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# An Ontological Approach to the Low-voltage Electrical Regulation

Evelio GONZALEZ[1], Alberto HAMILTON[1], Iván CASTILLA-RODRÍGUEZ[1], Roberto MARICHAL[1], Paul ELOKA[2], Javier SOCORRO[2]

[1] Departamento de Ingeniería Informática y de Sistemas, Universidad de La Laguna (Spain)
[2] Students. Universidad de La Laguna

ejgonzal@ull.es, albham@ull.es, rlmarpla@ull.es, icasrod@ull.es, alu0100892772@ull.edu.es, alu0101137865@ull.edu.es

ORCID 0000-0002-2203-3757, ORCID 0000-0002-2347-5792, ORCID 0000-0003-3147-894X, ORCID 0000-0003-3933-2582, ORCID Not available, ORCID Not available

**Abstract.** Electrical installations are regulated to ensure safety, and compliance with these regulations requires a thorough analysis of each component of the installation. Moreover, regulations in this field may change over time. This article proposes an ontology for Low Voltage Electrical Regulation, which aims to define and verify actual installations. The ontology is developed using standard procedures and enables to organize and process information based on a semantic evaluation of its content. It facilitates more accurate interpretation and analysis of queries related to electrical installations. To validate the ontology, a case study was conducted based on the Spanish regulation, and an analysis of the execution process was performed, considering the number of instances present in the ontology. The results demonstrate that the ontology is suitable for its intended purpose.

**Keywords:** Ontology, Semantic Web, Electrical Installation, Protégé, OWL Language

## 1 Introduction

The ontology of an electrical installation can be a valuable tool in various fields, including engineering and other technology-related disciplines. In today's world, where such installations are ubiquitous, it is often necessary to access their information in a comprehensible manner. The use of ontology in this context offers several advantages, particularly in the realm of engineering. It enables intelligent connections between multiple concepts within a broader topic, enhancing the understanding of their interrelationships.

Additionally, this ontological approach leverages the benefits of the Semantic Web. The Semantic Web aims to address the limitations of the current web by providing a more structured representation of content and services. It emphasizes explicit semantics that can be processed by machines (Berners-Lee, Hendler, and Lassila, 2001). By applying ontologies to electrical installations, specific advantages can be derived, as highlighted in previous works (Gonzalez et al., 2021) (Gonzalez, 2021).

- Establishing a common communication structure between different applications and/or possible users.
- Defining a prototype knowledge base that can make it easier to detect errors or inconsistencies with respect to the applicable legislation and propose improvements/modifications to the regulations.
- Reusing the applied knowledge in similar electrical installations.
- Integration with other similar technologies, such as Building Information Models (BIM) (Gonzalez et al., 2021).
- Reusing existing ontologies.
- Using the tools provided in the field of the Semantic Web.
- Encouraging the sharing of models.
- Possible integration in systems based on the Internet of Things (IoT).

In this work, the authors propose taking advantage of the items described above in the implementation of the structure of electrical installations in a system compatible with the Semantic Web. This system should collect the regulations of electrical installations by developing an ontology that allows this idea to be schematised and expressed in a general way. Another notable goal of this ontology should be to simplify the search for more specific information, despite the overwhelming amount of information that may exist. The authors have focused their work on the case of the Spanish Low-Voltage Electrical Regulation (Reglamento Electrotécnico para Baja Tensión, REBT) (BOE, 2002). From a review of related work on ontologies and electrical installations (detailed below in this paper), the authors have concluded that these works mainly refer to general building elements, not specific to the field of low voltage installations. Thus, it could be stated that this field has not been properly addressed.

The objective of this paper is to establish a framework that enables the comparison of real installations with the developed ontology, considering their specific characteristics and peculiarities. Furthermore, the aim is for the ontology to determine whether the installation complies with the current regulations. Hence, the topic of this work is not intended to cover law nor the field of low voltage electrical domain.

The rest of the paper is structured as follows. The next section lists the basic components of an electrical installation, as contained in REBT. Following it is a brief review of other significant related works. These sections contain the main information for defining and implementing the proposed ontology, which is explained in the section that follows. After this section, several tests performed with the ontology are described, by way of demonstrating the applicability of the ontology. Finally, the conclusions and open areas of research are presented.

