Design, Operation and Maintenance of Electrical Substations: Key Considerations for Building Information Modeling

Pedro Nogueira de Resende[1, 2]; João Rodolfo Côrtes Pires[2]; Alberto Luiz Francato[1]

[1]Department of Water Resources, University of Campinas (UNICAMP), Campinas, Brazil.

[2]Côrtes Consultoria e Assessoria, Côrtes Consultoria, Campinas, Brazil.

Corresponding author: p223458@dac.unicamp.br

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Abstract

In line with global digitalization trends, the power sector has increasingly adopted digital tools for assets like electrical substations. Despite the potential benefits, driven by significant investments and the need for operational reliability, current Building Information Modeling (BIM) standards and applications do not fully address the unique requirements of these infrastructures. This study employs an exploratory approach to map existing applications, identifying advances, challenges, and critical considerations. The findings reveal limitations in the IFC 4.3 schema, map relevant information sources for substation digitalization, propose an element identification system based on existing literature, and outline considerations for BIM implementation workflows. As a practical contribution, this study provides initial guidelines to support future BIM applications in substations, recommending validation through case studies and analysis of complementary standards.

Keywords: Building Information Modeling, BIM, Digitalization, IFC, Operation and Maintenance, Substation

1 Introduction

Digital technologies can improve efficiency, monitoring, and management of physical infrastructures. The digitalization of these infrastructures refers to the process of transforming analog systems into digital ones. This process involves the integration of technologies such as the Internet of Things (IoT), Big Data, Building Information Modeling (BIM), and Digital Twins (DT), driven by computational advances in various fields of engineering.

Although the digitalization of residential and commercial buildings has led to the development of digital tools and workflows, this does not mean that other types of infrastructure, such as substations, cannot also benefit from these advances. On the contrary, the specific challenges of these assets — related to technical complexity, continuous operation, and the need for high reliability — make digitalization even more promising in this context.

In this scenario, digital models applied to substations have the potential to support the entire asset lifecycle, from planning and design to the operation and maintenance (O&M) phases. Advantages include improved document control, cost reduction, better project quality, and support for applications such as quantity take-offs, lighting studies, and the design of protection and control systems (Redmond, 2022).

However, the lack of standards specific to this area of application has been pointed out as one of the main obstacles to adoption of BIM in substations, even leading Brazilian companies to abandon initiatives due to high costs, delivery delays, or a lack of clarity regarding the benefits (Cotes et al., 2024). This combination of application potential and absence of consolidated guidelines highlights a significant gap in both the literature and professional practice.

Another factor that reinforces the value of BIM for this sector is the growing adoption of computational simulation methods to support decision-making. Since electrical systems in operation cannot be used as test objects, digital models and simulations become essential tools for the safe and efficient planning of asset operation (W. Wang & Li, 2010).

This article aims to gather key considerations, references, and insights for professionals and teams interested in implementing BIM in substations, particularly those focused on the future use of digital models as tools to support operation and maintenance. To this end, the study analyzes available standards and models and their usefulness for implementing BIM in substations, as well as maps relevant information and data sources for professionals aiming to use these digital models during the operation and maintenance stages.

Accordingly, Section 2 and 3 present the theoretical background on BIM implementation in substations and the main challenges faced by such projects. Section 4 describes the methodology used to identify guiding principles. In Section 5, the results are organized around three central topics, and finally, Section 6 presents the study's conclusions.

2 Substations Project

Substations play a strategic role within the power system, serving as key nodes for the transformation and distribution of electricity. With the growing global demand for energy and the increasing need for reliable power supply, ensuring efficiency throughout the planning, construction, operation, and maintenance stages of these critical infrastructures has become essential. In this context, the expansion of substation networks and the ongoing modernization of existing facilities highlight the importance of exploring new techniques and methods aimed at improving performance, safety, and asset management.

