Towards Mapping Certification Rules over BIM

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Abstract

Nowadays, it is a hot challenge to address automatic verification requirements to warn the non-conformities with the associated 3D visualization, or to provide access to the technical documentation for a given digital model based on its sophisticated contextual information. In this paper, we contribute a framework for mapping certification rules over BIM to enable the compliance checking of the repository through the digital building model. Our aim is to align several specialized indexations of building components at both sides, by extending IfcOWL ontology with bSDD vocabulary (i.e., synonyms and description) as enriched eIfcOWL ontology to deal with the same abstract concepts or physical objects. Finally, we present and compare MVDXML and SWRL technologies for the model instance verification and conformance checking of Industry Foundation Classes (IFC) models, and demonstrate various important aspects and their limitation.

Keywords: BIM, Certification Rules, IfcOWL ontology, MVDXML, SWRL rules

1 Introduction

The regulations (i.e., rules and standards) of construction and certification corpus of building components are defined to ensure a minimum level of quality of the desired construction. Many construction professionals have already adopted the Body of Regulations regarding construction in the digital form for several years. The tools associated with it allow to consult all the relevant textual techniques and regulations for the design, implementation and operation of buildings and to meet effectively the information sought. The consideration, from the very early phases, of the expected requirements, either on the regulatory corpus or in terms of certification, would be an important factor in improving the achieved performance.

Industry Foundation Classes[1] (IFC) is the complete and fully stable open and international standard for exchanging BIM data. Building SMART organization aims at publishing IFC and related buildingSMART[2] data model standards. The buildingSMART data model standards are developed by the Model Support Group, and the implementation activities are coordinated by the Implementation Support Group. Together both groups organize the IFC software certification process. Although IFC is an open standard, its complex nature makes the information retrieval difficult from an IFC model.

Building Information Modeling[3] (BIM) with its interoperability properties is intended to facilitate exchanges and handovers between different stakeholders. Whereas the

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[1]IFC, http://www.buildingsmart.org/standards/ifc/
[2]Building Smart Data Dictionary (bSDD), http://bsdd.buildingsmart.org/
[3]Open BIM, http://www.buildingsmart.org/openbim/

visualization and geometric representation are intrinsic to the digital building model, the fields of quality requirements, evaluation and regulatory contextualization (destination, named areas, threshold values, certified data, evidence of compliance, etc.) need higher level of maturity.

Our enterprise, CSTB, through its research aims at providing direct access to regulatory documents, or certification repositories via BIM and also to automate as much as possible, or at least improves the control of regulations from a digital model design phase. Its goal is to provide automatic verification requirements to warn the non-conformities with the associated 3D visualization, or to provide access to the technical documentation for a given digital model based on its sophisticated contextual information. To achieve these goals, our research adopts a traditional approach using MVDXML (Chipman et al, 2012) and in addition focuses on the semantic web rule language (Horrocks et al, 2004) in the domain of construction and building. We have built enriched IFC ontology which contains not only important vocabulary about the original IFC schema, but also CSTB thesaurus which is required for the particular practical tasks such as querying, linking, validating, and reasoning over digital models. In addition, that enriched ontology should comprise of terminologies in French, English and IFC languages so that mapping between regulatory text and BIM can be achieved effectively. The following sections provide background on this domain and further elaborate our work.

The rest of the paper is organized as follows. Section 2 gives a reader with background knowledge of the domain and existing ontologies in the construction and building domain. Section 3 presents related work on the domain. Section 4 highlights the mission of our research and presents contributions of this paper. It also elaborates the framework for the mapping certification rules over BIM. Section 5 presents two approaches for the validation of rules and conformance checking. Section 6 concludes this paper and shows our future directions.

2 Background

Ontologies with their capabilities of interoperability and knowledge explication have been taken into account in the context of Building Information Modeling as well (wang et al, 2010). Regarding the construction and building domain, several IFC (Industry Foundation Classes) based ontologies have been developed, such as IfcOWL, optimized IfcWod, etc. For our research objectives, we also extend IfcOWL ontology. Therefore, following subsections elaborate features of these ontologies to present the reader with brief characteristics of these ontologies.