## 2 Elements of an electrical installation: brief description

The approach followed in this work is based on the use of ontologies applied to electrical installation. This type of installation is defined as the set of components between a source of power and consumers. Broadly speaking, an electrical installation consists of the following elements (BOE, 2002), which will be the basis of the proposed ontology. This should be taken as a brief description of the main elements, as the construction of an ontology is an iterative process and will require considerably extending this list of concepts, as will be seen in later sections.

- Connection line: The line that branches off the distribution grid and supplies the Consumer Unit.
- Consumer unit (CU): The unit that houses the protective elements of the general supply line. It has a series of fuses that protect against potential short circuits.
- General supply line (GSL): The line that connects the CU to the meter panel.
- Meter panel (MP): A panel that houses all the command, measurement, control and protection devices of the individual connections that are supplied from said panel. The meter is the device that is responsible for measuring and recording electricity consumption, and comprises the following main elements:
  - Main breaker: It is responsible for disconnecting the entire panel by cutting off the current coming from the Distribution Line that feeds it.
  - General busbar unit and safety fuses.
  - Measurement unit: A unit that tracks the electrical consumption of the users. It also has time switches and control devices.
  - Individual branch circuits and protection busbar.
- Individual branch circuits (IBC): Individual circuits that branch off from the user's meter and transport the electricity to the Power Control Switch.
- Power Control Switch (PCS): Responsible for limiting electricity consumption by cutting off power if the user exceeds the contracted power.
- General Control and Protection Devices (GCPD): Located as close as possible to the entry point of the individual connection in the user's premises or home. It may include the PCS.
- Ground connection.

## 3 Related work: Ontologies in electrical installations

Ontologies consist of a well-structured organization of a domain knowledge that, in addition to being able to store information, can also be used for searching and retrieving information/data. An ontology defines the relationships and basic terms for understanding an area of knowledge, as well as the rules to better adjust the definitions to the reality described (Weigand, 1997). The most accepted definition is usually the one proposed by Gruber (Gruber, 1995), expanded upon by Borst: "An ontology is a formal specification of a shared conceptualization".

There are scarce examples of the use of ontologies in the field of electrical installations, with the exception of small applications to power supply and smart homes. More examples can be found in the broader sector of construction (Gonzalez et al, 2021), including ifcOWL (Pauwels, 2015), a conversion of Industry Foundation Classes (IFC) Schemas into Ontology Web Language (OWL). IFC is a standard for exchanging Building Information Modeling (BIM) data which, in turn, is a widely used paradigm in the field of Architecture, Engineering and Construction/Facility Management (AEC/FM).

As stated above, one of the objectives of this paper is to establish an ontological framework for determining the compliance of electrical installations with applicable regulations, specifically the REBT (in the case study). This objective goes beyond merely representing the components of the electrical installation. It aims to achieve true semantic interoperability by extracting meaningful information from human-readable texts that exist outside the BIM/IFC formalism.

To achieve this, Bus et al. (2018) convert the texts of the French building code into semantic rules applicable to IFC models. These models, in turn, are transformed into structures based on the Resource Description Framework (RDF), which is the foundational language of the Semantic Web (Needleman, 2001). Another relevant proposal comes from Yurchyshyna et al. (2008), who present an ontology-based approach for modeling conformance checking in construction. Their approach includes metadata about various aspects of the regulation text, such as the date of publication, along with formalized expert knowledge.

These previous works contribute valuable insights into the development of the ontology, ensuring that it encompasses the necessary elements to enable effective compliance checking and semantic representation of regulatory information beyond the limitations of BIM/IFC formalism.

The aforementioned contributions exhibit the following characteristics: (i) they are based on BIM and IFC, and (ii) they pertain to general building elements rather than being specific to the field of low voltage installations. Regarding (i), it is worth noting that despite the widespread use of BIM, some authors emphasize that learning inertia hampers the intention to integrate BIM (Jia, Zhang, and Yang, 2022), and BIM is generally considered unsuitable for navigation purposes (Boysen et al., 2014). Additionally, although several extensions of ifcOWL have been proposed (Terkaj and Šojić A, 2015), these conversions present usability issues due to the complexity of the IFC structure and the size of ifcOWL.