Among the main challenges faced in the operation of these assets is the excessive workload (Cao et al., 2020), as conventional maintenance still relies on manual, repetitive, and time-consuming inspections. Furthermore, inefficiencies during inspections, poor quality of data collected in the field, and shortcomings in statistical analysis have been frequently reported (Yan et al., 2024). The inherent complexity of these facilities and the risks related to high-voltage systems also demand strict safety measures, further complicating operational activities (Xing et al., 2023).

Understanding the physical and functional structure of a substation is crucial to developing intelligent, safe, and digitally integrated solutions—such as the use of BIM models, SCADA (Supervisory Control and Data Acquisition) systems, and remote monitoring technologies. Table 1 below outlines the main components of a substation, organized by functional category (Krieg, 2021).

Category	Components	Main Function
Primary Connections and Distribution	Primary power lines or cables; Busbars and overhead conductors	Transmission and interconnection of power flows between different equipment
Transformation and Measurement	Power transformers; Instrument transformers (voltage and current)	Voltage level adjustment and measurement for protection and control
Switching and Protection	Circuit breakers; Disconnectors; Surge arresters	Fault protection and safe operational switching
Reactive Compensation	Reactors; Capacitor banks	Power factor correction and voltage control
Insulation and Support	Support insulators; Bushings	Electrical insulation and mechanical support for conductors and equipment
Control and Automation	Secondary control and protection systems; Control building	Monitoring, protection, and remote operation of the substation
Support Systems	AC and DC auxiliary systems (including emergency generator); Earthing system; Environmental systems (e.g., HVAC)	Support for continuous and safe substation operation
Physical Infrastructure and Security	Civil structures and structural supports; Security fences	Physical protection of assets and restriction of unauthorized access

Table 1 – Substations Components. Source: Adapted from (Krieg, 2021).

In this context, the use of three-dimensional (3D) models of substations during the design and operational phases can yield significant benefits. These models can support layout evaluation and the detection of physical clashes between components, as well as the analysis of interactions among elements. This enables validation of aspects such as electromagnetic field effects, fire protection strategies, signal transmission, and accessibility for monitoring and maintenance (Jiang et al., 2022).

Beyond geometric representation, these analyses require the collection, storage, and processing of relevant information. Therefore, mapping potential metadata sources is essential for the development of models suitable for such simulations. Such information can be explored using different analytical methods, including regression analysis, classification, and clustering. Regression analysis can be applied to predict continuous variables such as equipment lifespan and load demand. Classification algorithms can categorize data for fault diagnosis and condition assessment. Lastly, cluster analysis supports the identification of patterns and natural groupings, such as asset health states (Ju et al., 2024).

BIM stands out as an integrative platform capable of consolidating both geometric and non-geometric data within a unified information environment, known as the Common Data Environment (CDE), defined by ISO 19650. This centralization facilitates the application of advanced analytical methods and supports the design, visualization, and sharing of results throughout the substation lifecycle. The following section explores key applications of BIM in the context of electrical substations.

3 BIM for Substations

BIM is a digital representation of the physical and functional characteristics of a facility, providing a comprehensive platform for information management throughout the entire life cycle of a project. This includes the planning, design, construction, operation, and maintenance phases (Azhar, 2011). The increasing global implementation of BIM has reshaped the Architecture, Engineering and Construction (AEC) industry while also highlighting the need for standardization to ensure its consistent application. This demand has driven the development of norms and guidelines aimed at structuring its implementation (F.H et al., 2025).

Among the main internationally recognized standards are ISO 19650, IFC (Industry Foundation Classes), COBie (Construction-Operations Building information exchange), NBIMS-US (National BIM Standard – United States), and BS 1192. ISO 19650 stands out due to its international scope, establishing guidelines for information management across the entire asset life cycle and promoting structured collaborative environments.

