contractors and suppliers have already achieved the same level of BIM maturity, but rather acknowledges an ongoing transition period in which System Operators progressively require BIM-compliant deliverables from their supply chains.

Despite this clear regulatory momentum, BIM adoption within the electrical infrastructure sector remains at an early stage. Electrical grid operators should define electrical domain and adapt BIM—originally designed for building-centric applications—to **linear network assets**, which require seamless integration with territorial and operational datasets. The most desirable future development is the interoperability of BIM with other systems and databases used, such as **GIS (Geographic Information System)** and **CIM (Common Information Model)** [9]. BIM provides detailed, asset-level information, while GIS ensures geographical accuracy and large-scale spatial context. CIM, widely adopted by European utilities, standardizes electrical-system data exchange and operational modelling, ensuring consistency across planning processes, ADMS/SCADA systems, and regulatory reporting.

This underscores the growing need for harmonized and interoperable data environments capable of combining BIM's geometric precision with the operational intelligence of GIS and CIM. Such integration supports planning, design, construction, and maintenance activities in modern electrical grids, while facilitating efficient information exchange among stakeholders and with government agencies.

BIM provides key benefits for grid operators by improving planning accuracy, construction coordination, and asset documentation for predictive maintenance and lifecycle management. However, its widespread adoption is limited by the lack of mature standards for linear and electrical infrastructure, the difficulty of integrating BIM with GIS and CIM, fragmented legacy systems, and persistent skill gaps. Organizational inertia and the necessary investments in training, platforms, and data governance further slow progress. Nonetheless, BIM is steadily becoming a core element of the digital grid ecosystem, enabling Digital Twins, harmonized data models, and integrated planning to support Europe's energy and climate goals.

In the context of this work, the scope of application differs between the Transmission System Operator (TSO) and the Distribution System Operator (DSO), reflecting the specific characteristics of their infrastructures:

- **For the TSO (Terna):** The focus is on **transmission substations**, typically related to high-voltage grid connection assets designed by external producers.
- **For the DSO (Enel):** The scope is centred on **primary substations**, which represent key nodes in the medium-voltage distribution network.

While the validation approach remains consistent, the differences in asset types and operational contexts are reflected in the respective data models, requirements and implementation choices.

## 2.1 Designing a TSO and DSO transforming station

Electrical grid infrastructure constitutes a particularly favourable domain for BIM-based information management because it is characterized by a high degree of standardisation, modularity, and repeatability in both asset configurations and delivery processes. A substantial portion of the network is implemented through typified solutions (recurring layouts, equipment arrangements, functional schemes, and interface logics between civil works and electromechanical systems) that are instantiated across multiple projects with limited contextual variation. Such conditions amplify the value proposition of BIM, whose effectiveness increases when information can be formalised, reused, and governed through consistent object definitions, shared semantics, and rule-driven requirements. On this basis, transforming stations/substations at both transmission (TSO) and distribution (DSO) level represent an especially instructive use case: they integrate multi-disciplinary content (civil, electromechanical, protection and control systems), operate under strict technical prescriptions and regulatory constraints, and demand high informational completeness to support design approval, construction, commissioning, and subsequent digital-twin enablement. Moreover, given the prevalent reliance on external supply chains for design and construction, substations provide a representative setting in which to investigate how interoperable information structures and automated validation can mitigate heterogeneity in deliverables, reduce interpretative ambiguity, and improve coordination across stakeholders—thereby offering a concrete, scalable basis for methodological generalisation beyond the specific asset class.

Transmission and distribution stations represent key assets within the electrical grid, serving different operational purposes while sharing common design and modelling principles.

Transmission stations, typically managed by Transmission System Operators (TSO) such as Terna, are primarily associated with high-voltage grid connection infrastructures. In the Italian context, these assets typically operate at voltage levels ranging from 132 kV up to 380 kV. These assets are often linked to the integration of new producers into the transmission network and may involve external designers operating under TSO requirements and constraints.

Distribution substations, such as primary substations managed by Distribution System Operators (DSO) like Enel, operate at medium-voltage level and represent fundamental nodes for energy distribution to end users, typically interfacing the HV network (132–150 kV) with MV networks operating at 15 kV or 20 kV.

Despite these differences, both types of substations share several common characteristics. They include a combination of civil works and electromechanical components, follow standardized layout schemes and design principles, and require a high level of information associated with each object. In

both contexts, assets are subject to technical constraints, regulatory requirements and internal standards.

However, key differences impact how BIM models are structured and validated:

- Design responsibility: transmission substations are often designed by external producers, while distribution substations are typically developed by contractors under DSO supervision;
- Asset complexity and scale: transmission substations involve higher voltage levels and more complex connection schemes;
- Data models and classification systems: TSO and DSO adopt different object taxonomies and parameter structures;
- Validation needs: the validation process may differ in scope and focus depending on the asset type and organizational workflows.

For example, both TSOs and DSOs may manage similar physical assets such as transformers, circuit breakers and support structures. The main differences do not lie in the assets themselves, but in the information requirements, naming conventions, classification systems, validation criteria and organizational workflows associated with them. As a result, interoperability challenges are often related less to the physical assets themselves than to the way information about those assets is structured, governed and validated. For instance, a cable trench may require different information structures depending on maintenance and construction requirements, while a transformer may share the same physical function in both environments but require different classification codes, property sets and validation criteria according to voltage level and organizational processes.

These similarities and differences highlight the need for a flexible validation approach, capable of adapting to different asset types while maintaining a consistent methodological framework.

## 2.2 The Design Validation Use Case

The design validation process is a critical step in ensuring that electrical infrastructure projects comply with technical requirements, regulatory constraints, and internal standards defined by the System Operator.

In the context of this work, the validation use case is analysed across both transmission and distribution domains, reflecting the different operational scenarios of TSO and DSO.

In the **transmission domain (TSO)**, the focus is on high-voltage substations related to grid connection processes. When new power generation plants connect to the grid, the design is provided by external designer – the power generation plants’ designers requesting access to the transmission network. The TSO acts as the validation authority, ensuring compliance with technical requirements, regulatory constraints, and internal TSO standards before approval. A key activity in this task involved the analysis **of laws and regulations** to translate them into a **machine-readable classification**. This allowed for the definition of the **Level of Information Need (LOIN)**, ensuring that the BIM model of the power station contains the exact degree of detail required for automated **clash detection** and **model checking** activities.

In the **distribution domain (DSO)**, the focus is on primary substations. These assets include complex electromechanical components and civil works. The work addressed the **AS-IS scenario evaluation**, focusing on the enhancement of the 3D model validation process. A central element was the integration between the **Common Data Environment (CDE)** and the **Asset Domain platforms**. By

leveraging the CDE, the DSO can perform systematic **quality checks** (such as **Code Checking** and clash detection) to verify the accuracy of project deliverables submitted by contractors at different stages of development.

**In both the transmission and distribution contexts**, the validation process focuses on clash detection and the verification of technical constraints. Given the vast number of objects and properties characterizing such complex power infrastructures, these activities have traditionally relied on manual or semi-automated procedures. However, these conventional methods often prove time-consuming and prone to inconsistencies, potentially leading to unforeseen errors or cost overruns during the execution phase.

**The transition to a BIM-based approach**, while providing a more detailed and information-rich representation of assets, significantly increases the volume and complexity of the data to be verified. This shift necessitates structured and rigorous validation workflows that move beyond simple visual inspections. Consequently, there is a clear requirement for advanced methodologies capable of systematically checking that both **clash prevention** and informational depth are fully aligned with the System Operator's established requirements.

To address this, the developed automated validation approach formalizes technical and regulatory constraints into machine-readable rules (utilizing standards such as **IDS - Information Delivery Specification**). This enables the implementation of a dedicated **Rule Engine** that performs comprehensive and repeatable checks. This transition not only minimizes manual effort but also facilitates the automatic generation of monitoring reports, which provide a structured analysis of identified issues and confirm the final validation status within the project's data environment.

**Finally, the availability of these predefined validation rule sets** at the beginning of the project lifecycle fosters a more collaborative relationship between operators and designers. By sharing these rules in advance, external designers can perform preliminary self-checks, significantly improve clarity and reduce the number of design iterations. This proactive approach ensures a streamlined approval process, guaranteeing that the final validated model serves as a high-quality **Digital Twin**, ready to support the entire operational lifecycle of the infrastructure.

### 3 Methodology and implementation pathway

The implementation process is based on a common methodological framework shared between the TSO and the DSO. While this approach ensures consistency in terms of data structuring, rule definition, and validation logic, each system operator develops the pilot according to its own specific requirements and operational context.

The investigation into the feasibility of data sharing between TSO and DSO has provided a comprehensive state-of-the-art analysis. The analysis performed within the project confirmed that both DSOs and TSOs retain ownership and control over the data associated with the models under their respective responsibilities.

However, the lack of standardized dictionaries for components used by DSOs and TSOs, combined with the absence of a common data structure that respects their operational independence, presents a significant challenge. This calls for the development of a shared process—one that aligns objectives across both operators while preserving their autonomy in data management. Establishing such a framework would provide a structured pathway for interoperability, ensuring consistency and efficiency in data exchange between entities (designers, DSOs, TSOs, authorities).

#### 3.1 Proposed solution

The proposed solution is fundamentally structured into three main blocks:

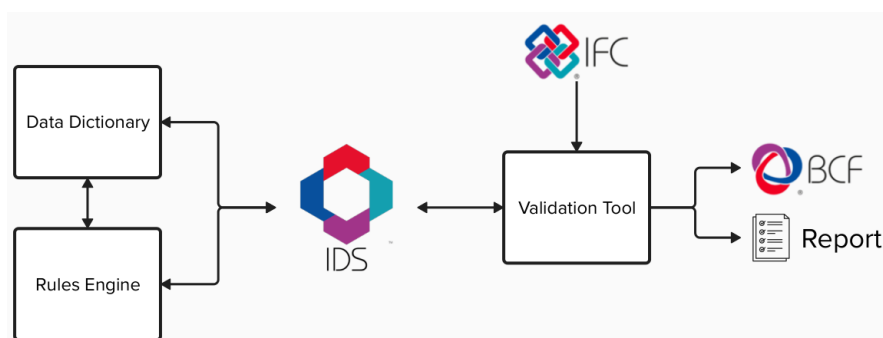


*Figure 1: Building blocks and formats*

These blocks represent distinct but interconnected layers of the validation framework, each addressing a specific aspect of the process: data structuring, rule definition and validation execution. Where:

- **Data Dictionary:** defines classes (components) and attributes (properties) of the components, creating a library where elements can be reused, avoiding duplication and promoting corporate standardization. This layer provides the semantic foundation needed to ensure consistency and interoperability across the validation process.
- **Rules Engine:** create a library of rules that can be applied to the properties defined as attributes of a class. This layer formalizes validation logic in a machine-readable way, enabling consistent rule definition and reuse across different validation scenarios. Where needed, these rules can be translated into interoperable formats such as IDS, while in other contexts they may also be implemented through native rule configurations within specific platforms.
- **Validation Tool:** executes automated checks on BIM models by assessing their compliance against the defined validation rules. This layer transforms structured model data and

validation logic into compliance results, supporting the identification of non-conformities and the generation of validation outputs that can feed issue management and feedback workflows.