Based on this assessment, the authors identify a lack of a small to medium-sized ontology specifically designed for low voltage installations. Such an ontology should be manageable by individuals outside the complexities of BIM or IFC and possess adequate scalability. It is important to note that this consideration does not imply renouncing the undeniable benefits of BIM. Given the reusable nature of ontologies, the proposed ontology can be integrated into third-party systems based on BIM or IFC, leveraging the advantages offered by these technologies.

## 4 Proposed ontology based on REBT

Like any ontology, the proposal herein includes classes (the general concepts that we wish to specify), relationships (interactions between the different classes), attributes (descriptions of the internal structure of the classes), instances (specific objects of a class) and axioms (valid rules in the knowledge domain). The authors have implemented the ontology in OWL. OWL is an extension of well-known languages, such as RDF, but it is better able to express meaning and semantics. Hence, computer systems can reason based on the information expressed in that language.

For the development of the ontology and subsequent testing, the authors have used the following tools:

- The ontology was created with the Protégé tool, the most widely used tool for developing ontologies. Protégé is an open source ontology editor and framework, developed by the Stanford Center for Biomedical Informatics Research. It offers a plug-and-play architecture that can be adapted to the specific needs of each user. Ontologies developed in Protége can be easily integrated with rule-based systems or other problem solvers.
- SWRLAPI library (O'Connor et al, 2008). SWRLAPI is a Java API for applications that require the use of OWL-based SWRL rule languages, and Semantic Query-Enhanced Web Rule Language (SQWRL). For its use, this API requires an implementation of the SWRLAPI-based rule engine, such as Drools. The authors note that there are other alternatives available such as SWRLJessBridge.
- Pellet reasoner. A basic characteristic of ontologies that are described using OWL-DL is that they can be processed by a reasoner. Among other advantages, this type of program can be used to validate the consistency of an ontology and ensure compliance with the concepts of the ontology. The reasoner used in this paper is Pellet, an open source OWL DL ontology reasoner developed in Java. Pellet includes functionality to view classes validation, check ontology consistency, classify taxonomies, check implications and respond to a subclass of RDQL queries (RDF Query Language) (Sirin et al, 2007).

The determination of elements to be included in the ontology was achieved through an analysis of the hierarchical structure found in the REBT. The identified terms deemed necessary were added to the ontology following a methodology similar to the one presented by Kerrigan and Law (2005) and the steps outlined by Noy and McGuinness (2001). These steps involved defining classes within the ontology, organizing them in a taxonomic hierarchy, specifying slots, describing permissible values for these slots, and populating the slot values for instances. Throughout this process, the aim was to minimize any potential loss of information. It is essential to emphasize that this work primarily focuses on the data extracted from the legislation, specifically the REBT, rather than encompassing the physical structure or components of an electrical installation.

In the ontology, the elements described in Section 2 are made to correspond to classes, structured into taxonomies as per Table 1. The Uniform Resource Identifier (URI) prefix has been omitted for the sake of simplicity. In some of the classes, abbreviations have been added in brackets for the same purpose of simplifying later notations. In this case, each class is assumed to be disjoint from others in the same level, except for some related to installation materials. For example, the consumer unit is not disjoint from the installation materials, meaning an individual can be a consumer unit and an installation material simultaneously (Eq. 1).

$$ConsumerUnit^I \cap InstallationMaterial^I \neq \varnothing \tag{1}$$

Within the classes defined, the first class to be highlighted is *ElectricalInstallation*. The individuals defined in the electrical installations (derived from the elements defined