Despite the efforts to structure BIM implementation in the AEC industry, due to its multidisciplinary nature and complex scope, the general standards still fail fully addressing the specific needs of specialized sectors, such as the power sector. In the case of substations, there is a noticeable gap in existing BIM standards and methodologies (Cotes et al., 2024), stemming from the particular characteristics of these assets in comparison with conventional buildings. This is due, among other factors, to the fact that traditional approaches are not sufficient to deal with the inherent risks of substations, requiring specific solutions (CIGRE Working Group B3.38, 2018).

Although the IFC standard is widely used in BIM environments, its application in substations faces limitations, particularly in representing complex equipment and integrating 3D models with 2D schematics. Elements such as high-voltage transformers demand specific abstractions — for electromagnetic simulations, fire protection, and maintenance planning — that are not yet supported by the IFC standard. As a result, companies in the power sector have adopted alternative standards, such as Grid Information Modeling (GIM) (Jiang et al., 2022).

Moreover, the power sector stands out for its high capital investment, technological complexity, and stringent quality requirements, which justifies investing in high-quality design practices (Hu et al., 2016). The importance of substations within the electrical system is associated with their structural complexity, the presence of multiple equipment types, and the diversity of voltage levels. This makes the development of three-dimensional simulation systems especially relevant for operational and maintenance purposes (Meng & Kan, 2010). These characteristics reinforce the potential benefits of implementing BIM in this sector, as demonstrated in pilot projects where advantages such as intelligent design automation, interdisciplinary collaboration, automatic drawing generation, and cost reduction have been observed. These initiatives have also demonstrated the limitations of 2D approaches in terms of time efficiency, consistency, and accuracy when compared to 3D design (Redmond, 2022).

The literature indicates that the application of BIM in electrical infrastructure has progressed along specific development directions, bringing the sector closer to an ideal implementation of BIM in substations. One such front is the use of BIM-based designs for the prefabrication of steel profiles in substation structures, which increases production accuracy and reduces rework during assembly (Tang et al., 2018). Applications in substation projects show promising efficiency gains, with reports of time savings of up to 40% for design teams (Bentley Systems, [s.d.]). During the construction phase, models have also been used with image recognition and augmented reality technologies. BIM was employed for real-time overlay between digital models and the actual environment. This enables quantity comparisons, tracking of physical progress on site, and the provision of accurate data for intelligent statistical analyses (Qin et al., 2024).

It is also possible to integrate BIM with Geographic Information Systems (GIS), creating new opportunities for cross-referencing spatial and technical data (Azevedo et al., 2021). Furthermore, the use of BIM models integrated with virtual reality technologies has been explored for training substation operators, providing immersive environments that enhance familiarity with infrastructure, improve practical training, and contribute to operational safety (Nasyrov & Excell, 2018; M. Wang et al., 2023). Virtual reality (VR) immersion initiatives using game-based simulations have already been tested (Figure 1), showing high acceptance among utility technicians (Bernal et al., 2022).