### 3.1.1 Data Dictionary

The first step in this process is to define an enterprise Data Dictionary that ensures uniformity of language among participants in the process. A fundamental action is to share this "language" with the interested stakeholders in order to guarantee interoperability. This layer plays a key role in enabling consistent interpretation of model data, which is a prerequisite for applying validation rules in a reliable and scalable way.

The scouting of potential solutions aligned with the principles of OpenBIM and the need for an open and adaptable framework led to the identification of bSDD (buildingSMART Data Dictionary) <sup>1</sup> as a viable implementation. In compliance with ISO 12006-31, ISO 233862, and ISO 233873 [6] [7] [8], bSDD provides a structured approach to managing and standardizing data across different entities while preserving autonomy in data governance. In particular, the development of a sector-specific bSDD represents a strategic opportunity to define a standard for high-voltage asset classification. While bSDD represents a relevant reference for structuring and standardizing data, the definition and management of the Data Dictionary can be implemented through different approaches depending on the specific needs and constraints of each system operator.

By structuring data in a consistent and shared way, the Data Dictionary enables the definition and execution of validation rules across different tools, actors, and use cases, supporting a scalable and interoperable validation framework.

### 3.1.2 Rules engine

The main objective of this component is to enable the definition of structured validation rules that can be consistently applied to BIM models. These rules are associated with classes, properties, and model conditions, allowing both parameter- and relationship-based checks to be defined in a formalized and reusable way.

The system supports users in the rule definition process by guiding the creation of rules and linking them to the relevant elements of the adopted Data Dictionary, such as classes, property sets and attributes. This ensures consistency between the data structure and the validation logic applied to it.

In addition, the system provides a library of predefined rules that can be reused across different projects and use cases, promoting standardization, reducing redundancy, and supporting scalability of the validation process.

The defined rules can be translated into machine-readable formats to support interoperability and automated validation. Among these, IDS (Information Delivery Specification) represents a standardized approach for structuring and exchanging validation requirements using a human- and machine-readable XML format. However, rule definition is not limited to IDS and can also be

---

<sup>1</sup> ISO 12006-3:2022, Building construction — Organization of information about construction works - Part 3: Framework for object-oriented information

<sup>2</sup> ISO 23386:2020, Building information modelling and other digital processes used in construction — Methodology to describe, author and maintain properties in interconnected data dictionaries

<sup>3</sup> ISO 23387:2020, Building information modelling (BIM) — Data templates for construction objects used in the life cycle of built assets — Concepts and principles

implemented through native configurations within specific platforms, depending on the chosen technological environment.

This approach ensures that validation logic is formalized in a consistent and reusable way, independently from the specific tools used for validation execution.

Once defined, these rules can be directly used within validation processes or exchanged across different tools and stakeholders through interoperable formats.

```
<ids:property cardinality="required" dataType="IFCTEXT">
  <ids:propertySet>
    <ids:simpleValue>SUBCOMP_TYPE_MASTERDATA</ids:simpleValue>
  </ids:propertySet>
  <ids:baseName>
    <ids:simpleValue>SUBCOMP_TYPE_MASTERDATA__GLOB_CAT_CODE</ids:simpleValue>
  </ids:baseName>
  <ids:value>
    <ids:simpleValue>_TR</ids:simpleValue>
  </ids:value>
</ids:property>
```

**Figure 2: Example of rule described into a snippet of ids file (machine-readable representation)**

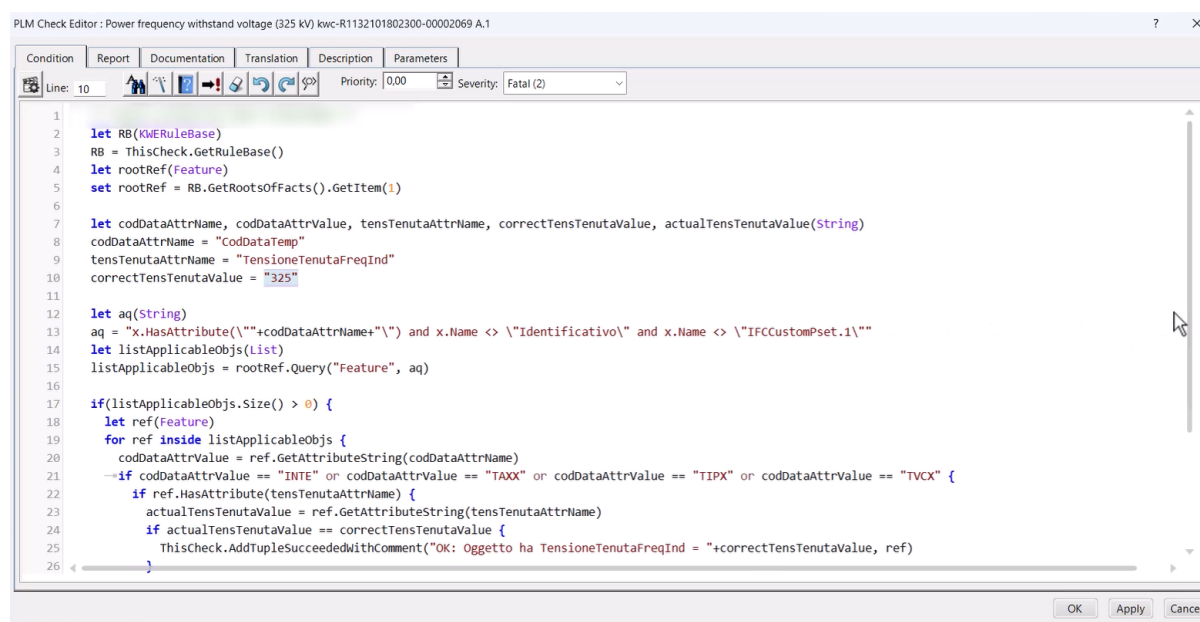


**Figure 3: Example of rule defined through platform-native configuration (user-oriented representation of validation logic)**

### 3.1.3 Validation tool

The aim of the validation tool is to verify the compliance of an IFC (Industry Foundation Classes) file against a defined set of validation rules. The tool receives model data (e.g. IFC files) and applies the previously defined rules, which can be provided either through interoperable formats such as IDS or through native rule configurations, depending on the adopted approach. This component represents the execution layer of the validation framework, where structured data and formalized

validation logic are processed to generate compliance results. In this context, IDS-based validation represents a key interoperable approach, particularly for rule exchange across different stakeholders.

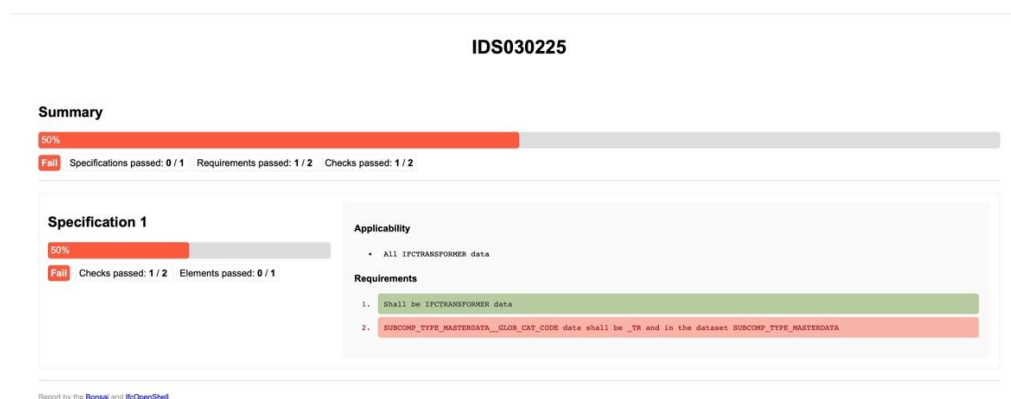


**Figure 4: Example of report of validation via IfcOpenShell<sup>4</sup> with Blender<sup>5</sup> and Bonsai<sup>6</sup> plugin**

The validation can cover different aspects, including property checks, model completeness and relationships between elements.

At the end of the validation process, the tool generates structured outputs that highlight which rules are satisfied and which are not. These results can be defined at a granular level, enabling the identification of individual non-conformities associated with specific model elements.

Such outputs can be used to support issue management processes, where each detected non-compliance can be tracked, assigned and resolved within a coordinated workflow. This can be implemented through interoperable formats such as BCF (BIM Collaboration Format) [5] or through platform-integrated issue management systems, depending on the technological environment.

In this way, the validation tool not only verifies compliance but also enables a continuous feedback loop between model authoring and validation, contributing to improving model quality and reducing iterative cycles in the design process.

As an illustrative example, a circuit breaker may be represented as a class within the Data Dictionary. Associated attributes can include manufacturer, rated voltage, rated current, installation location and asset identifier. A model instance of that class represents a specific circuit breaker installed in a given project. Validation rules can then verify whether mandatory attributes are present, correctly formatted and compliant with the information requirements defined by the System Operator. For example, a validation rule may require that all circuit breakers connected to a 132 kV section include a rated voltage attribute equal to 132 kV and a non-empty asset identifier.

## 3.2 TSO Implementation

In general, the Terna pilot aims to verify whether all elements of a project model are designed and planned according to Terna's rules and constraints. The application scenario is based on the hypothesis of a prosumer requesting connection to the transmission network, who is responsible for

<sup>4</sup> <https://ifcopenshell.org>

<sup>5</sup> <https://www.blender.org>

<sup>6</sup> <https://extensions.blender.org/add-ons/bonsai/>

designing and building the required infrastructure in compliance with System Operator requirements and national regulations.

In this context, the proposed design is developed by external actors and submitted to the TSO for validation. The validation process therefore represents a critical approval step, where Terna acts as the authority responsible for ensuring that externally developed designs are fully compliant with technical requirements, constraints and standards before integration into the transmission network.