**Table 1.** Classes in the proposed ontology

| Classes without subclasses | |
|---|---|
| Connection, ProtectionAndMeasurementBox (PMB), ConsumerUnit (CU), MeterPanel, GeneralControlAndProtectionDevice (GCPD), IndividualBranchCircuit, ElectricalInstallation, PowerControlSwitch (PCS), GeneralSupplyLine, GroundConnection, DistributionGrid | |
| Classes with subclasses | |
| Classes | Subclasses |
| GeneralControlAndProtectionDevice | ResidualCurrentDevice<br>AutomaticMainBreaker<br>SmallAutomaticBreakers |
| ComplementaryTechnicalInstruction | TechnicalInstructionForConnection<br>TechnicalInstructionForUnits,<br>TechnicalInstructionForIndividualBranchCircuit,<br>TechnicalInstructionForGCPDAndPCS,<br>TechnicalInstructionForInteriorInstallation,<br>TechnicalInstructionForGeneralSupplyLine,<br>TechnicalInstructionForGroundConnections,<br>TechnicalInstructionForDistributionGrid |
| InstallationMaterial | Lighting, Support, Cable, JunctionBox, Conduit, ControlPanel, ElectricalPanel, Detector, SafetyFuse, Switches, Timer, OtherMaterial |
| Standard | StandardForConduits, StandardForConductors, StandardsForPanels |

in Section 2) are going to be related from this class by means of the *inclusion* and *communication* properties.

The rest of the classes can be divided into two groups. The first group contains the elements related to the electrical installation. Thus, among others, the *InstallationMaterial* class is defined, which is superclass of all classes referring to installation materials. For example, individuals of the *Cable* class belong to the *InstallationMaterial* class (Eq. 2).

$$Cable^I \subset InstallationMaterial^I \tag{2}$$

The second group of classes refer to the technical documentation coming from REBT, which contains standards mentioned in the regulation, and complementary technical instructions. The *ComplementaryTechnicalInstruction* class implements the latter, and includes several subclasses related to the different elements it refers to (Eq. 3). As will be seen later, this type of classes will need semantic support to include information from REBT.

$$\begin{aligned} TechnicalInstructionForConnection^I \subset \\ ComplementaryTechnicalInstruction^I \end{aligned} \tag{3}$$

The properties implemented in Protégé for the Electrical Installation were extracted from REBT to link the different classes. Tables 2 and Table 3 contain a non-exhaustive list of these properties (object properties and data properties respectively). It is important to note that the proposed scheme can be extended and applied to other types of electrical installations. Eq. 4 and 5 express the *supplies* and *ensureActionOf* properties through Description Logic (DL) syntax, with their respective domain and range. For their use, individuals (that is, instances) from the involved classes are previously defined in order to be integrated in the function.

$$supplies^I \subseteq Connection^I x \\ (ConsumerUnit^I \sqcup ProtectionAndMeasurementBox^I) \tag{4}$$

$$ensureActionOf^I \subseteq Grounding^I x GeneralControlAndProtectionDevice^I \tag{5}$$

**Table 2.** A selection of object properties included in the ontology

| Property | Inverse property | Domain | Range |
|---|---|---|---|
| electricityCutOffBy | cutsOffElectricityTo | IndoorInstallation | PCS |
| givesRiseTo | comeOutOf | Meters | IBC |
| disconnects | isDesconnectedBy | MB | MP |
| distributesEnergyVia | receivesEnergyFrom | DistributionGrid | Connection |
| protects | isProtectedBy | GCPD | IndoorInstallation |
| ensureActionOf | actionEnsuredBy | Grounding | GCPD |
| isTechnicalInstructionOf | hasTechnicalInstruction | CTI | All Classes |

**Table 3.** A selection of data properties included in the ontology

| Property | Domain | Range |
|---|---|---|
| abbreviation | All classes | xsd:string |
| hasInsulation | Cables | xsd:string |
| hasHeight | ConnectionLine or CU or PMB or GCPP or GCPD | xsd:decimal |
| hasColor | Grounding | xsd:string |
| hasCurrent | Cable | xsd:integer |
| hasLength | ConnectionLine or IBC or GSL or Cable | xsd:float |

The ontology also implements a series of rules using Semantic Web Rules Language (SWRL). This language is a combination of the OWL Lite and OWL DL sublanguages, with the Unary/BinaryDatalogRuleML sublanguages of the Rule Markup Language.