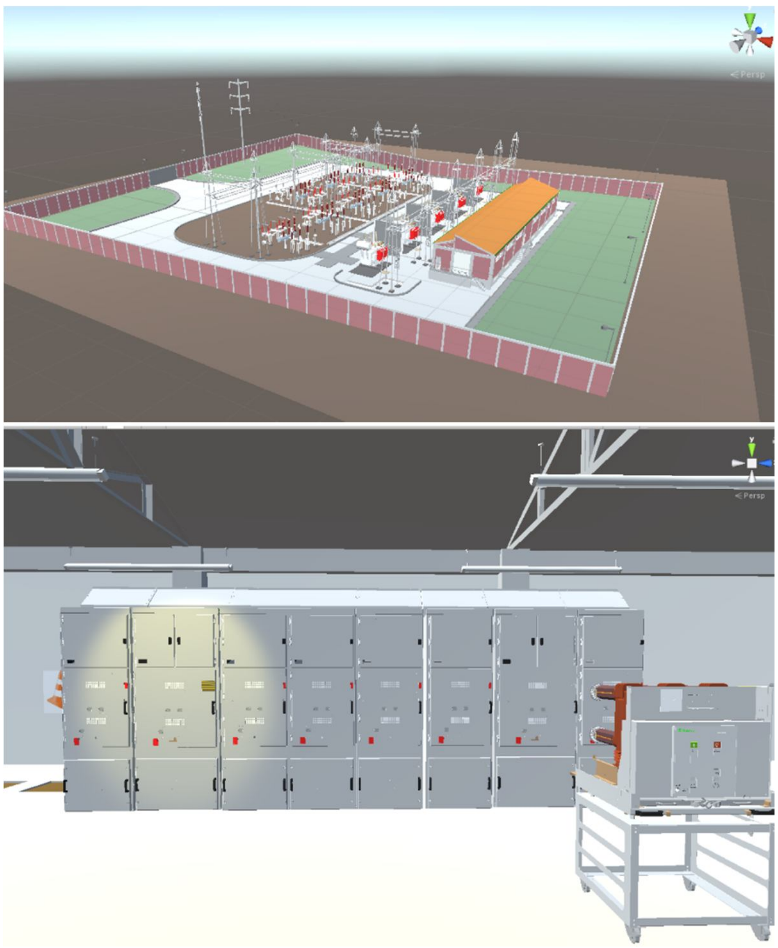

Figure 1 – Substation rendered via Unity3D: general view (above) and control room with medium-voltage switchgear and backup circuit breaker (below). Source: Bernal et al. (2022)

Although useful for visualization purposes, conventional digital models still face significant limitations in accurately representing operational characteristics and engineering requirements, which restricts their applicability as design and technical validation tools (Tong et al., 2023). This limitation highlights the need for guidelines that enable the use of digital models in more advanced simulations, particularly for supporting the technical and operational management of electrical substations.

In this context, notable examples include the application of parametric models in finite element analysis (FEA), such as predicting temperature rise in high-capacity connectors — directly contributing to the optimization of critical components and the mitigation of thermal failures (Capelli et al., 2017). Another relevant case involves the use of 3D models for the design of internal systems, such as the layout of flexible cables in 500 kV substations (Tong et al., 2023).

Among the recent approaches toward digitalization, the use of digital twins also stands out. Commercial tools like *primtech DT* supports substations design in virtual environments, supporting integration with asset management systems and operational simulations (Figure 2). The platform enables, for example, the analysis of current flows, switching operations of equipment, and simulation of the performance of lightning protection systems — making it possible to evaluate lightning arrester coverage and technically validate the adopted system (Cotes et al., 2024). These applications serve as the foundation for organizing and defining the premises addressed in the subsequent sections.

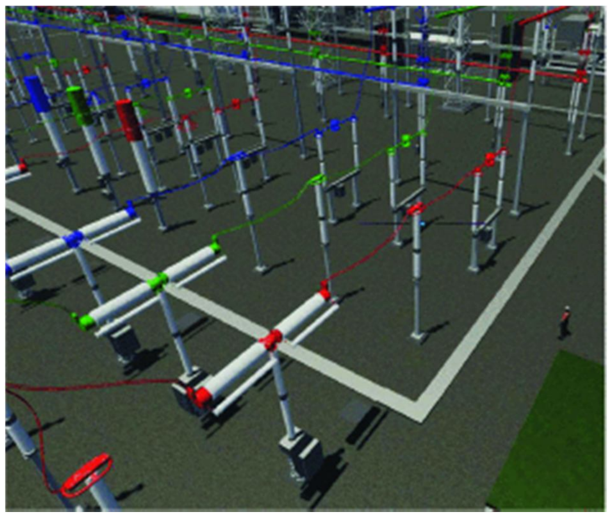

Figure 2 – Simulation of phase routing and switching in the primtech DT platform. Source: Cotes et al. (2024)

4 Methodology

This study adopts an exploratory and qualitative approach, centered on technical data collection and document-based analysis. The main objective of the investigation is to identify guidelines for BIM modeling with a focus on important aspects for Operation and Maintenance (O&M).