The implementation of the pilot follows the common framework described in Section 3.1, structured around Data Dictionary definition, rule formalization and validation execution. In this context, the validation process has been further defined through an operational workflow, where BIM models provided by external designers are checked against predefined rules and the results are structured to support feedback and model improvement processes.

The use case develops through different phases:

1. A first phase in which the rules for the validation of the digital twin are analyzed and, where possible, translated into a structured validation workflow and machine-readable regulations;
2. Based on the defined rules, the data model and LOIN for an electrical substation are developed, identifying the level of information required for validation purposes. The definition of the required information represents a key element of the experimentation;
3. The following phase consists in the construction of the BIM model of the asset (a substation for power generator connection to the network), implemented according to the defined data model and LOIN;
4. The requirements for the BIM validation environment are then defined in order to identify and select the most suitable solution for the scope;
5. The final stage involves the configuration of the selected validation environment with the defined rule sets, enabling automated validation and the generation of structured outputs to support the identification of non-compliances.

The validation outputs generated in this process enable a structured interaction between designers and the TSO, supporting iterative model improvement and ensuring compliance before final approval.

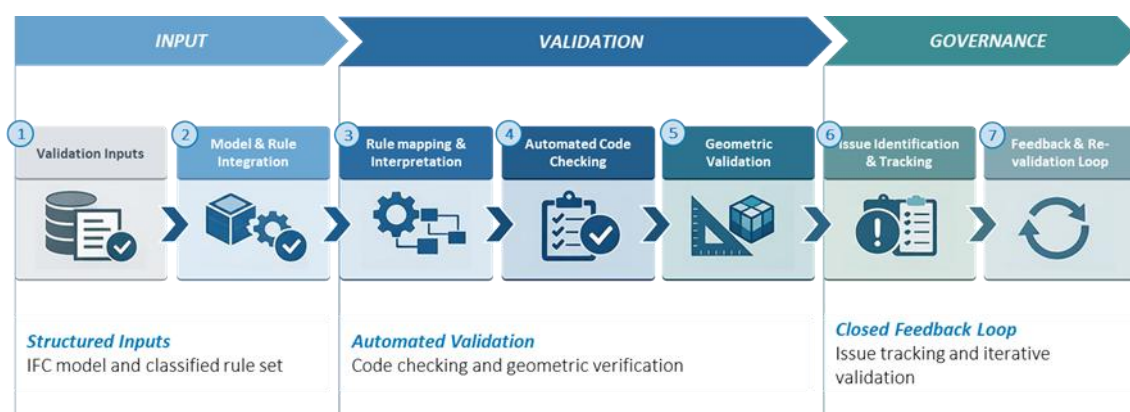


**Figure 5: High-level validation workflow within the TSO validation process**

Following the pilot implementation, further activities will focus on assessing the scalability of the approach and its applicability to additional use cases and asset types within the transmission domain. In this context, a cost-benefit analysis will be carried out to evaluate the potential impact of the

automated validation process in terms of efficiency gains, reduction of manual effort and improvement of model quality.

### 3.3 DSO Implementation

In the DSO context, the validator is positioned as a core enabling component of the BIM-driven digitalization pathway within a sector where infrastructure design and construction activities are predominantly outsourced. Consequently, the generation of the information model—intended to constitute the foundational representation for a digital twin—is largely delegated to external designers and contractors. Under these conditions, systematic verification and validation of delivered information are not merely operational best practices, but also a regulatory requirement [2]. This creates a clear need for a structured assurance mechanism capable of guaranteeing the completeness, correctness, and internal consistency of project data, while reducing the time, ambiguity, and variability typically associated with manual review processes.

Consistent with the reference architecture described in Chapter 3.1 and illustrated in Figure 1, the implementation adopts an OpenBIM-based approach in which the data dictionary, rule definition, and validation execution are explicitly coupled within a coherent workflow. Specifically, the DSO Data Dictionary is implemented in accordance with the bSDD structure and APIs, thereby ensuring compatibility with existing frameworks and enabling—where relevant—the publication of organizational dictionaries within buildingSMART services. The alignment with bSDD is further motivated by its role as a key enabler of two pivotal OpenBIM standards:

- IFC (Industry Foundation Classes)<sup>7</sup> [3], which governs the structuring and exchange of files containing both geometry and metadata;
- IDS (Information Delivery Specification)<sup>8</sup> [4], which formalizes how information is to be exchanged among stakeholders by expressing information requirements and associated validation rules in a machine-interpretable manner.

Within this configuration, the Rules Engine governs the rule set and its evolution, IDS provides the verifiable specification of requirements, IFC acts as the standardized exchange container, and the Validation Tool operationalizes the checks, producing actionable outputs (e.g., structured reports and traceable issues such as BCF-based findings) to support timely and collaborative remediation.

A distinguishing feature of the proposed implementation is that validation is conceived not as a single ex post control, but as a recurring quality-assurance process throughout project development. Validation can be performed by both the client (DSO) and the contractor, enabling non-conformities to be detected and resolved incrementally. As a result, the final verification milestone—while retaining its formal function of validation—tends to be non-blocking in practice, since progressive alignment with requirements has already been achieved through iterative checks. Furthermore, by leveraging open standards and interoperable formats, the validator enhances not only the DSO's internal efficiency but also the contractor's delivery effectiveness (through self-assessment prior to submission), reducing rework and shortening approval cycles, while strengthening collaboration via a shared, standardized information language.

---

<sup>7</sup> <https://www.buildingsmart.org/standards/bsi-standards/industry-foundation-classes/>

<sup>8</sup> <https://www.buildingsmart.org/standards/bsi-standards/information-delivery-specification-ids/>

### 3.4 Reference KPIs and validation

Regarding the development of the design validation pilot, the KPIs identified in T2.4 are confirmed. Below is a summary:

**Table 1: Key performance indicators (UC ID EACL-IT-01)**

| <b>Key performance indicators (UC ID EACL-IT-01)</b> |                             |                                                                       |                                                                               |
|------------------------------------------------------|-----------------------------|-----------------------------------------------------------------------|-------------------------------------------------------------------------------|
| <b>ID</b>                                            | <b>Name</b>                 | <b>Description</b>                                                    | <b>Reference to mentioned use case objectives</b>                             |
| 1                                                    | Rule's analysis             | Evaluate the number of the rules to analyse how is automatable.       | Progress analysis to achieve the definition of the Design validation workflow |
| 2                                                    | Translation of the standard | Percentage of the number of rules translated into automatable actions | Progress analysis to achieve the definition of the Design validation workflow |
| 3                                                    | Data model development      | Number of loin needed, per object, completed                          | Progress analysis to achieve the definition of Data Model and LOIN.           |

**Table 2: Key performance indicators (UC ID EACL-IT-02)**

| <b>Key performance indicators (UC ID EACL-IT-02)</b> |                                 |                                                                                                                                       |                                                                                 |
|------------------------------------------------------|---------------------------------|---------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------|
| <b>ID</b>                                            | <b>Name</b>                     | <b>Description</b>                                                                                                                    | <b>Reference to mentioned use case objectives</b>                               |
| 1                                                    | Objects in model production     | Progress of design in terms of objects                                                                                                | Speed up validation of project, minimize error and increase quality of design.  |
| 2                                                    | Reduction of documents          | Fewer documents exchanged compared to the traditional process.                                                                        | Minimize exchanges of documents and simplify communications.                    |
| 3                                                    | Efficiency of design validation | Evaluation of the checks carried out automatically, and errors detected, compared to the total number of detectable errors and checks | Speed up validation of project, minimize errors and increase quality of design. |

Table 3: Key performance indicators (UC ID EACL-IT-03)

| Key performance indicators (UC ID EACL-IT-03) |                             |                                                                                                                                                                                                   |                                            |
|-----------------------------------------------|-----------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------|
| ID                                            | Name                        | Description                                                                                                                                                                                       | Reference to mentioned use case objectives |
| 2                                             | Extension of the data model | Number of objects that should still be evaluated to extend the solution to all types of connection stations. The objects affected by the scalability hypothesis concern assets related to the TSO | Scalability of the solution                |

### 3.4.1 KPI assessment methodology adopted in the TSO pilot

The Key Performance Indicators reported above are used in the TSO pilot to assess the maturity of the validation framework consistently with the methodology introduced in the accompanying presentation. Rather than being interpreted as isolated performance metrics, the KPIs are analyzed as indicators of progressive maturity along three complementary dimensions:

- **Rule readiness**
- **Model readiness**
- **Validation performance**

This approach allows the validation process to be evaluated as an evolving system, where progress in one dimension enables and amplifies progress in the others.

**Rule readiness** indicators are used to measure the degree to which validation requirements derived from technical standards and regulations have been analysed and translated into structured, machine-readable rules. In the TSO pilot, these KPIs are calculated by comparing the number of requirements analysed and formalized against the total set of applicable rules, making explicit both the portion of requirements suitable for automation and those that remain document-based at the current stage.

**Model readiness** indicators assess whether the BIM model provides the information required to support the defined validation rules. The calculation method combines the evaluation of data model definition (e.g. completion of product sheets and LOINs) with the actual presence of modelled objects and attributes in the BIM deliverables. This dimension captures the alignment between information requirements and delivered data, which represents a prerequisite for effective automated validation.

**Validation** performance indicators evaluate the effectiveness of automated validation by comparing the number of checks executed automatically and the non-compliances detected against the total validation scope. These KPIs are used to monitor how increases in rule and model readiness translate into a growing proportion of automated checks and a reduction in reliance on manual verification activities.

The KPI assessment reflects the natural progression of the pilot activities over the course of the project. KPI values were recorded at three different moments corresponding to successive stages of development, as data models, validation rules and workflows were incrementally defined and implemented.