The idea is to apply *DatalogRuleML* to our ontology, as proposed by World Wide Web Consortium (W3C) to expand the set of OWL axioms for rules. As an example, the rule expressed in Eq. 6 refers to the protection rating (IK) of the consumer unit. This means that the connection supplies the consumer unit and, if the connection is underground, then, as a consequence, the CU must have an IK protection rating of 10, as per the UNE-EN 50.102 standard, as indicated in the REBT (more specifically, in ITC-BT-13).

$$\begin{aligned} Connection(?co) \wedge supplies(?co, ?cu) \wedge \\ typeOfConnection(?co, \text{``}Underground\text{''}) \wedge ConsumerUnit(?cu) \\ \rightarrow hasProtectionRatingIK(?cu, 10) \end{aligned} \tag{6}$$

Other examples of rules define the minimum rated voltage of conductors (Eq. 7); the minimum height of CU (Eq. 8); the minimum cross section of copper conductors (Eq. 9); and the minimum number of small automatic switches for each home (Eq. 10).

$$\begin{aligned} Cables(?c) \wedge typeOfConductor(?c, \text{``}Insulated\text{''}) \rightarrow \\ hasMinimumRatedVoltage(?c, \text{``}0.6/1Kv\text{''}) \end{aligned} \tag{7}$$

$$\begin{aligned} Connection(?co) \wedge supplies(?co, ?cu) \wedge \\ typeOfConnection(?co, \text{``}underground\text{''}) \wedge ConsumerUnit(?cu) \\ \rightarrow hasMinimumHeight(?cu, 0.3) \end{aligned} \tag{8}$$

$$\begin{aligned} Cable(?c) \wedge typeOfConductor(?c, \text{``}Insulated\text{''}) \wedge \\ typeOfMaterial(?c, \text{``}Copper\text{''}) \\ \rightarrow minimumCrossSection(?c, 6) \end{aligned} \tag{9}$$

$$\begin{aligned} GeneralControlAndProtectionDevice(?gcpd) \wedge \\ isComposedOf(?gcpd, ?sas) \wedge \\ SmallAutomaticSwitches(?sas) \\ \rightarrow hasMinimumNumberOfSas(?sas, 5) \end{aligned} \tag{10}$$

These rules will increase the expressiveness and deduction capability of the ontology. The effect can be checked using the SWRLTab tab of the Protégé tool, or with ontology processing tools, such as SWRLAPI. In the latter case, the following code is responsible for the inference of new knowledge from the triggering of rules included in the ontology.

```
OWLOntologyManager ontologyManager =
   OWLManager.createOWLOntologyManager();
OWLOntology ontology =
   ontologyManager.loadOntologyFromOntologyDocument(ontologyFile);
SWRLRuleEngine ruleEngine =
  SWRLAPIFactory.createSWRLRuleEngine(ontology);
ruleEngine.infer();
```

The proposed ontology can be integrated into external applications (e.g. web-based systems and mobile devices). A key feature in the work is that a user can perform queries directly through the Protégé tool but there are other possible way to perform this kind of interaction. The ontology and the SWRL rules can be embedded in an application, following the pattern used in previous works (Gonzalez et al, 2021). The use of SWRLAPI results in an inferred ontology. The designed application can perform queries on this ontology in supported languages such as SQWRL or SPARQL (SPARQL Protocol and RDF Query Language). Eq. 11 uses SQWRL to locate those instances of the *Cable* class whose type of material is copper and whose section is smaller than the minimum established in REBT (and therefore indicated in the ontology). This kind of queries may simplify the location of those structures that do not comply with REBT in the event of a change in regulations.

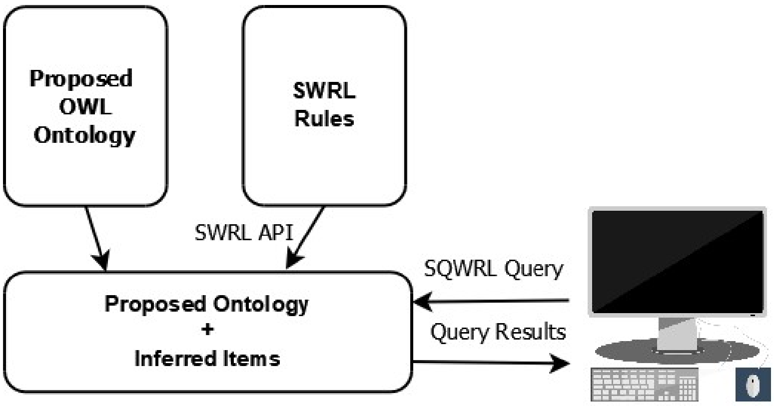


**Fig. 1.** An example of flow for ontology inclusion in third-part applications, adapted from (Gonzalez et al,2021)

$$\begin{aligned} Cable(?c)\ \wedge\ typeOfConductor(?c, \text{``}Insulated\text{''}) \wedge \\ typeOfMaterial(?c, \text{``}Copper\text{''}) \wedge \\ minimumCrossSection(?c, ?min) \wedge \\ hasCrossSection(?c, ?section)\ \wedge\ swrlb : lessThan(?sec, ?min) \\ \rightarrow sqwrl : select(?c, ?sec, ?min) \end{aligned} \tag{11}$$