2.1 IfcOWL ontology

The BuildingSMART Linked Data Working Group has developed ifcOWL ontology to allow extensions towards other structured data sets that are made available using semantic web technologies (Terkaj and Pauwels, 2014). There are many version of IfcOWL ontology since the work has been started. We have been working on ontology IFC4_ADD1.owl version came on 25 Sept. 2015. This ontology should be enriched with English-French and IFC vocabulary (synonyms, descriptions, etc.) to be used in our research project. In addition, concepts of IfcOWL ontology should be assigned with Global Unique Identifier (GUID) to serve as a unique language-dependent serial number from the bSDD.

2.2 IfcWoD ontology

There is also an optimized version of IFC ontology that aims at semantically adapting IFC model relations into OWL properties by allowing enhanced inference and reasoning over datasets (Mendes de Farias et al., 2015). It is designed to take advantage of various OWL built-in classes and define logical characteristics for the semantic properties such as owl:TransitiveProperty, owl:SymmetricProperty, owl:ReflexiveProperty. The initial results over IfcWoD linked to IfcOWL show that it helps simplifying query writing and improving query response time for retrieving the building data.

2.3 bSDD ontology

The *building Smart Data Dictionary* (bSDD) is an ontology for the building and construction industry based on ISO 12006-3. It uses the *Global Unique Identifier* (GUID) as a basic building block to serve as a unique, language-dependent serial number assigned to every concept registered in the bSDD. A *GlobalUniqueID* (GUID) is an identifier that is unique throughout the software world. Through GUIDs various language terms and definitions are associated linking semantically with each other. This GUID enables bSDD users to be 'assured' that when a concept is used, a different concept from any other source will not share the same identity. There is a support to access bSDD in different languages via C, .net and Java client libraries. It supports *Representational State Transfer* (REST) model for accessing a set of resources through a fixed set of operations. We have used REST API (Raw JAXB or Jersey Client) to explore concepts and get their synonyms and descriptions in various languages.

2.4 MVD and MVDXML

The subset of the IFC schema needed to satisfy one or many Exchange Requirements of the AEC industry is called *Model View Definition* (MVD). The XML format used to publish the concepts and associated rules is MVDXML and is regarded as an open standard (Chipman et al, 2012). MVDs provide additional rules for IFC validation and focus on extracting integral model subsets for IFC implementation purposes.

2.5 SWRL and SQWRL

The semantic web technologies, SWRL and SQWRL are widely being used for the inference of new knowledge, validation and querying ontologies (Horrocks et al, 2004). Ontologies, although, they are best for knowledge modeling, have limitations and may not suffice for all applications. There are statements that cannot be expressed in OWL, therefore Semantic Web Rule Language (SWRL) is designed on top of ontologies to be an alternative paradigm for knowledge modeling that adds expressivity to the OWL. Besides this, SWRL rules infer new knowledge from the existing knowledge modeled in the ontologies. SQWRL is the query language of the Semantic Web for querying RDF data (Brickley et al, 2004). Along with query language SQWRL, it has more access characterizes on the RDF graph.

3 Related Work

There are many developments regarding automatic rule checking applied to a standardized BIM, such as Smartcodes, Solibri, EDM, House Designer, ePlan.

Smartcodes is the result of a joint project with the International Code Council (ICC), AEC3 and Digital Alchemy (Wix, 2008). It is a process more than a tool, where the process will be designed and converted into a computable rule. Although it is not a tool but its prominent feature of generating direct link between rule source and computable rule is significant for the industry. By using Smartcodes, the domain expert clarifies implicit rules in the rule source by coloring certain textual parts and then these are parsed by a computer to generate computable code.

Solibri Model Checker is a tool developed by the SOLIBRI which is a Finish software company (Khemlani, 2009). The main goal achieved is to compare two IFC based BIMs and check for collisions or other conflicting configurations. Although it provides a significant contribution by 3D modeling of the BIM but most of the rules are hard coded into the software. It does not support any configurable user friendly language to specify new rules.