*Table 4: KPI IDs, validation maturity dimension, and percentage results for the three assessment dates*

| Validation maturity dimension | Use Case | KPI ID  | Name                            | KPI Calculation Method                                                         | Results of Analysis - 01/09/2025 | Results of Analysis - 22/01/2026 | Results of Analysis - 24/04/2026 |
|-------------------------------|----------|---------|---------------------------------|--------------------------------------------------------------------------------|----------------------------------|----------------------------------|----------------------------------|
| Rule readiness                | UC1      | KPI 1.1 | Rule's analysis                 | % of analyzed rules / total rules                                              | 31%                              | 100%                             | 100%                             |
| Rule readiness                | UC1      | KPI 1.2 | Translation of the standard     | % of algorithms derived from standardizable rules / total standardizable rules | 0%                               | 69%                              | 69%                              |
| Model readiness               | UC1      | KPI 1.3 | Data model development          | % of product sheets produced / total required                                  | 100%                             | 100%                             | 100%                             |
| Model readiness               | UC2      | KPI 2.1 | Objects in model production     | % of modelled objects / total objects                                          | 91%                              | 100%                             | 100%                             |
| Validation performance        | UC2      | KPI 2.2 | Reduction of documents          | % of documents exchanged (BIM) / traditional method                            | 0%                               | 0%                               | 71%                              |
| Validation performance        | UC2      | KPI 2.3 | Efficiency of design validation | % of errors found by tool / total errors                                       | 31%                              | 56%                              | 69%                              |
| Model readiness               | UC3      | KPI 3.1 | Extension of the data model     | % of object sheets developed / total needed                                    | 49%                              | 49%                              | 100%                             |

The combined analysis of KPI evolution across rule readiness, model readiness and validation performance allows the definition of an overall **validation maturity level**, as illustrated in the validation maturity chart reported below. This representation highlights how coordinated progress in rule formalization, data structuring, and automated execution supports a scalable and increasingly automated validation process.



Figure 6: Validation maturity assessment based on rule readiness, model readiness and validation performance.

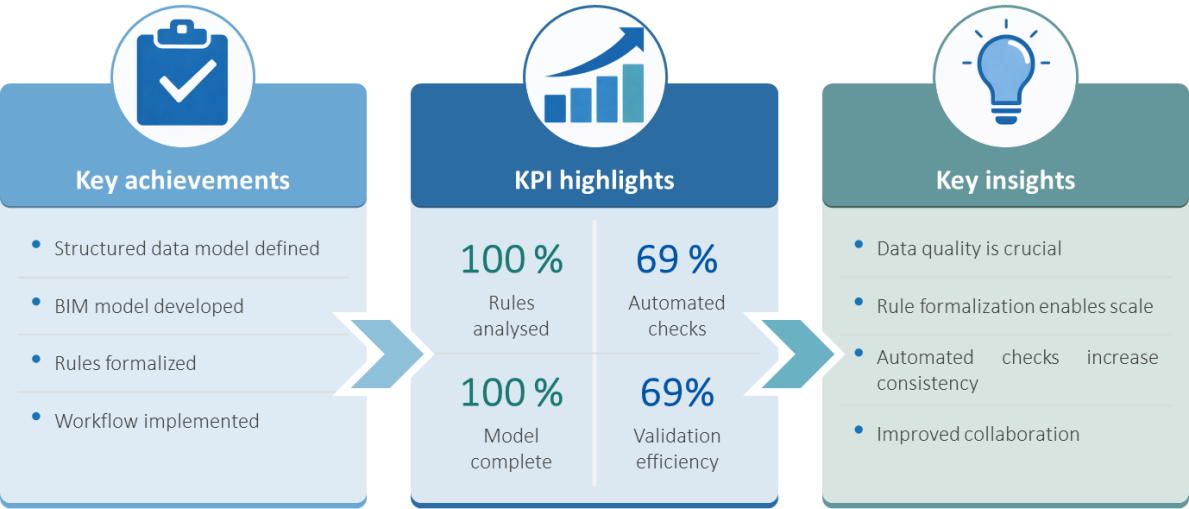


Figure 7: Synthesis of key achievements, KPI highlights and insights derived from the validation pilot.

## 4 Pilots results and scalability

The results of the pilot activities carried out by both TSO and DSO confirm the feasibility and effectiveness of the proposed validation approach. Despite differences in data models and organizational contexts, both implementations highlighted the applicability of a common validation framework based on structured data, formalized rules and automated checks. Although TSOs and DSOs manage many similar physical assets, the lack of a consolidated energy-domain information model means that both operators currently rely on a combination of reusable buildingSMART classes and custom domain-specific definitions. Consequently, differences arise not only in validation requirements and attributes, but also in the classification and representation of assets within the respective data models. Nevertheless, the validation methodology itself remains largely domain-agnostic, as it is based on the separation between Data Dictionary, validation rules, and validation engine, enabling the same framework to be applied regardless of the specific asset taxonomy adopted by each operator.

A key outcome of the experimentation is the identification of common rule families and validation logics that can be generalized across different use cases and asset types.

### 4.1 TSO results

The activities carried out within the Terna pilot provided concrete evidence of the applicability of the proposed validation framework to real-world transmission use cases, in line with the objectives defined in Chapter 1 and the methodology described in Chapters 2 and 3. In particular, the pilot addresses a typical transmission scenario in which the TSO is required to validate BIM-based designs developed by external actors, ensuring compliance with technical requirements, standards and constraints before approval.

The results highlight both the feasibility of structuring validation rules starting from regulatory and technical prescriptions, and the critical role of a well-defined data model in enabling automated and repeatable validation checks.

The main outcomes of the Terna pilot can be summarized as follows:

- **Definition of a structured data model aligned with validation needs**, supporting the explicit association between assets, properties and verification requirements;
- **Development of BIM models based on the defined data model and Level of information Need (LOIN)**, ensuring consistency between required and delivered information.
- **Identification of recurring validation rule families**, enabling the transition from project-specific checks to reusable validation logic.
- **Implementation of a consistent classification system through a Product Breakdown Structure (PBS)** supporting semantic consistency and rule applicability.

Overall, the Terna pilot demonstrates that the combination of a structured data model, a well-defined classification system and formalized validation rules enable a consistent and scalable approach to automated design validation in the transmission domain, reducing reliance on manual verification and supporting more objective and traceable validation outcomes.

The following section provides a detailed example of the implemented approach, illustrating how these results have been concretely achieved within the pilot.

### 4.1.1 Example - TSO results

The following example illustrates how the defined data model is implemented within a BIM model and how validation rules are applied within the Terna pilot.

In particular, explaining the example, the following will be detailed:

- Product Breakdown Structure (PBS)
- Parameters and Properties
- Validation Rules
- Validation outcomes and considerations

#### Product Breakdown Structure (PBS)

A Product Breakdown Structure (PBS) is identified as the asset breakdown in order to achieve a hierarchical decomposition into smaller, manageable components. Based on this structure, the data model for the identified objects was developed, also with the objective of supporting the verification of the defined validation rules.

The definition of the PBS proved to be a key enabler for validation, as it allows the consistent classification of assets and supports the association between objects, properties and validation rules.

Defining the PBS serves to:

- Break down the project into elementary objects, grouped by technical or functional areas (e.g. civil, electromechanical);
- Cluster elements with similar properties to ensure consistent identification;
- Define the parameters required to describe each object at the desired level of detail.

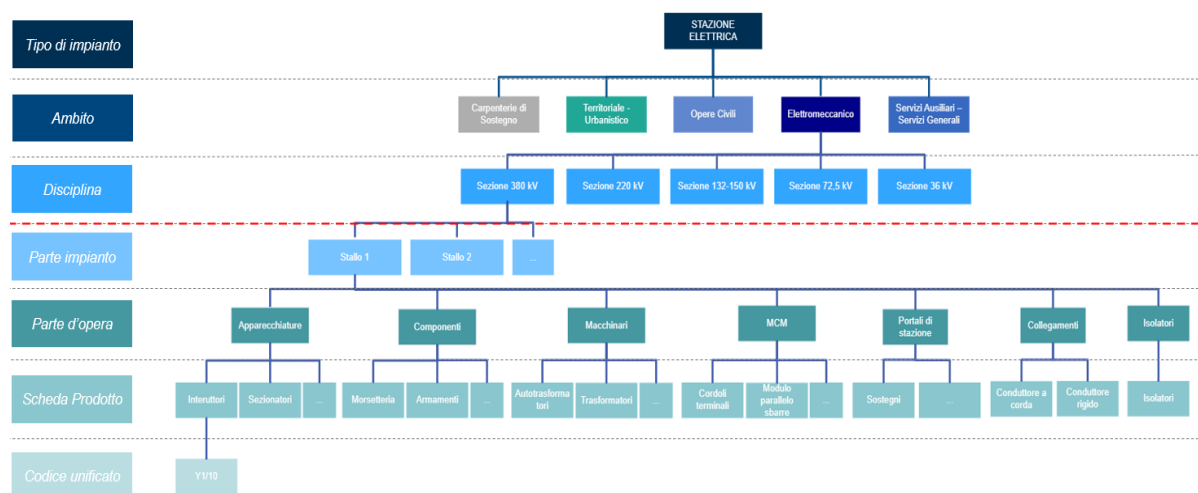


**Figure 8: Example of Product Breakdown Structure adopted in the TSO pilot**

By filling in the specific parameters of the Identification Property Set (Pset), referred to as “Identificativo”, each object can be classified according to the defined PBS.

Property sets and their attributes are directly linked to validation needs. Through the analysis of verification requirements, properties are defined to provide a direct response to specific checks.

This confirms that the definition of properties is not only a modelling activity but a critical step to enable effective validation, as each parameter is designed to respond to specific verification needs.

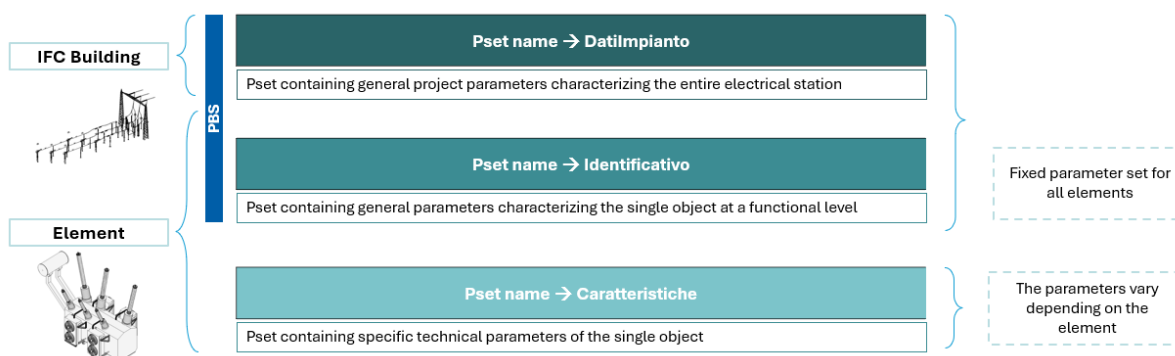


**Figure 9: Structure of property sets adopted in the TSO pilot to support validation activities**

Through the analysis of applicable regulations and technical specifications, a set of required checks for a reference project has been identified.