One class that illustrates the potential of inference within the developed ontolgy is *InvalidElement*. This class allows checking that the implemented installation is correct, by comparing its characteristics with those defined by means of the instances of the ontology. A series of rules written by using SWRL allows the application to compare every value entered for a data property with the one previously established. In the case that an element does not comply with any of the pre-established rules, it is inferred that this element is an instance of the *InvalidElement* class. This fact makes it possible to locate potential non-compliance with REBT. Hence, Eq. 12 defines an alternative to Eq. 11 where the elements not complying with REBT are inferred as instances of InvalidElement.

$$\begin{aligned} Cable(?c) \wedge\ typeOfConductor(?c, \text{“}Insulated\text{”}) \wedge \\ typeOfMaterial(?c, \text{“}Copper\text{”}) \wedge \\ minimumCrossSection(?c, ?min) \wedge \\ hasCrossSection(?c, ?section) \wedge\ swrlb: lessThan(?sec, ?min) \\ \rightarrow InvalidElement(?c) \end{aligned} \tag{12}$$

## 5 Evaluation of applicability and performance scalability

### 5.1 Representation of actual electrical installations

As Fernández et al. point out, there is no definitive quantitative method to establish whether one ontology is better than another as long as it meets the needs of the developer (Fernandez et al, 2009). A common way of validating the competence of an ontology is by proving that it provides sufficient semantic capacity to express the components of real problems.

The ontology has been applied to represent the structure of actual electrical installations. In particular, this section shows the case of a residence with four dwellings, which would be an illustrative example to check the performance of the proposed ontology. At the same time, this installation is simple enough to be reproduced and analysed. A version of the ontology and this case (in Spanish) is avalaible at

https://sites.google.com/ull.edu.es/ontologiaie.

The features of the test installation are:

- Connection line: an underground line with an inlet and outlet installation system. It uses insulated cables with a rated voltage of 0.6/1 kV, and a length ranging between 12 and 14 meters. This type of installation will be done in accordance with ITC-BT-07 document.
- Consumer unit: installed in a hole in the wall at a height of 0.4 meters from the floor. The door is IK10 rated, as per UNE-EN 50102 standard.
- General supply line: made up of insulated conductors inside buried tubes.
- Meter panel: located inside a cabinet that is IK 09 and ingress protection (IP) 40 rated, it houses four meters for each dwelling. These meters have an integrated power control switch, meaning it will not be necessary to install the meter panel in the general control and protection panel.
- Individual branch circuit (IBC): the building has four IBCs, one for each dwelling. It consists of insulated conductors inside protective conduits that cannot be accessed without the help from a professional. The conductors used are insulated and unipolar, made of aluminum and have a rated voltage of 450/750V.

- Main breaker: located between the general supply line and the meter panel, with a current of 160 A.
- General control and protection panel: located on the side of the entrance door to the dwellings, at a height of 1.6 meters and IP30 rated.
- General control and protection devices: a 25 A residual current device (RCD) with a 300 mA sensitivity, a 25 A automatic switch and five circuit breakers (at 10, 2x16, 20 and 25 amps) have been installed for each dwelling.
- Grounding: LEXMAN H07V-K vd cable, yellow 2.5 mm² 10 m.

The terms of the ontology allow analyze where the design of the installation is correct with respect to the considered properties of the design. It is important to note that extensive use has been made of the *differentFrom* property to indicate those elements that are different from each other. This is a consequence of the open-world assumption that is taken by default by the used tools. Table 4 shows the metrics of the ontology with the inclusion of the individuals related to the test installation.