EDM Model Server is a model manipulating tool based on the open international standard EXPRESS, and is developed by Jotne EPM Technology. The functionality of EDM is similar to the Solibri by providing a set of built-in rules, but it also overcomes its drawback. EDM Model Server helps their users in creating new rules using experts on EXPRESS from Jotne EPM Technology. Through this tool, users may build and execute computable rules on an open standard format. The drawback is seen as it is complex to use and requires highly skilled professionals to run.

House designer is another complex rule engine developed by Selvaag Blue Think (Opdahl et al 2009). It provides a specialized viewer, to combine information about broken rules with a visual image of the building. Unlike other softwares and tools, it is able to generate buildings from rules, not just passively checking if an existing building satisfies certain rules.

ePlan Check (Xu et al 2004) is developed by the Singapore Authorities for a code checking platform build upon EDM Model Server. It employs specialized library built in C++ named Fornax which allows a computer programmer to build computable rules with the help of domain expert. This tool allows builders to check models against the building codes automatically, but built rules cannot be transferred to other platforms.

Besides these projects that do automatic rule checking, recent years revealed some contributions based on semantic web technologies. SWOP-PMO project is one of recent contributions that uses formal methodology based on the semantic web standards and technologies (Josefiak et al 2008). It uses OWL/RDF to represent the knowledge, and SPARQL queries and Rule Interchange Format (RIF) to represent the rules. The RDF/OWL representation is not derived from the written knowledge but have to be remodeled in accordance with the rules of OWL/RDF.

There are some other works aims at semantically enrichment of ontologies in the construction and building domain. Emani et al., (2015) proposed a framework for generating an OWL Description Logic (DL) expression of a given concept from its natural language definition automatically. Their framework also takes into account IFC ontology and the resultant DL expression is built by using existing IFC entities. Vu Hoang and Torma (2015) developed an open-source Java application aimed at multilayer conversion from IFC schemas developed in EXPRESS into OWL2 ontologies and IFC data from STEP physical file format (SPFF) into RDF graphs aligned with the ontologies. Their multi-layer model facilities users to get three ontology layers according to the requirements of an application, where each ontology layer is compatible with essentially the same IFC-derived RDF data.

IfcDoc tool (2012) is developed by buildingSMART International for generating MVDXML through a graphical interface and rule checking. It is based on the MVDXML specification to improve the consistent and computer-interpretable definition of Model View Definitions (MVD) as true subsets of the IFC Specification with enhanced definition of concepts. The tool and methodology can be applied to all IFC releases (IFC2x3, IFC4, etc.). We use IfcDoc tool to validate the mapping rules in our research work.

4 Mapping certification rules over BIM

4.1 Context

We are working on the project named *Quality through Building Information Model (QualiBIM)* by our client CERQUAL which is a certification provider for the building domain. Through this project, we have many core objectives. First, it needs to filter rules repository (by the type of elements or genre of building, etc.) via annotating them with IFC labels and finally classifying them into categories. Second, it needs to formalize and implement a rule engine to analyze building models and get inference over construction data sets. Third, it needs to convert their natural language rules into logic based rules that can process and reason the underlying repositories.