A bottom-up approach was adopted, starting from specific rules and progressively generalizing them into broader validation logics applicable across different scenarios.

This approach enabled the identification of recurring validation patterns, supporting the transition from project-specific checks to more generalizable rule structures.

The main rule families identified include

- Base distance comparison;
- Counting and comparison of elements against standard values;
- verification of permissible parameter values.

These rule families represent recurring validation patterns that can be generalized across different projects and asset types, confirming the scalability of the rule-based validation approach and scalability highlighted in the common framework.

The following are some examples:

| Requirement Description                                                    | Rule Type  | Check Type      | Methodological approach                             |
|----------------------------------------------------------------------------|------------|-----------------|-----------------------------------------------------|
| Distance between phases for busbars and equipment (2.20 m)                 | Geometric  | Clash detection | Interference detected in the clearance volume model |
| Distance between adjacent phases of two busbar systems (6 m)               | Geometric  | Clash detection | Interference detected in the clearance volume model |
| Distance between phases for busbars and equipment (2.20 m)                 | Geometric  | Clash detection | Interference detected in the clearance volume model |
| Distance between phases for line anchoring and overtaking conductors (3 m) | Geometric  | Clash detection | Interference detected in the clearance volume model |
| Insulation level for 132 kV and 150 kV sections ( $U_m = 170$ kV)          | Functional | Code checking   | IDS (Information Delivery Specification)            |
| Power frequency withstand voltage (325 kV)                                 | Functional | Code checking   | IDS (Information Delivery Specification)            |
| Lightning impulse withstand voltage (750 kV)                               | Functional | Code checking   | IDS (Information Delivery Specification)            |
| Minimum phase-to-ground and phase-to-phase distance (1500 mm)              | Geometric  | Clash detection | Interference detected in the clearance volume model |
| Operating current for busbars (2000 A)                                     | Functional | Code checking   | IDS (Information Delivery Specification)            |
| Nominal values for circuit breakers (2000 A)                               | Functional | Code checking   | IDS (Information Delivery Specification)            |
| Nominal values for disconnectors (2000 A)                                  | Functional | Code checking   | IDS (Information Delivery Specification)            |
| Nominal values for current transformers (400/5, 800/5, 1600/5 A/A)         | Functional | Code checking   | IDS (Information Delivery Specification)            |
| Nominal values for current transformers (200/5, 400/5 A/A)                 | Functional | Code checking   | IDS (Information Delivery Specification)            |
| Distance from road centerline to electrical equipment                      | Geometric  | Clash detection | Soft clash                                          |
| Danger zone distance (1.5 m)                                               | Regulatory | Clash detection | Interference detected in the clearance volume model |
| Minimum vehicle protection distance (1.6 m)                                | Regulatory | Clash detection | Interference detected in the clearance volume model |
| Proximity zone distance (3.5 m)                                            | Regulatory | Clash detection | Interference detected in the clearance volume model |

**Figure 10: Examples of validation rule families identified and implemented in the TSO pilot**

The application of the defined validation rules to BIM models enables the identification of non-compliances related to both information completeness and model configuration.

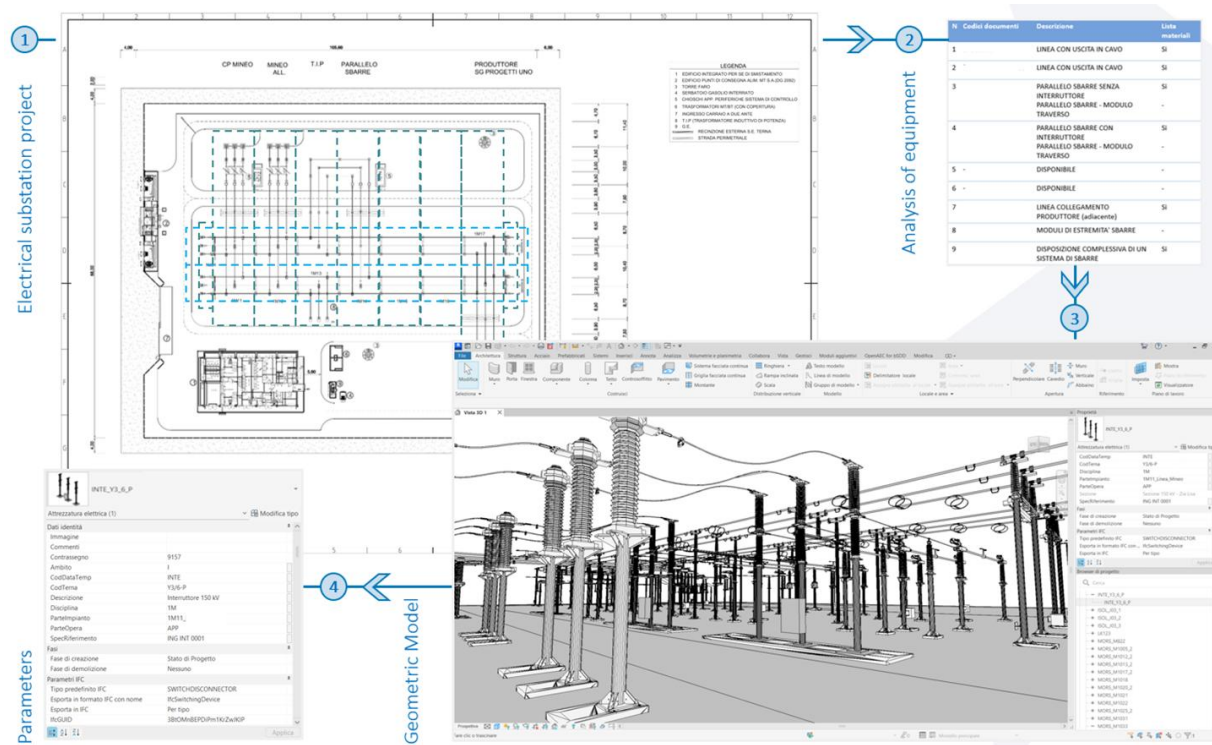


Figure 11 - BIM model development process extract

The rule-based validation approach allows systematic and consistent verification of model properties, relationships between elements and compliance with predefined requirements, significantly reducing the need for manual checks.

The validation process also highlights the strong dependency between data quality and validation effectiveness, confirming that a well-structured data model is a fundamental prerequisite for reliable results.

In this context, the adoption of automated validation is expected to improve the efficiency of the design review process, enabling faster identification of issues, increased consistency of checks and a more structured interaction between designers and the TSO.

Furthermore, the structured outputs generated by the validation process can support issue management workflows, ensure traceability of non-conformities and facilitate their resolution within iterative model development cycles.

Figure 12 illustrates object level identification of non-compliances, linking verification rules to specific model elements and parameters. Structured validation results enhance traceability of issues and support iterative feedback between designers and the TSO during the validation process.

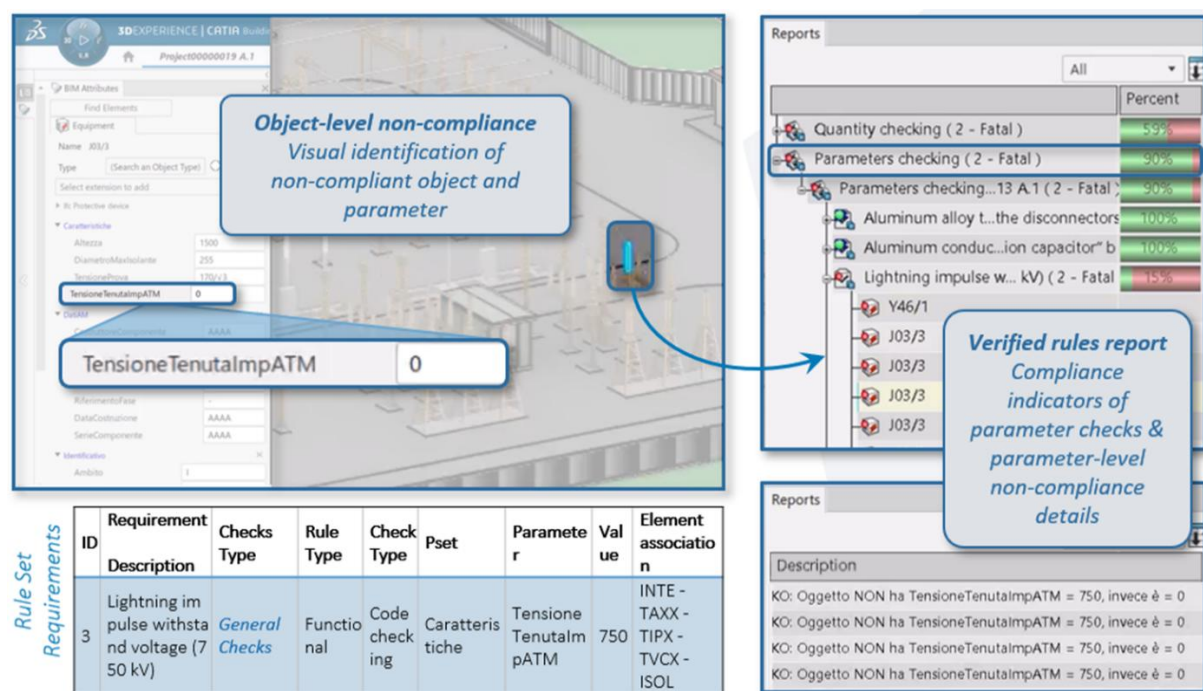


Figure 12 - Example of validation structured outcomes generated in the TSO pilot.

## 4.2 TSO Scalability assessment

The results of the Terna pilot highlight the strong scalability potential of the proposed validation approach, confirming that scalability is not achieved by replicating the validation tool, but by progressively extending a structured and reusable validation framework.

Despite the specificity of the data sheets adopted in the pilot, both TSO and DSO experiences confirm that general validation rules (rule families) are largely shared across asset types and projects. This commonality enables the reuse of validation logic independently from individual project configurations and represents a key enabler for scalability.