The methodology was structured into three main components. The first consisted of a technical review of international interoperability and modeling standards, with emphasis on the IFC schema and the COBie standard. The objective was to identify entities, attributes, and limitations of these standards regarding the representation of typical substation components and their operational data. It is important to note that, although the IFC standard still presents challenges in representing power generation equipment, it was deemed relevant for this study due to its accessibility and international scope (Jiang et al., 2022).

The second methodological phase involved the survey of technical information sources commonly used in the design and operation of substations. This stage was supported by a general analysis of the main systems and components present in substations, along with a literature review aimed at identifying key data for O&M-oriented modeling. For the identification of informational parameters, the concept of *power big data* was adopted as a reference (Zhang et al., 2019), which organizes large volumes of data from the electric sector into categories such as equipment data, failure history, operation logs, inspection, and maintenance records (Khuntia et al., 2019).

Finally, a BIM Element Identification System was proposed. To support the organization and interoperability of modeled elements, a BIM model identification system following the framework proposed by Qi et al. (2020) was adopted. This approach critiques the automatic identifiers generated by authoring software and suggests a standardized and intelligible structure for engineering applications. All results were discussed, and considerations regarding the implementation of BIM in substations were presented.

5 Results and Discussion

5.1 IFC and COBie Analysis

IFC is an open data format developed with the aim of enabling interoperability between different software tools used in BIM processes. Its broad acceptance within the AEC sector has contributed to its consolidated use in disciplines such as architecture, structural design, plumbing systems, and HVAC, where IFC has proven effective as a medium for information exchange across different platforms.

However, the general nature of the IFC schema presents limitations when it comes to modeling systems with specific and complex characteristics, such as substation. The application of the IFC standard in this context faces a series of technical barriers that hinder its full adoption (Jiang et al., 2022). Among the main challenges identified are:

i) Multiple representation schemas for complex equipment: Components can be exported to the IFC format in different forms depending on the software used, which compromises the standardization required for collaborative workflows.

ii) Scattered data for a single component: Information related to a single piece of equipment is not always cohesively organized within the IFC structure, making it difficult to selectively share data with specific teams.

iii) Limited connection between three-dimensional models and two-dimensional schematics: Substation projects involve both 3D models (related to physical layout and clash detection) and 2D schematics (representing process flows, control logic, protection, and automation). Due to its current structure, IFC still presents limitations in integrating these two dimensions in a satisfactory manner.

Although the IFC schema exhibits shortcomings in representing specific substation elements and logic, such gaps can be mitigated through tailored customization of components not originally covered by the schema, provided that the modeling is grounded in a clear understanding of the associated processes and operational workflows. The State Grid Corporation of China, for instance, developed the GIM standard precisely to address these issues in a more targeted manner. However, given that it is a proprietary and restricted-access standard, this study chose to explore the potential of open formats such as IFC 4.3, which remain strategically relevant in the context of interoperability. Therefore, the proposed approach is based on establishing well-defined modeling premises, aiming to guide professionals in the qualified use of IFC for substation modeling, even considering its limitations.

To mitigate limitation (i) regarding the lack of standardized equipment representation, a correspondence table was developed between the components listed in Table 1 of this study and the recommended IFC entities for export. For this purpose, Section 7.4 of the IFC standard— *IfcElectricalDomain* —was analyzed to select the entities that best match the mapped components. It is important to note that the domain is limited to low-voltage installations. Medium- and high-voltage systems are listed as within scope but are not detailed in the schema. Thus, the selection of IFC entities followed the most appropriate representations for the mapped components.

This phase focused primarily on the key components of the substation. It is acknowledged, however, that other secondary systems (such as fire protection, conventional building services, and auxiliary infrastructure) are also present and may be addressed in future stages of model enhancement.