In the context of our project, we have repository of rules developed in the French natural language. One of an example of such rules is as follows: Code_Métier#FL.1.1.1 - *Dans les salles d'eau et WC, 1 main courante.* This text rule in french language first requires natural language processing to be processed and matched further to achieve the desired goals. Secondly, we also need to capture our required IFC vocabularies as a Thesaurus CSTB. We have built manually such a thesaurus named SKOS ontology that contains more than 1000 individuals that belong to IFC classes. Our framework requires on this thesaurus to better execute the process of generating mappings over BIM and regulatory texts. Therefore, we chose semantic technologies to better model and infer information in the sound semantic manner.
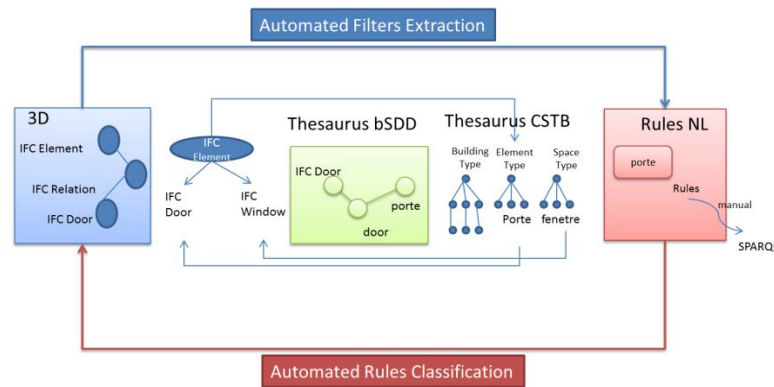
Figure 1 Various ontologies for establishing mappings

In practice, we aim to provide different services based on three mappings as follows:
- Mapping certification rules over regulatory texts to facilitate access to official documents justifying the control rules. The key element of this mapping is the modeling of semantic relationships between vocabularies describing the building components included in the regulatory texts and their equivalents in the certification corpus of building components (e.g., QUALITEL).
- Mapping certification rules over BIM to enable the compliance checking of the repository through the digital building model. At this stage, the aim is to align several specialized indexations of building components at both sides, assuming that they deal with the same abstract concepts or physical objects, but according to their separate representation prisms. This paper elaborated this aspect in detail and the sub-section elaborates how to achieve the desired goal.
- Mapping BIM over regulatory texts to allow navigation in regulatory texts through the digital building model. This is to establish semantic correspondences between the building components defined in the regulatory texts and their equivalents in BIM.

4.2 A Framework for Mapping certification rules over BIM

4.2.1 Building Unified Repository based on IFC + SKOS + bSDD ontologies

At first phase, we need a single ontology that contains enriched concepts and individuals which have annotations in natural language French, English and IFC as well. Therefore, we need to consult underlying ontologies in the domain of construction and building as well as data dictionary that maps labels in various languages. We achieved that ontology in two steps.

Building Enriched IFC (eIFC) Ontology: We have to build an enriched corpus to establish semantic reasoning over it to establish mappings rules between IFC and regulatory text rules in French and English natural language. For this, data dictionary (bSDD) can provide vital information that maps terminologies in various languages. bSDD contains mappings of terminologies via GUID of specific languages. As a foundation stone, we have benefited from the IFC ontology as a semantic model. Then, we enriched IFC ontology (named as eIFC ontology) with the information (i.e., labels, description, etc.) extracted from the building Smart Data Dictionary (bSDD) ontology via Rest API. This enriched ontology eIFC (IFC + bSDD) serves as a semantic model to facilitate several objectives of our project. Our enriched IFC ontology contains: total number of concepts are # 1234, total number of Individuals are # 3938, total number of datatype properties are # 7, total number of object properties are # 1691, etc. As a result of this step, we get *enriched IFC* (eIFC) ontology that contains IFC vocabulary with labels and description in French, English and IFC2X4 terminology.

Merging SKOS with eIFC: In the next step, we merged SKOS ontology based on our CSTB Thesaurus with enriched eIFC ontology which we got as a result of first step above so that only one global ontology should be taken into account for matching and generating

mappings. With our mapping algorithm, we mapped entities from SKOS onto eIFC ontology. Once mappings are established then we merged common individuals from SKOS and eIFC, and copied un-mapped individuals from SKOS into eIFC ontology to build a single ontology that contains enriched concepts and individuals.