From a methodological perspective, the Terna pilot shows that scalability is driven by the progressive extension of the Asset Data Model. The validation framework follows a structured evolution path in which data models, rules and validation processes are progressively consolidated without requiring redesign of the validation logic. In particular, the scalability assessment can be described through successive stages of maturity:

- **Pilot Use Case - Project-driven setup**, in which the Asset Data Model is defined for a single transmission station. In this phase, coverage of station components is limited to the pilot scope, resulting in partial data model completeness (KPI 3.1 ≈ 49%). The validation framework is tested in a controlled project context to verify its applicability and robustness.
- **Extended Assets - Complete station Asset Data Model**, achieved through the progressive extension of the data model to include all station components. This phase leads to full coverage of Product Sheets for the station domain (KPI 3.1 = 100%), enabling the application of reusable validation rules across the complete asset data model while preserving the same validation framework.
- **Multi-Project - Future multi-asset scalability**, in which the validation approach can be extended to additional electrical asset domains beyond the single station. In this stage,

scalability is achieved through data model enrichment, while the same validation logic and workflow are preserved across different asset types.

- **Standard process and methodological maturity**, in which the validation framework is consolidated into a repeatable and reusable standard process. Validation workflows become independent from specific projects and configurations, enabling consistent application across different contexts and supporting long-term adoption.

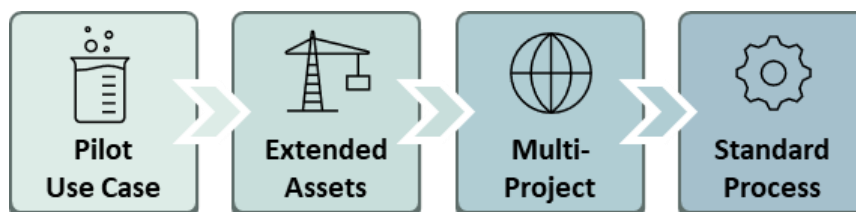


*Figure 13 -Asset-data-model-driven scalability path of the validation framework*

In this context, scalability is enabled by a set of key architectural factors that support the asset-data-model-driven evolution of the framework:

- The identification of **recurring rule families**, which can be applied as the Asset Data Model evolves from pilot-specific configurations to complete stations and additional asset domains;
- The use of **structured and standardized Asset Data Models**, which act as the primary driver for scalability by enabling progressive enrichment of information coverage without modifying the validation logic;
- The clear separation between **data models, validation rules and execution mechanisms**, which allows the same validation framework to be preserved across different projects, asset types and technological environments.

Together, these factors confirm that scalability is achieved through the reuse and progressive enrichment of Asset Data Models and validation rules, rather than through the replication of project-specific solutions or the redesign of validation processes.

Based on these principles, the pilot validation framework can evolve from a single use case towards broader adoption by progressively extending the Asset Data Model, while preserving the same validation logic, to:

- additional types of transmission assets (e.g. substations, lines and related components);
- different project phases, from design validation to construction and potentially operation;
- broader sets of requirements, including regulatory, technical and organizational constraints.

From a process perspective, this evolution enables increasing benefits over time. An initial effort concentrated on data modeling and rule formalization is progressively compensated by reduced marginal effort in subsequent projects, decreased manual validation activities, earlier identification of inconsistencies, and improved repeatability and traceability of checks.

In this context, scalability and cost-benefit considerations are tightly connected, supporting the transition from pilot experimentation to industrialized and standardized validation workflows within the transmission domain. Further activities will focus on consolidating this assessment through a

structured cost-benefit analysis and on defining a roadmap for progressive adoption across additional use cases and lifecycle phases.

### 4.3 DSO results

The activities conducted in the DSO context have led to a consolidated set of results that establish the foundational technical and methodological framework for OpenBIM-based validation, while deliberately leaving the detailed discussion of the pilot implementation to the subsequent chapter. Within a sector where infrastructure design and construction are predominantly outsourced, the generation of information models—intended to serve as the foundational representation for future digital twins—is largely delegated to external designers and contractors. Consequently, the development of a structured assurance mechanism is not merely an operational best practice but a fundamental requirement to guarantee the completeness, correctness, and internal consistency of project data while reducing the ambiguity and time typically associated with manual review processes.

A central pillar of this research implementation is the integration of the validation tool within the DSO's existing **Common Data Environment (CDE)**. The CDE is positioned as the core enabling component of the digitalization pathway, acting as the primary data exchange area between external designers and the DSO. It provides the necessary digital interface through which users can access the validation tool to verify deliverables. For the current project phase, this integration is implemented as a partial deployment, focused primarily on internal DSO oversight. This allows the DSO to maintain authoritative control over the validation process before potentially expanding access to the broader supply chain.

A key outcome was the formalization of open exchange formats, with **IFC (Industry Foundation Classes)** selected as the reference standard for model delivery and interoperability. This vendor-neutral foundation was chosen specifically to support heterogeneous authoring tools and ensuring long-term scalability of the validation framework. In parallel, the **DSO Data Dictionary** was fully implemented within the **Asset Domain**, which serves as the authoritative system governing asset information. The dictionary currently covers the technical properties for all asset types. The establishment of this semantic layer represents an essential prerequisite for reliable validation, as it ensures that information requirements are unambiguously defined before being translated into machine-checkable rules.

Building on this foundation, the research team defined the reference structure of the IFC model for validation purposes. This activity clarified how information is expected to be organized within the model, thereby reducing interpretative variability in deliveries and enabling systematic quality checks. Furthermore, the conceptual structure of the **IDS (Information Delivery Specification)** was defined as the formal container for validation logic. The IDS structure is articulated into two main sections: (i) a section that contextualizes the information defined in the Data Dictionary with respect to a specific model, and (ii) a section that encodes the rules used to verify compliance between the model data and the information governed in the Asset Domain.

The rule-definition process then focused on classifying and specifying the checks to be implemented through IDS. Two main categories of rules were identified: **information rules**, addressing the completeness and correctness of attributes (such as presence, datatype, and basic value constraints), and **model-structure rules**, addressing disciplinary and organizational aspects such as naming conventions, classification consistency, and Level of Information (LoI) requirements.

The effectiveness of this integrated approach was demonstrated through a Proof of Concept (PoC),

which successfully validated the workflow for information rules across all basic information types. The PoC produced standardized outputs in the form of structured reports and actionable tasks, confirming the feasibility of integrating automated validation within the DSO BIM framework. While the effectiveness of model structure rules has been defined at conceptual level and will be further assessed, the current results provide a standards-aligned mechanism to support recurring checks during project development and reduce friction at formal verification milestones.

Overall, these results confirm the feasibility of integrating automated validation within the DSO BIM framework, providing a standards-aligned mechanism to support recurring checks during project development and to reduce friction at formal verification milestones. This consolidated baseline enables the pilot implementation discussed in the next chapter, where the validation framework is applied to a concrete use case to assess its operational impact and practical adoption.

#### 4.3.1 Example - DSO results

The pilot for DSO implementation was developed using a primary substation as the representative use case for validating the proposed OpenBIM framework. The specific asset was selected due to its high information density and multi-disciplinary nature, where electromechanical equipment, civil works, and complex project constraints coexist, necessitating the consistent management of diverse information requirements. The primary purpose of the pilot was to verify the end-to-end operability of the framework—including the data dictionary, validation rules, and the validation engine— while demonstrating the value of self-checking for all the involved actors. By making validation accessible across the supply chain through the exchange area, designers/contractors and DSO experts are empowered anticipate compliance prior to formal submission, allowing the DSO to reduce time, ambiguity, and variability typically encountered during verification milestones.

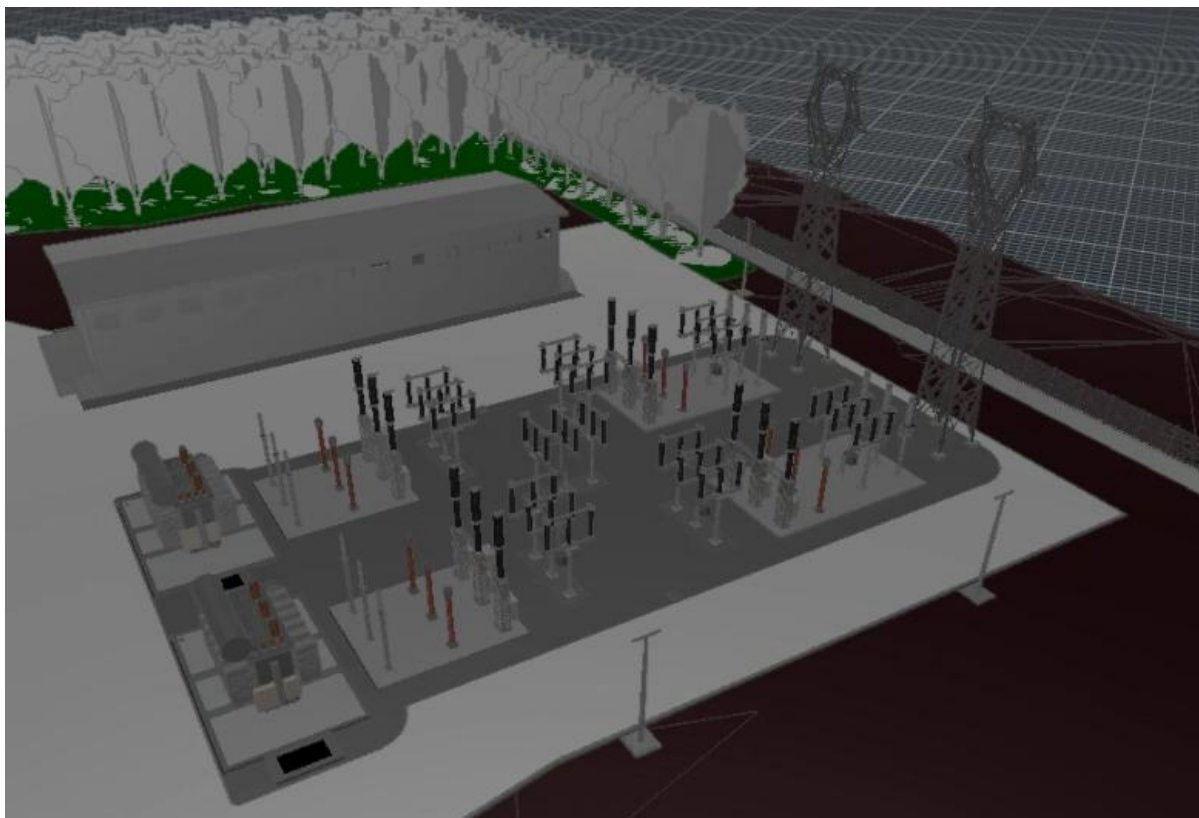


*Figure 14 - IFC model overview of the primary substation*

To ensure a traceable and repeatable process, the pilot relies on a strictly controlled set of inputs: (i) a representative IFC model of the primary substation, (ii) a specific version of the Data Dictionary governed within the Asset Domain, to serve as the semantic reference for defining and contextualizing requirements, and (iii) a pilot-specific IDS package created ad hoc, containing the information requirements and the corresponding validation rules applicable to the deliverable. For the purposes of this research phase, the analysis was deliberately limited to information rules, intentionally excluding more complex structural constraints to focus on assessing the quality of the informational content itself. This rule set includes presence checks to verify the existence of mandatory properties, datatype checks to ensure compliance with expected formats (such as strings or booleans) and allowed value checks to evaluate membership in specified datasets or patterns.