Components	IFC Entity
Primary power lines or cables	IfcCableSegment
Busbars and overhead conductors	IfcCableSegment
Power transformers	IfcTransformer
Instrument transformers (voltage and current)	IfcSensor
Circuit breakers	IfcProtectiveDevice
Disconnectors	IfcSwitchingDevice
Surge arresters	IfcProtectiveDevice
Reactors	IfcElectricFlowTreatmentDevice
Capacitor banks	IfcElectricFlowTreatmentDevice
Support insulators	IfcCableFitting
Bushings	IfcCableFitting
Secondary control and protection systems	IfcController
AC and DC auxiliary systems (batteries, inverters, charges, generators)	IfcElectricFlowStorage/IfcElectricGenerator/ IfcElectricFlowTreatmentDevice
Earthing system	IfcCableSegment

Table 2 – Mapping of components and corresponding IFC 4.3 entities. Source: Author

Table 2 shows that IFC 4.3 covers several typical substation components, such as transformers, cables, and protective devices. However, there is a lack of distinction between different types of equipment responsible for controlling energy flow, as diverse devices such as capacitors, reactors, chargers, and inverters are all grouped under *IfcElectricFlowTreatmentDevice*. Additionally, certain components could not be directly mapped to existing IFC classes and required adaptations — for instance, support insulators and bushings were provisionally assigned to the *IfcCableFitting* entity. Lastly, the entities *IfcSensor* and *IfcController* were also considered, despite not being part of the *Eletrical Domain*.

The COBie standard, as defined in Version 3 of the NBIMS-US, structures BIM model information with a focus on facilitating asset operation and maintenance. In the context of substations, the use of COBie can be beneficial in ensuring equipment traceability, system organization, and quick access to technical documentation. However, it is important to note that not all COBie entries need to be completed in a project. The selection of relevant tables should be guided by the purpose of the BIM model, avoiding the inclusion of data that does not add operational value.

Among the available tables, several are particularly relevant to substation modeling. *Type*, *Component*, and *System* help organize installed equipment, their respective types, and their functional groupings (e.g., protection or control systems). *Space* table can be used to represent technical compartments or outdoor areas of the substation. The *Document* and *Attribute* tables are essential for linking technical files and recording properties such as manufacturer, voltage class, or rated current. The *Connection* entries allow for the indication of interconnections between assets, which is key to understanding the electrical and signal topology. Finally, *Spares* and *Resource* can be used for managing spare parts and auxiliary resources. This selective and structured approach helps ensure that the BIM model effectively supports operations and maintenance throughout the substation’s lifecycle.

5.2 Mapping of Information Sources

The BIM modeling of substations with a focus on operation and maintenance requires careful mapping of the information sources that will provide data to the model. These sources can be organized into two main categories: sources of information for the construction of the geometric/spatial model and sources of data for parameterization and operation/update of the model.

5.2.1 Geometric and Spatial Model Data Sources

These sources are essential for the initial construction of the BIM model, especially when the objective is to reflect the existing infrastructure. They include:

a) Point clouds, obtained through laser scanning or photogrammetry, used for accurate mapping of terrain, buildings, and equipment. These serve both topographic surveys and the digitalization of existing structures (Figure 3).
b) As-built projects, 2D drawings, and technical documentation related to the design or physical documentation of the facility.
c) Electrical diagrams and functional schematics, which help integrate interconnection and operational logic into the geometric model.
d) Photographs, videos, and visual records, which assist in the verification and validation of spatial representation.
e) Ongoing interaction and validation with field professionals, especially from operation and maintenance teams, to ensure the model's accuracy and up-to-date status.