4.2.2 Methodology for Mapping Certification Rules over BIM

As Natural Language rules include un-necessary stop-words and phrases which are not in the normalized form, therefore we developed algorithm for the natural language processing. First we tokenize the text into various tokens, and then pass by the stopword remover that eliminates the stopwords from the token stream. Then we used FrenchStemmer (Lucene API) to get the base form of each token so that we can have root form of each token to find its mapping. Once we get stems of token stream, we perform matching of tokens over eIFC ontology to get their mappings. Figure 2 illustrates various steps of our methodology.
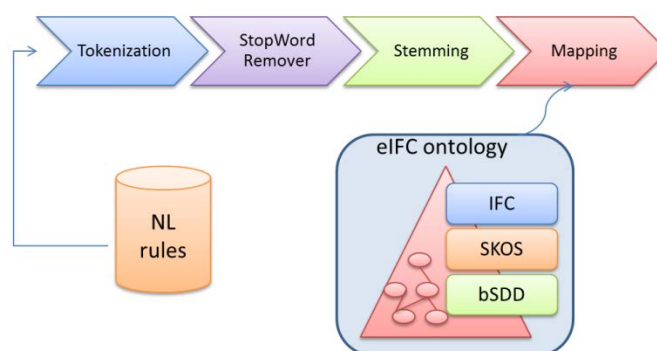
Figure 2 Methodology for mapping verification rules / BIM

In the running example «Dans les salles d'eau et WC, 1 main courante», after stopword removing, we get «salles eau wc 1 main courante» as a result of first step. Then, after performing stemming we got «sall eau wc 1 main cour». With the French stemmer, we got sall instead of salle, though it is not ideal and accurate but applying it at both sides will not affect the result. Once we have a stemmed-token stream, the mapping process starts that does matching of these tokens over eIFC ontology. When it gets *IFCRailingTypeEnum*, it found mapping elements of stems with the labels in French language. Figure 3 illustrates this example for a quick understanding. Similarly, it keeps on matching stemmed-token stream over all the eIFC ontology and select all the individuals that match the criteria. Finally it generates xml that contains text rule code and mapped list of individuals inside the RuleMap xml elements. These RuleMap elements serve as semantic annotations with the regulatory text NL rules.

Figure 3 Illustration of an Example of Mapping text rules over IFC labels

These semantic RuleMap annotations with the regulatory NL text rules (i.e., annotation with Ifc labels from eIfc ontology) also do filtering of rule repository (by the type of elements or genre of building, etc.). These mappings are regarded as a great contribution because in our project an end-user is not familiar of Ifc labels and regulatory NL rules are also in French language. With the help of these semantic annotations, human expert will generate logic based rules in SWRL or MVDXML language to process and reason the underlying repositories. Once logic based rules are generated, they are verified by MVDXML and SWRL technologies for the compliance checking of Ifc model. This is further elaborated in the next section.

5 Verification of Rules via MVDXML and SWRL

The verification of IFC building models is vital in the BIM-based collaboration processes. We have adopted two methods for the verification of rules. Firstly, we use MVDXML checker which performs three step automatic control sequence. The IfcDoc engine loads the IFC file and MVD files, and then it executes the defined rules. Finally, it generates a report indicating compliance (compliant/non-compliant) of each item under the rule. It assigns each rule a green or red depending on whether the item is/is-not in compliance to the defined rules. Secondly, we have built a SWRL based rule engine to verify our rules. For this, we have converted our IFC model into RDF which is the input of the rule engine by using IFC2RDF tool (Vu Hoang and Törmä, 2015). Each method has its own pros and cons and should be used according to requirements of the research project. The following subsections present these two approaches of verification, and also presents a comparison between two technologies MVDXML and SWRL side by side.

5.1 Verify the presence of an Attribute Value

When we need to access the name/label of an IfcSpace, we can simply access the name attribute of the IFC schema. Figure 4a shows the MVDXML template and Figure 4b illustrates how we can access it with the help of SQWRL. In addition, SQWRL provides a lot of built-in functions which we can apply on the name to get results more appropriate according to their order, size, etc. For example, Figure 4b also illustrates how the names of IfcSpaces are obtained with the help of built-in ordered function.