The validation workflow follows a structured sequence within the digital environment, encompassing the ingestion of IFC and IDS files, the binding of model data to the Data Dictionary, the automated execution of checks, and the final generation of a comprehensive report. The core value of this automated process lies in its inherent repeatability, which allows for consistent self-checking by all actors prior to formal delivery. By enabling the supply chain to detect and resolve errors iteratively, the framework effectively reduces late-stage non-conformities and accelerates the overall convergence toward organizational requirements.

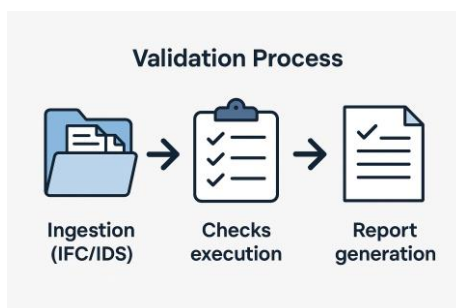


**Figure 15: Validation process**

| Nome proprietà                           | Codice proprietà                         | Tipo   | Unità di misura | Valori consentiti | Milestone | Azioni |
|------------------------------------------|------------------------------------------|--------|-----------------|-------------------|-----------|--------|
| SUBTYPE_MASTERDATA__COUNTRY              | SUBTYPE_MASTERDATA__COUNTRY              | String | -               | -                 | LOD300    | ⋮      |
| SUBTYPE_MASTERDATA__DESCRIPTION          | SUBTYPE_MASTERDATA__DESCRIPTION          | String | -               | -                 | LOD300    | ⋮      |
| SUBTYPE_MASTERDATA__DISTRIBUTION_COMPANY | SUBTYPE_MASTERDATA__DISTRIBUTION_COMPANY | String | -               | -                 | LOD300    | ⋮      |
| SUBTYPE_MASTERDATA__GLOB_CAT_CODE        | SUBTYPE_MASTERDATA__GLOB_CAT_CODE        | String | -               | -                 | LOD300    | ⋮      |
| SUBTYPE_MASTERDATA__GLOB_TYPE_CODE       | SUBTYPE_MASTERDATA__GLOB_TYPE_CODE       | String | -               | -                 | LOD300    | ⋮      |
| SUBTYPE_MASTERDATA__GLOB_TYPE_DESC       | SUBTYPE_MASTERDATA__GLOB_TYPE_DESC       | String | -               | -                 | LOD300    | ⋮      |
| SUBTYPE_MASTERDATA__MATERIAL_CODE        | SUBTYPE_MASTERDATA__MATERIAL_CODE        | String | -               | -                 | LOD300    | ⋮      |
| SUBTYPE_MASTERDATA__MATERIAL_CODE_OLD    | SUBTYPE_MASTERDATA__MATERIAL_CODE_OLD    | String | -               | -                 | LOD300    | ⋮      |
| SUBTYPE_MASTERDATA__PARENT_MODEL_ID      | SUBTYPE_MASTERDATA__PARENT_MODEL_ID      | String | -               | -                 | LOD300    | ⋮      |
| SUBTYPE_MASTERDATA__REVISION_CODE        | SUBTYPE_MASTERDATA__REVISION_CODE        | String | -               | -                 | LOD300    | ⋮      |

**Figure 16: Example of attributes from the data dictionary, which can be translated into rules**

The rule set applied in the pilot is deliberately limited to information rules to evaluate the deliverable's adherence to requirements in a clear and auditable manner. This scope includes presence checks to verify the existence of mandatory properties/attributes, datatype checks to ensure

the compliance of the expected information type (such as strings, numbers, booleans, or enumerations), and allowed values checks to evaluate membership in specific dataset or patterns.

Figure 17 shows the 'Set new rule' dialog box. It has a progress bar with two steps: 1. Select type of rule (completed) and 2. Set the rules (active). Under step 2, there is a section for 'Allowed Value' with an 'Add value' input field containing 'IT' and a green checkmark. There are 'Back' and 'Confirm' buttons at the bottom.

Figure 17: Example of creating a text rule

The validation outputs resulting from this process are provided in an operational form designed to support both high-level interpretation and granular corrective action. These outputs consist of (i) a structured report that summarizes the overall compliance status—providing auditable evidence of results—and (ii) a set of generic issues that function as non-conformance notifications. These attention points are intended to guide designers through an iterative remediation process. Consequently, the interpretation of these results is organized at two distinct levels. At the “macro” level, the system provides a synthesis of overall compliance and the identification of recurring error categories. At the “micro” level, the tool is oriented toward direct correction by providing granular issues that reference the specific model element and the exact requirement that was violated. This dual-level interpretation shifts validation from a purely final control into a progressive convergence mechanism, enabling a significantly faster correction loop between the supply chain and the DSO.

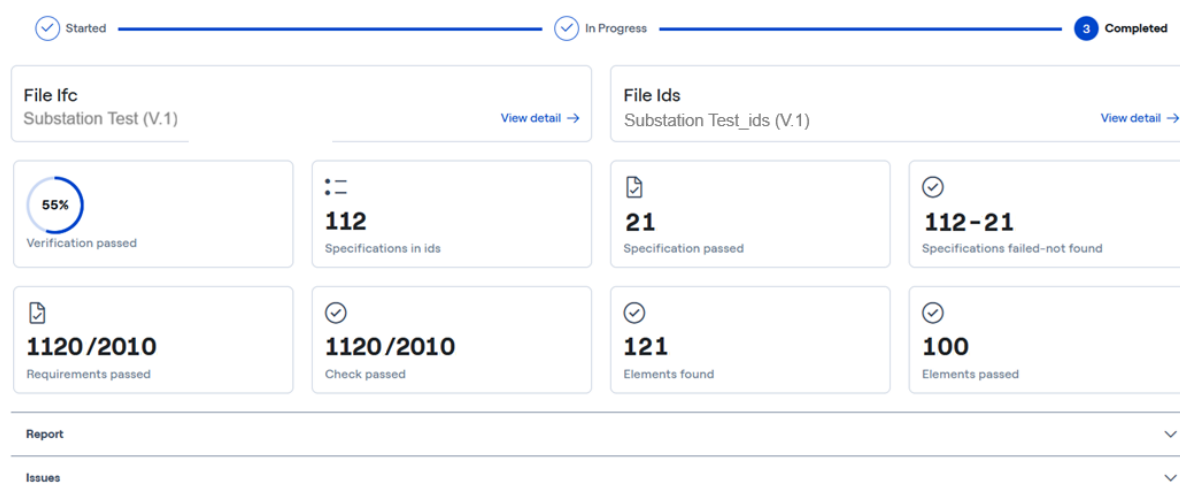


Figure 18: Example of a report generated by the validator

## 4.4 DSO Scalability assessment

Within the proposed BIM methodology, scalability should be understood as an intrinsic property of the information management approach rather than as the simple ability to extend a single checking or verification tool. In the context of a DSO, this scalability primarily relates to the ability to progressively structure, govern, and expand a coherent framework for managing information requirements and controls across diverse assets classes, project phases, and operational scenarios. This approach shifts the focus from individual software tools to the overall architecture of data and rule management, emphasizing the total adoption of BIM principles across the infrastructure's lifecycle. A central enabler of this long-term adaptability is the methodological choice to maintain a clear separation between the core components of the framework: the Data Dictionary for semantic alignment, the validation rules, and the validation engine itself. By externalizing requirements and controls through machine-readable formats, the DSO ensures they remain explicit, manageable, and capable of evolving alongside changing technical or regulatory needs.

At the technical level, a fundamental principle of this methodology is the decoupling of the information model from the validation logic. Through the implementation of Information Delivery Specifications (IDS), requirements are formalized independently of both the specific IFC model structure and the software used for validation. This modularity allows for the incremental extension of the scope, enabling the DSO to begin with a limited and well-defined asset class, such as a primary substation, and subsequently incorporate additional grid elements like overhead lines, secondary substations, or distributed energy resources. Over time, this growth becomes increasingly efficient as many validation rules are reusable across multiple assets and use cases, further embedding the BIM methodology into the core operational processes of the utility.

The transition from manual, experts-based review to automated and repeatable controls is a critical methodological shift for DSOs managing increasing design volumes and renewable energy integration. By standardizing activities that historically relied on individual interpretation, the framework ensures a high level of data quality and procedural consistency. While the current implementation focuses on internal DSO oversight within the Common Data Environment (CDE), there is a clear strategic vision for future expansion. The CDE integration is intended to be extended once the library of models and rules has reached a sufficiently broad scope, and DSO experts have finalized the definitive rule sets for deployment. At that stage, the DSO intends to grant direct access to contracted designers, allowing them to utilize the validation engine for iterative self-checking during the model development phase. This methodological shift is particularly relevant in environments characterized by increasing design volumes, tighter timelines, and a growing number of stakeholders, such as DSOs managing network expansion and renewable integration. Scalability, in this sense, is not only quantitative but also procedural, as the same validation logic can be consistently applied across a large number of projects.

At the organizational level, the methodology supports a clearer allocation of roles and responsibilities along with the BIM process. The DSO retains ownership of information requirements and validation rules; designers and contractors are responsible for producing models compliant with those requirements, and the validation system provides objective and automated feedback. Importantly, the availability of the validation framework to all actors enables iterative self-checking during model development, before formal submission. This aspect is particularly relevant within BIM methodologies, as it fosters early error detection, reduces rework, and shortens review and approval cycles, ultimately improving collaboration across the supply chain.

Finally, the adoption of OpenBIM standards—such as IFC for data exchange, IDS for requirement specification, and bSDD for semantic alignment—reinforces the methodological scalability of the proposed approach. By avoiding dependence on proprietary tools or project-specific solutions, the framework remains aligned with broader BIM standardization efforts and can be more easily adapted to different organizational contexts or regulatory environments. This openness also supports the potential replication of the methodology beyond the single DSO or national context.