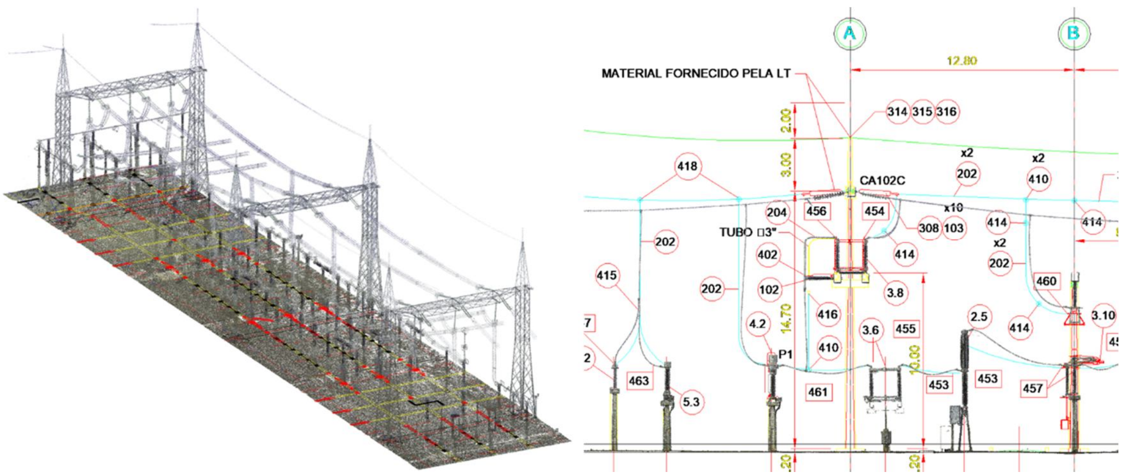

Figure 3 - Overlay of as-built drawings and point cloud for as-is substation modeling. Perspective view (left) and section view (right). Source: Author

These sources are generally static and used in the initial stage of substation digitalization. They serve as the foundation for structuring the model, assigning BIM elements the shape and location that correspond to the physical reality of the facility. It is also worth noting that they are applicable both to the development of a new substation model and to the digital representation of an existing one.

5.2.2 Operational and Management Data Sources

This second category refers to dynamic systems and data that continuously feed the model over time, providing parameters related to operation, maintenance, reliability, and risk analysis. Based on Wang et al. (2016), the following sources were identified according to the concept of *power big data*:

a) MIS (*Management Information System*): stores static and administrative data of components, such as manufacturer, installation date, rated voltage and current, operating time, load losses, and no-load losses. This information supplies the model with essential metadata for traceability and decision-making.
b) EMS (*Energy Management System*): provides operational data such as active and reactive power, current, and voltage in real time. These data help understand load cycles and identify optimal periods for interventions.
c) PMS (*Production Management System*): contains records of defects, previous failures, inspections, and preventive tests. This source is critical for modeling the maintenance history of each component and supporting predictive maintenance strategies.

d) Online monitoring data: include variables such as partial discharges, dissolved gases in oil, and moisture content — important for diagnosing anomalies in transformers and other equipment. These data can be integrated into the model to represent the current condition of assets.
e) Condition and risk assessments: provide health metrics of assets and their criticality, such as EENS (Expected Energy Not Served) or failure probability. These analyses can be linked to model elements to prioritize maintenance actions.
f) LCC (*Life Cycle Cost*): gathers economic data on acquisition, maintenance, and disposal costs of components, useful for feasibility analyses of maintenance strategies.
g) Updated electrical diagrams and operational interdependencies: logic of holistic operation among assets. This information is important for planning coordinated maintenance and reducing downtime.

By integrating these two classes of sources — static and dynamic — the BIM model moves beyond a digital representation of the substation and becomes a strategic operational tool, interconnected with management systems and decision support.

5.3 Element Identification System

During the 3D modeling process, BIM authoring software tools automatically assign identifiers to the inserted elements. However, these default systems are not always aligned with project conventions, which may harm comprehension by engineers and compromise compatibility with specific supplementary systems used in later stages of the asset's life cycle.

Therefore, if the model manager identifies the need for a more robust and coherent coding system aligned with the plant's organizational structure, it is recommended to adopt a structured and efficient identification method. This standardization facilitates communication across disciplines, ensures traceability of elements, and enables integration with systems such as SCADA, CMMS (Computerized Maintenance Management System), or collaborative platforms.