Figure 4 Accessing attribute of IfcSpace in (a) MVDXML, (b) SWRL and SQWRL

5.2 Verify the presence of an Element

When there is a need to restrict the relation between elements of IFC, we can use the IfcRelAggregates relation in MVDXML to specify relating objects. For example, Figure 5a illustrates when we want to check IfcProject should contains an IfcBuilding as represented by the cardinality involved between IFC objects. On the other side in case of ontology, we can restrict IfcProject by a restriction: IfcProject contains some IfcBuilding (i.e., IfcProject $\supset$ $\exists$contains.IfcBuilding) as illustrated in Figure 5b. We can also check this with the help of SQWRL by counting the number of buildings related to IfcProject and verifying whether their number is greater than one.
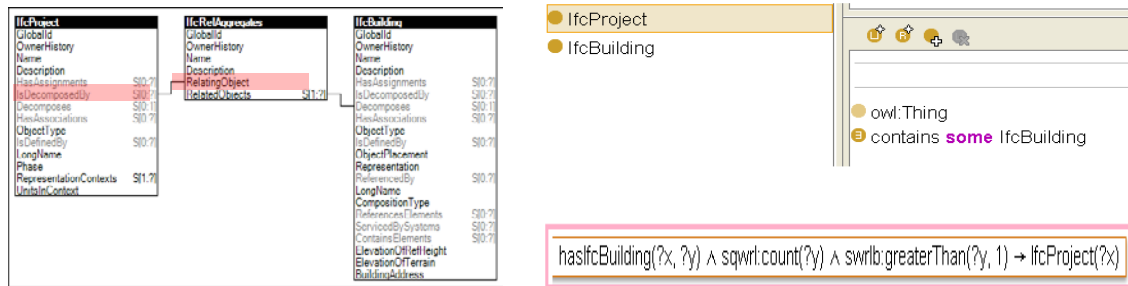
Figure 5 Verify the presence of an element in (a) MVDXML, (b) SWRL

5.3 Verify the value of a Simple Attribute

In MVDXML and SWRL, we can create various types of conformance checking conditions on the attributes of objects. For example, when we need to check the *overAllWidth* value of a door to be greater than 0.8. Figure 6a and 6b illustrates how we can verify this in two technologies. Both the technologies support a lot of function for the implementation of conditions (such as:= , ≠ , < , > , ≤ , ≥).
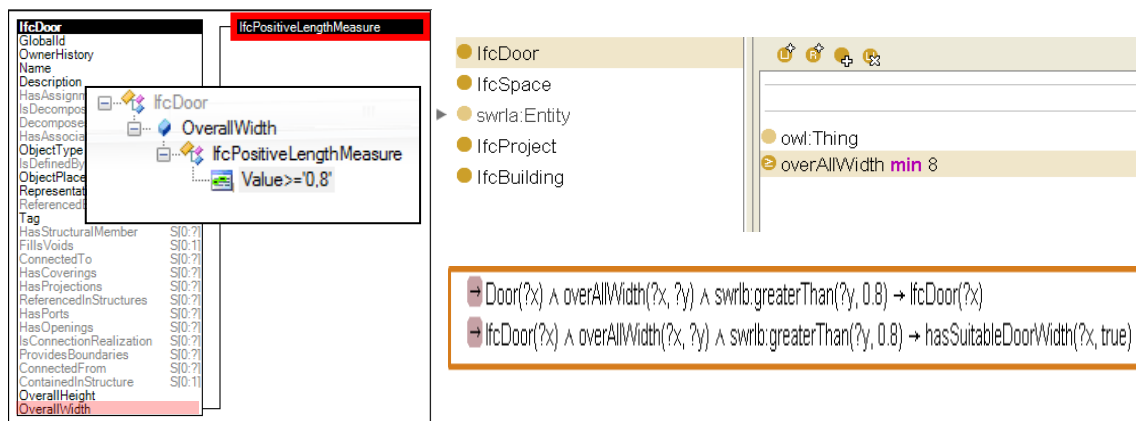