**Table 4.** Ontology metrics with the test installation

| | |
|---|---|
| Axiom | 768 |
| Logical axiom count | 530 |
| Declaration axioms count | 238 |
| Class count | 61 |
| Object property count | 39 |
| Data property count | 65 |
| Individual count | 74 |

Concerning the applicability, as it can be seen, the ontology has been applied to a simple example. Simply applying the ontology to a specific example of a residential complex with four dwellings does not guarantee that it fully meets its intended purpose. While this case study serves as an initial evaluation, it is important to consider that the ontology should be capable of handling more complex scenarios as well, in fact, it has been applied to other examples, such a building of 10 dwellings (Socorro, 2022). Although it stands to reason that the ontology can be applied to a more complex example, it is necessary to assess its capability in effectively addressing relevant questions within the domain of disclosure, often referred to as competency questions. During the process of defining the ontology, several competency questions were defined. These questions were raised in order to cover various aspects of electrical installations, such as safety regulations, component specifications, and compliance with standards. Table 5 shows a subset of these competency questions and their related SQWRL queries.

Using this ontology to describe a more complex scenario implies some threats that need to be considered. A more complex example may introduce additional intricacies and nuances that were not present in the simple example. This would imply to include new axioms and/or rules when other ontology elements are used (new types of wiring, for example). That is, the ontology may require advanced modeling constructs or expressive power to represent intricate relationships and constraints accurately.

Another threat lies on scalability, that is analyzed in the following subsection.

**Table 5.** Subset of competency questions and SQWRL queries

| Competency question | SQWRL query |
|---|---|
| Which elements of the installation do not comply with the regulations? | InvalidElement(?a) -> sqwrl:selectDistinct(?a) |
| What type of material are the cables in the electrical installation made of? | Cables(?c) ∧ hasMaterial(?c,?m) -> sqwrl:selectDistinct(?c,?m) |
| How many protection fuses do we have in the installation? | ProtectionFuse(?pf) -> sqwrl:count(?pf) |
| What is the minimum height of the general protection box in an underground wiring installation? | UndergroundWiring(?uw) ∧ hasGeneralControlAndProtectionDevice(?uw,?m) ∧ hasMinimumHeight(?m,?h) -> sqwrl:selectDistinct(?h) |

The structure of the ontology has been shown to effectively address the competency questions outlined in Table 5, as well as other relevant queries. This indicates a successful outcome in the analysis of the ontology's ability to meet the information needs and requirements of the domain within the field of electrical installations.

A second test process involves checking the ontology using a reasoner. In the case of the proposed ontology, the reasoner has not detected any inconsistencies.

### 5.2 Scalability test

The data inference carried out in the previous subsection will be the basis for testing the scalability of the use of the ontology. This test is made by measuring the inference time as the number of individuals present increases when a SQWRL search is requested. The method, also used in (Gonzalez et al, 2018), has been as follows. Several individuals with random properties have been created using SWRLAPI, and included in the ontology. After that, the time used by the rule engine is measured and stored. This experiment is repeated three times to reduce the effect of randomness and the mean of the times is calculated. The results are shown in Figure 2, where we can see that, for a value of 14,000 individuals, the inference time of the rules is less than 20 seconds, which may be deemed suitable on a practical level. This is surely due to the simplicity in the proposed structure of the ontology and the non-use of third-part ontologies . The tests were carried out on a computer with an Intel® Core™ i7-2600, 3.40-GHz processor and 8

GB RAM, used in other works by the authors (Gonzalez et al, 2021) (Gonzalez, 2021) (Gonzalez et al, 2018). This allows comparison of the complexity of the structures with respect to their processing time. As it can been seen from the Figure 2, the processing time follows an exponential pattern at some point. This is clearly one of the threats of the use of the ontology.