As a reference, the system proposed by Qi et al. (2020), inspired by the KKS (*Kraftwerk-Kennzeichensystem*) and adapted for BIM implementation in substations, will be adopted. This system organizes identifiers into three levels: one related to the component's function, another to the type of equipment, and a third to the specific modeled detail. The aim is to ensure clarity, consistency, and uniqueness in element identification. For a comprehensive explanation, the original article is recommended.

Level	Code	Value Description
0	G	General professional scope, overall plan and construction
1	1	Building number – e.g., Building 1 in the project
	U	Professional subdivision – e.g., building
	F	Building category – e.g., indoor station building
	A	Subdivision of building type – e.g., substation building
	96	Floor height – e.g., underground floor between 3.0 and 3.99 meters
2	H	Component category – e.g., concrete wall
	C	Axis letter – position of the component along axis C
	0	Position on the letter axis – e.g., at position 0
	3	Clock position of the intersection with the axis – e.g., 3 o'clock
	0	Position on the number axis – e.g., at position 0
	E	Number axis – e.g., digital axis (among five axes)
3	BB	Small parts – e.g., HVAC (Heating, Ventilation, and Air Conditioning)
	0	Material – e.g., material type
	1	Sequential number of the part from the axis intersection – e.g., first piece

Table 2 – Example of identification for an HVAC louver (Q1UFA96HC030EBB01). Source: Adapted from Qi et al. (2020)

5.4 Considerations for BIM Implementation in Substations

The adoption of BIM in electrical substations requires a strategic approach tailored to the context of each project. Before initiating any modeling, it is essential to clearly define the intended uses of the model. The scope of applications—such as asset management, maintenance planning, and integration with other systems—will directly determine the required level of detail and the amount of effort necessary.

Next, it is crucial to map the information already available or that can be feasibly collected, both technically and economically. This analysis must consider not only the existence of data but also its reliability and currency. It is also important to highlight that some information may be outdated or unreliable due to the lack or failure of documentation update processes (Cotes et al., 2024). Using outdated data can compromise the entire digitization.

Once the scope is defined and feasibility is confirmed, the next step is to determine the parameters that will be included in the model and to select the interoperability standard to be adopted—IFC being the most internationally consolidated. Still, as discussed in section 5.1, IFC presents limitations regarding support for specific substation components such as instrument transformers and protection systems. It also has limitations to represent the operational logic of electrical systems, which may hinder integration with operational platforms.

The following phase involves configuring the modeling software to ensure consistency in properties, parameters, and naming conventions. It is also necessary to understand geometric modeling strategies to represent equipment accurately without overloading the model with unnecessary elements. Only then should the process of field data collection or extraction from technical documents begin, followed by the actual modeling.

6 Conclusion

This article explored the uses of BIM in the electrical sector, with a particular focus on substations, aiming to consolidate assumptions, challenges, and trends that may guide future initiatives. The review showed that, despite advancements in standards such as IFC 4.3, significant gaps remain in the representation of substation-specific elements. These limitations can hinder interoperability and the systematic application of BIM models in other computational processes. However, such gaps can be mitigated through the tailored customization of components not originally covered by the schema, as long as the modeling is grounded in a clear understanding of the relevant processes and operational workflows.

Additionally, relevant information sources for modeling were identified and categorized into two main groups: geometric/spatial model data sources and operational/management data sources. It was observed that gathering this data enables a more comprehensive approach to substation's design, operation and maintenance. A structured element identification system was also proposed to support early design stages. This system seeks to facilitate interdisciplinary communication, ensure element traceability, and enable integration with other systems.

As a practical contribution, the study organized a set of key considerations that can support professionals seeking to implement BIM in substations, considering technical, operational, and managerial aspects. For future work, it is recommended to apply these guidelines in a real case study, explore standards beyond IFC and COBie, and evaluate the practical effectiveness of the proposed BIM model applications in the context of asset operation and maintenance.

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