Figure 6 Condition on OverAllWidth attribute of an IfcDoor in (a) MVDXML, (b) SWRL

5.4 Verify Attributes of Element relative to the Classification

Both the technologies allow us to verify attributes of elements relative to the classification. Figure 7a and 7b illustrates how MVDXML and SWRL support various representations of Ifc objects with respect to the classifying element.
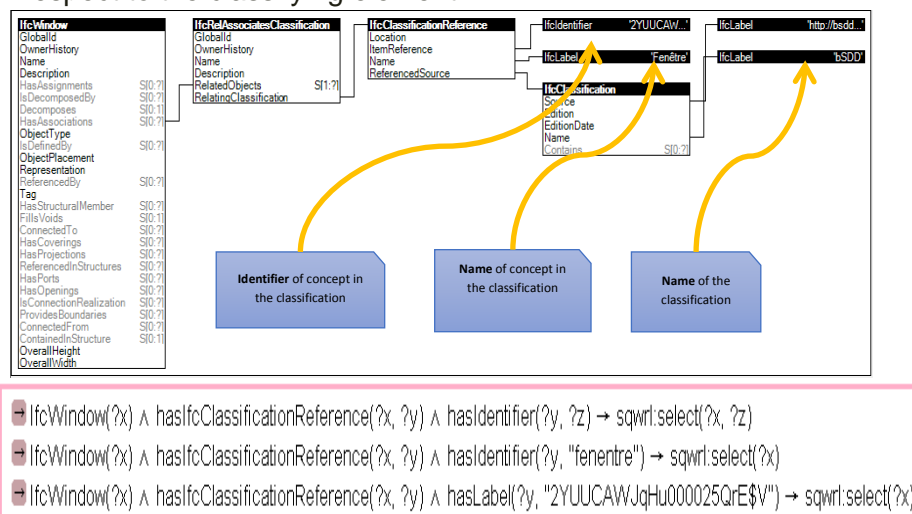

Figure 7 Selection of the concept by 'Fenêtre' OR id '2YUUCAWJqHu000025QrE$V' in (a) MVDXML, (b) SWRL

5.5 Verify the Cardinality of an Element

Both MVDXML and OWL schema allow verifying the cardinality of an element. For an example, verifying whether IfcGroup has two WCs. Figure 8a and 8b illustrates how these technologies support the verification of the cardinality of an element. There can be many ways do perform this semantically as depicted in the Figure 8b.
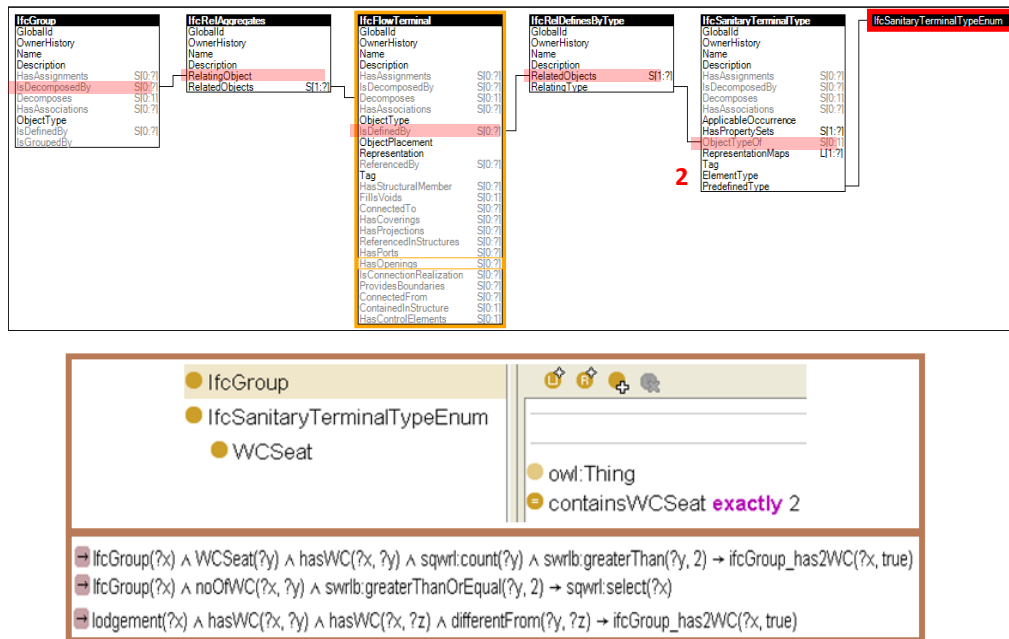