In conclusion, within the proposed BIM methodology, scalability should be interpreted as the ability to progressively extend information requirements, validation rules, and controlled assets while maintaining coherence, data quality, and governance: the total adoption of this methodology ensures that the information model matures into a structured and manageable Digital Twin. The long-term scalability of the grid's digital ecosystem is thus secured by the clear governance of data, rules, and validation mechanisms, supporting Europe's broader energy and climate goals.

## 4.5 Transversal Results: Immersive Reality Integration

Beyond the specific pilot results documented in the previous sections, the project achieved a significant transversal milestone by demonstrating how validation outputs can effectively fuel advanced digital tools within the TwinEU ecosystem. A critical aspect of this development involves the evaluation of the project's technical architecture and the strategic choice of integration components. While the **TwinEU-connector** has been designed as a key enabling component for data flows in various other pilots, the specific requirements of the design validation task highlighted that the **Common Data Environment (CDE)** already provides a sufficient and intrinsic interconnection for its current purposes. Within this framework, the CDE acts as the primary integration layer, ensuring that model data and validation rules remain tightly coupled without the immediate necessity of external connectors for the validation workflow itself.

Furthermore, the research team concluded that discussions regarding full-scale model exchange and complex interoperability between different System Operators (SOs) remain premature at this stage. The current focus of the work is firmly placed on the fundamental task of constructing and perfecting the **physical Digital Twin**—ensuring its geometric accuracy, alignment with the **Level of Information Need (LOIN)**, and overall informational depth. Establishing this solid physical foundation is a prerequisite that must be fulfilled before addressing the higher-level complexities of inter-operator data sharing and cross-domain interoperability.

Despite these focused boundaries, a highly productive synergy was established with the immersive reality team, involving a collaborative effort between the Task 6.2 members and partners **Areti** and **Engineering (ENG)**. This cooperation focused on the implementation of an **Immersive Reality (IR)** tool as one of the project's transversal solutions. During the early analytical stages, Areti participated in the comparative study of DSO and TSO data models. Although the IFC model provided by Areti featured a distinct internal structure compared to the primary Terna and Enel pilots, this diversity was instrumental in testing the flexibility and robustness of the validation methodology. Areti effectively served as a strategic bridge between the validation experts and the developers at Engineering (ENG), ensuring that the technical requirements and operational constraints of grid operators were seamlessly integrated into the transversal tool's functional design.

In the final implementation phase, the Task 6.2 team leveraged its specialized know-how to define a specific set of automated validation rules tailored for immersive visualization. These outcomes were successfully integrated into the IR tool as a primary use-case demonstration. This integration showcases how validation results—such as clash detection findings and metadata compliance—can

be intuitively navigated within a 3D immersive space, providing grid operators with enhanced situational awareness and a powerful interface for technical supervision. For a more comprehensive description of the immersive reality transversal tool and its technical architecture, readers are referred to Deliverables D4.1 and D4.3.

## 5 Conclusions

The work documented in this deliverable represents a fundamental milestone in the journey toward the digitalization of energy infrastructure management. By moving from a fragmented, manual review process to a structured, automated validation framework, the project has not only developed a technical solution but has also defined a clear methodology for the adoption of Building Information Modelling (BIM) within the High Voltage (HV) and Medium Voltage (MV) sectors. This journey began with a rigorous analysis of the "AS-IS" scenarios for both the Italian Transmission System Operator (TSO) and the major Italian Distribution System Operator (DSO), identifying the inherent inefficiencies and risks associated with traditional design verification. The subsequent implementation of a common framework—based on the strategic decoupling of the Data Dictionary, the Rules Engine, and the Validation Tool—has proven that a standardized, OpenBIM-based approach is not only viable but essential for managing the increasing complexity of modern power grids.

The success of the pilots demonstrated that the core of design validation lies in the quality and governance of data. The establishment of an enterprise-level Data Dictionary, aligned with international standards such as bSDD, provided the necessary semantic foundation to ensure that all stakeholders speak the same technical language. This allowed for the translation of complex regulatory and technical constraints into machine-readable Information Delivery Specifications (IDS), effectively turning static prescriptions into dynamic, checkable rules. The results from the TSO and DSO pilots, ranging from high-voltage connection stations to multi-disciplinary primary substations, confirmed that automated validation can dramatically reduce the time and ambiguity involved in project approvals, fostering a more collaborative relationship between System Operators and their external supply chains.

However, the project has also served as a critical lens through which the limits of current BIM adoption in the energy sector have been highlighted. While other industries, particularly the civil and architectural construction sectors, have achieved a level of "total integration," the energy industry is still in an intermediate phase. In a mature architectural BIM environment, the objects within a model possess intrinsic intelligence and interconnectedness: for example, when a designer inserts a door into a building model, the system can automatically recalculate room volumes, update thermal transmittance values, and adjust the Bill of Materials (BoM) in real-time. This is possible because the "Building Domain" has been standardized for decades, with clearly defined relationships between physical objects and their functional properties. In the electrical infrastructure domain, we are currently constructing the "Physical Digital Twin"—a precise 3D representation enriched with technical metadata—but we have yet to achieve full "Functional Integration". The true missing piece remains a dedicated, industry-specific data domain that seamlessly bridges the gap between physical representation and electrical logic. One of the most significant gaps identified during this project is the lack of direct correspondence between the 3D physical model and the single-line diagram (SLD). In current workflows, these two fundamental representations of the same asset often exist in separate silos, requiring manual synchronization. A truly integrated BIM methodology would require a system where a change in the electrical scheme (such as replacing a circuit breaker) would automatically propagate to the 3D model and its associated technical validation rules.

Furthermore, the project highlighted the difficulty of automating specific electrical safety verifications, such as the precise checking of clearances (franchi) [14] [15]. In a traditional design, verifying the minimum distances between conductors, or between live parts and non-live parts, is a complex task that depends strictly on the voltage level and environmental conditions. While the current validation framework can check if a parameter exists and falls within a range, it lacks the

geometric-electrical intelligence to dynamically calculate and verify these clearances based on the active state of the network. To achieve this, the BIM model must transcend its role as a static container of information and become a computationally active element of the grid's operational logic. This intermediate phase has been essential for System Operators to identify these bottlenecks. TwinEU has provided the sandbox needed to test the robustness of OpenBIM standards like IFC and IDS in a sector that is traditionally characterized by proprietary formats and fragmented legacy systems. The decision to prioritize the Common Data Environment (CDE) as the central hub for validation, rather than relying on external connectors, has emphasized that the immediate priority for SOs is the consolidation of internal data governance and the perfection of the physical twin before tackling the higher-level complexities of inter-operator interoperability.

In conclusion, the scalability of the proposed methodology is not merely a technical property of the tool, but a strategic roadmap for the total adoption of BIM across the infrastructure lifecycle. By formalizing the limits of current adoption, this deliverable outlines the necessary steps for the "second period" of development. The transition from manual, expert-based review to automated, repeatable controls is a non-reversible shift that is critical for managing the energy transition. As the library of rules grows and the integration between physical and functional data models matures, the validated BIM model will finally evolve into a high-quality Digital Twin, ready to support not only design and construction but the entire operational and maintenance lifecycle of the European energy grid. The clear governance of data and rules established here will serve as the bedrock for Europe's broader goals of grid resilience and renewable energy integration.

## References

- [1] **International Organization for Standardization** (2018). *Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling — Part 1: Concepts and principles* (ISO Standard No. 19650-1:2018). <https://www.iso.org/standard/68078.html>
- [2] **International Organization for Standardization** (2018). *Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling — Part 2: Delivery phase of the assets* (ISO Standard No. 19650-2:2018). <https://www.iso.org/standard/68080.html>
- [3] **International Organization for Standardization** (2024). *Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries — Part 1: Data schema* (ISO Standard No. 16739-1:2024). <https://www.iso.org/standard/81044.html>
- [4] **buildingSMART International** (2024). *Information Delivery Specification (IDS) — A machine-readable definition of data exchange requirements based on IFC*. <https://technical.buildingsmart.org/standards/information-delivery-specification-ids/>
- [5] **buildingSMART International** (2020). *BIM Collaboration Format (BCF) — XML Data Schema and REST API v2.1*. <https://technical.buildingsmart.org/standards/bim-collaboration-format/>
- [6] **International Organization for Standardization** (2007). *Building construction — Organization of information about construction works — Part 3: Framework for object-oriented information* (ISO Standard No. 12006-3:2007). <https://www.iso.org/standard/38706.html>
- [7] **International Organization for Standardization** (2020). *Methodology to describe, author and maintain properties in interconnected data dictionaries* (ISO Standard No. 23386:2020). <https://www.iso.org/standard/75401.html>
- [8] **International Organization for Standardization** (2020). *Building information modelling (BIM) — Data templates for construction objects used in the life cycle of any built asset — Concepts and principles* (ISO Standard No. 23387:2020). <https://www.iso.org/standard/75403.html>
- [9] **International Electrotechnical Commission** (2020). *Energy management system application program interface (EMS-API) — Part 301: Common Information Model (CIM) base* (IEC Standard No. 61970-301:2020). <https://webstore.iec.ch/publication/60996>
- [10] **European Commission** (2023). *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - Grids, the missing link - An EU Action Plan for Grids* (COM/2023/757 final). <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52023DC0757>

- [11]**European Commission** (2025). *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions – ‘European Grids Package’*: (COM/2025/1005). <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52025DC1005>
- [12]**European Parliament and Council** (2014). *Directive 2014/25/EU on procurement by entities operating in the water, energy, transport and postal services sectors and repealing Directive 2004/17/EC*. <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32014L0025>
- [13]**Italian Republic** (2023). *Legislative Decree no. 36 of 31 March 2023 - Public Contracts Code (Codice dei Contratti Pubblici)*. [Specifically referencing Annex I.9 regarding the gradual mandatory introduction of digital methods and electronic tools for construction and infrastructure].
- [14]**European Committee for Electrotechnical Standardization (CENELEC)** (2021). *Power installations exceeding 1 kV a.c. and 1,5 kV d.c. — Part 1: AC* (EN Standard No. 61936-1:2021 / CEI EN 61936-1). [Reference for the dynamic calculation of electrical clearances, phase-to-phase distances, and safety zones in substations].
- [15]**Italian Electrotechnical Committee (CEI)** (2014). *High voltage electrical installations* (CEI Standard No. 11-1). [Historical and methodological reference for technical prescriptions on safe clearance boundaries for grid assets integration].