For the experiment, the installation described in section 5 has been taken, loaded with the SWRLAPI library and elements with code structures similar to the following have been added. The instance of OWLNamedIndividual is defined with the IRI reference of the individual's class, the related axioms are created and added to the ontology. Random values are defined for certain properties of individuals such as the height of the installation or the thickness of the cables.

```
OWLNamedIndividual obs1 =
    df.getOWLNamedIndividual(IRI.create(nameOfTheIndividual));
OWLDeclarationAxiom da1 = df.getOWLDeclarationAxiom(obs1);
OWLClassAssertionAxiom caa = df.getOWLClassAssertionAxiom
   (df.getOWLClass(IRIClassOfNewIndividual), obs1);
ontologyManager.addAxiom(ontology, da1);
ontologyManager.addAxiom(ontology, caa);
```

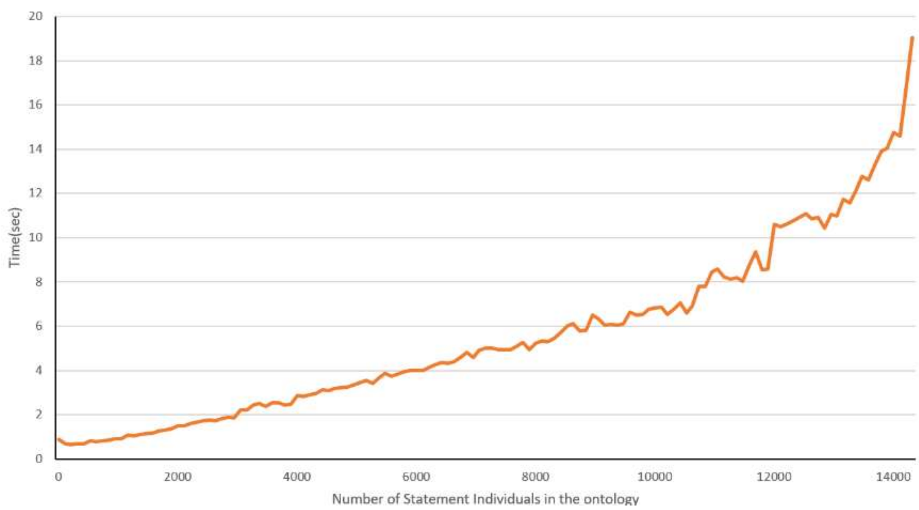


**Fig. 2.** Results from SQWRL searches in the ontology.

## 6 Conclusions and open areas of research

This article presents an ontology that represents the knowledge expressed in the Low-Voltage Electrical Regulation, using a case study in the Spanish context. The ontology aims to achieve several objectives, such as establishing a common communication structure among different applications and users and defining a knowledge base to identify inconsistencies with the applicable legislation. It is based on the terms related to electrical installations mentioned in the aforementioned document and the information from various regulations.

To enhance the ontology, SWRL rules have been incorporated, allowing for greater semantic interoperability and the inclusion of knowledge that is challenging to formalize in the standard OWL language. These rules cover aspects such as the composition of connections, the minimum height of the control unit (CU), and the minimum rated voltage of the conductors. While initially designed for electrical installations, the ontology has the potential for extension to other related components.

Several tests were conducted on the ontology, including the implementation of a simple electrical installation, the use of reasoners, and an analysis of the change in inference time of SWRL rules as the number of individuals in the ontology increases. In each case, satisfactory results were obtained, despite the possible loss of information that typically occurs in this type of conversion. The proposed ontology, although an initial simplification, has proven to be suitable for its intended purpose. However, the authors acknowledge that testing with more complex electrical installations is necessary to ascertain the completeness of ontology concepts and its suitability for complex systems.

Based on the obtained results, the implementation of a small to medium-sized ontology, tailored to the domain of low voltage installations, is feasible. This ontology enables users to describe the fundamental elements of real installations. Moreover, the ontology demonstrates acceptable scalability features when it comes to reasoning about its content. It is shown that the processing time follows an exponential pattern at some point when the number of individuals grows.

Practically, the implemented ontology facilitates searches, particularly for non-compliant elements, making it easy to verify installations for potential regulatory changes. Additionally, the ontology shows satisfactory query performance and inference of new knowledge.

Overall, the findings indicate that the implemented ontology effectively serves its purpose, enabling users to describe and analyze low voltage installations, perform queries, and ensure compliance with regulations. However some threats about its use are identified.

Open areas of research include automating the extraction of knowledge from technical documents, updating information when new regulations are issued, integrating with BIM-based data, and developing more advanced tools and searches for compliance testing. Furthermore, testing the ontology against representative data or scenarios, comparing its performance with alternative approaches, and seeking feedback from domain experts are important avenues for ensuring accuracy and usefulness.

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