Figure 8 Verifying IfcGroup should have two WC in SWRL (a) MVDXML, (b) SWRL

5.6 Composition of simple rules to build complex rules

MVDXML and SWRL allow building complex rules which are formed from basic rules. We can concatenate simple rules with operators to form more complex rules. Figure 9a and Figure 9b shows an example of building complex rules with the composition of simple rules.
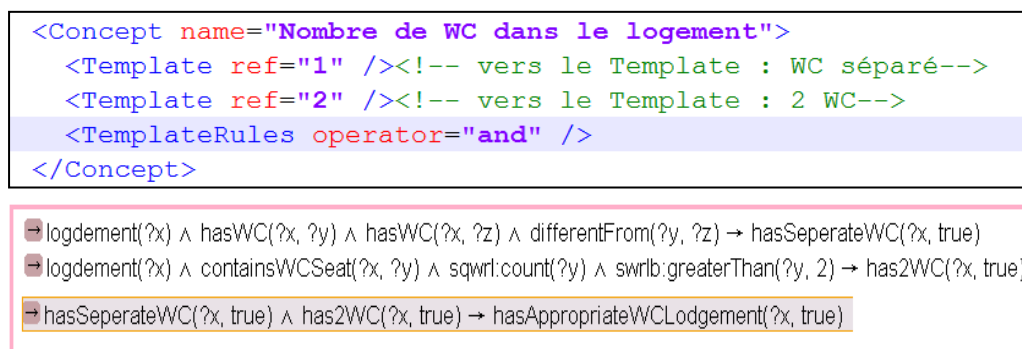

Figure 9 Composition of complex rules based on simple rules in (a) MVDXML, (b) SWRL

5.7 Beyond MVDXML - More Functionalities in SWRL

As SWRL is a W3C recommendation, therefore a lot more functionality is added to meet the requirements of the real world. For example one can perform calculations in SWRL which we cannot do in MVDXML. For instance, volume of a door can be calculated given length, width and height of the door. In SWRL, we use *multiply* function to get *LxWxH* to calculate and display the volume of the door. Besides mathematical library, we have a large number of functions for the string manipulation. In addition, we can also define new attributes and elements and give them values based on the initial axioms in the repository and store them back in our repository for further processing. This is a very interesting feature of semantic

technologies as we cannot define everything in the repository at the initial stage. Some information which is missing, evolving, or new, can be inserted in the repository during the later stages of design and processing. For example, if we want a new attribute *isWheelChairAccessible* associated with the WC based on the dimensions of its door, then we can verify its width and height, and assign a value to the attribute *isWheelChairAccessible* and store its value back in the repository.

6 Conclusion

The contribution presented in this paper has two folds. First, we have presented mapping certification rules over BIM. We have contributed eIfcOWL ontology as an extension of IfcOWL ontology which is engineered by adding bSDD vocabulary. This ontology acts as a foundation stone for the mapping certification rules over BIM. Secondly, we have presented how compliance checking of these rules can be performed by MVDXML and SWRL approaches. The traditional MVDXML technology is a good candidate for the simple rule. There is no intermediate state and IfcDoc tool gives no explanation on the reason of non-compliance. Whereas the semantic web technology is a good compromise between development efforts and opportunities. Verification by SWRL requires prior conversion of the IFC model in RDF. This graphical representation allows MVD and rules to be more intuitive and more efficient. Each method has its own pros and cons and should be used according to requirements of the research project.

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