

Towards Validation of IFC Models with IfcDoc and SWRL

A Comparative Study

Muhammad Fahad

Centre Scientifique et Technique du Bâtiment
290 Route des Lucioles,
Sophia Antipolis 06904, France
fahad.muhammad@cstb.fr

Nicolas Bus, Franck Andrieux

Centre Scientifique et Technique du Bâtiment
290 Route des Lucioles,
Sophia Antipolis 06904, France
{firstname.lastname}@cstb.fr

Abstract—Recent years have witnessed the need of 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 study two approaches for the validation of IFC Models, i.e., with IfcDoc and SWRL. The traditional approach is by using IfcDoc tool developed by buildingSMART International to improve the consistent and computer-interpretable definition of Model View Definitions. On the other hand, Semantic Web technologies, especially Semantic Web rule language, allow the semantic validation of IFC models to enable the compliance checking of IFC construction models with unmatched query performance and flexibility. Therefore, we present and compare IfcDoc and Semantic Web rule language technologies for the model instance verification and conformance checking of IFC models, and demonstrate various important aspects and their limitations. We conclude that both technologies have their specific significances, but Semantic Web technologies provide a better hand over the traditional approach. The Semantic Web approach with the goal of combining the strengths of an ontology and IFC technologies makes information retrieval from an IFC model faster, flexible and also enables interoperability between IFC documents.

Keywords—*Validation of IFC models; SWRL; Ontology; BIM; Querying IFC models; MVDXML.*

I. INTRODUCTION

To understand a building through the usage of a digital model which draws on a range of data assembled collaboratively before, during and after construction is referred to as Building Information Modeling (BIM) [1]. It brings together all the information about every component of a building, in one place. BIM with its interoperability properties is intended to facilitate exchanges and handovers between different stakeholders. While the 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 [2]. Industry Foundation Classes (IFC) is the complete and fully stable open and international standard for exchanging BIM data [3]. Building SMART organization aims at publishing IFC and related buildingSMART 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 [4]. Together, both groups organize the IFC software certification process. It aims to be a global standard for the BIM data exchange. The subset of the IFC schema needed to satisfy one or many Exchange Requirements of the Architecture, Engineering and Construction (AEC) industry is called Model View Definitions (MVD). The XML format used to publish the concepts and associated rules is MVDXML and it is regarded as an open standard [5]. MVDs provide additional rules for the IFC validation and focus on extracting integral model subsets for the IFC implementation purposes. There are many drawbacks of MVDXML for extracting building views such as: lack of logical formalisms, solely consideration of IFC schema and MVD-based view constructors are not very flexible and dynamic [6]. Although IFC is an open standard, its complex nature makes the information retrieval difficult from an IFC model, and thus affects the validation process by MVDXML rules. Many tasks for IFC model such as information retrieval, model validation, etc., do not achieve real-time performance in the real-world BIM scenarios.

Our enterprise, Centre Scientifique et Technique du Bâtiment (CSTB), through its research and development efforts, aims at automatic validation 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 [5] and, in addition, focuses on the Semantic Web rule language SWRL [7] for the validation of IFC construction and building models. The traditional approach by using IfcDoc tool developed by buildingSMART International is to improve the consistent and computer-interpretable definition of MVD as true subsets of the IFC Specification with the enhanced definition of concepts. Therefore, first, we present background knowledge about both these approaches and then compare IfcDoc and SWRL technologies for the model instance verification and conformance checking of IFC models. In addition, we demonstrate various important aspects and their limitation as well. We also performed experiments via queries by the traditional approach via IfcDoc and the ontology-based Resource Description Framework (RDF)

approach IFC-to-RDF via SPARQL queries [8]. IFC-to-RDF is a set of reusable Java component that allows parsing IFC-SPF files and converts them into RDF graphs. Our approach uses IFC to RDF conversion and then stores RDF triples into Stardog [9] knowledge graph that gives unmatched query performance. We investigated that IFC; although is an open standard, it has a complex nature which makes information retrieval difficult from an IFC model. On the other hand, Semantic Web technologies, especially SWRL, allow for the semantic verification of IFC models to enable the compliance checking of IFC construction models with fast querying performance.

The rest of paper is organized as follows. Section 2 provides the background knowledge of the domain. Section 3 presents the related work. Section 4 presents two approaches for the validation of rules and conformance checking. Section 5 discusses our experimental findings via MVDXML validation rules on IfcDoc and SPARQL queries. Section 6 concludes this paper.

II. BACKGROUND

In this section, we provide some background about the two approaches that can be used for the validation of IFC models.

A. *IfcDoc Tool and MVDXML*

The subset of the IFC schema needed to satisfy one or many Exchange Requirements of the Architecture, Engineering and Construction (AEC) industry is called *Model View Definition* (MVD). The XML format used to publish the concepts and associated rules is MVDXML and it is regarded as an open standard [5]. MVDs provide additional rules for the IFC validation and focus on extracting integral model subsets for IFC implementation purposes. The buildingSMART is willing to support construction domain developers in reusing its leading openBIM standard IFC as a baseline to set up specific data exchange protocols to satisfy exchange requirements in the industry. The buildingSMART International has developed IfcDoc tool for creating Model View Definitions. Based on the newly developed mvdXML standard, just Model View Definitions can now be easily developed using the IfcDoc tool. The tool and methodology can be applied to all IFC releases (IFC2x3, IFC4, etc.). For the validation of an IFC file against a particular model view, IfcDoc tool user interface displays a pane on the right side containing object instances within the file matching definitions selected in the tree view. The end-user can generate a report in the HTML format indicating if the file is valid according to the specified model view, and detailing what passes or fails. However, it does not show the cause or provide mechanisms for reasoning the inconsistencies or anomalies.

B. *SWRL and SQWRL*

The Semantic Web technologies, SWRL and SQWRL, are widely being used for the inference of new knowledge, validation and querying ontologies [7]. 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 Ontology Web Language; therefore, Semantic Web Rule Language is designed on top of ontologies to be an alternative paradigm for the 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 the RDF data [10]. Along with query language SQWRL, it has more access to characterize on RDF graphs. SWRL rule engine employed with an ontology-based on IFC specifications can be used for the information retrieval process from an IFC model and is the focus of our research.

III. RELATED WORK

To achieve the benefits of ontologies, there are many efforts to build an ontology for the IFC construction industry. One of the outcomes can be seen as an IFC-based Construction Industry Ontology and Semantic Web services framework [11]. With simple reasoning built over the ontology, their information retrieval system could query the IFC model in XML format directly. 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 [12]. There are many versions of IfcOWL ontology since the work has been started. We have been working on an ontology IFC4_ADD1.owl that was launched on 25 Sept. 2015. We have enriched this ontology with English-French and IFC vocabulary (synonyms, descriptions, etc.) from bSDD semantic data dictionary in our research project where we map regulatory text and certification rules over BIM [13]. In addition, we assigned concepts of IfcOWL ontology with Global Unique Identifier (GUID) to serve as a unique language-dependent serial number from the bSDD.

Data models formally define data objects and relationships among data objects for a domain of interest. EXPRESS is a standard data modeling language for product data [25]. There are some research projects that bring BIM to the Web, to overcome drawbacks due to several limitations of EXPRESS, by converting IFC models into RDF graphs. Then, the RDF models become accessible from the Web; they can be processed and queried in more flexible ways, and they can be interlinked using the Linked Data technologies. This way of bringing BIM to the Web allows to take advantage of the fast evolution of the Web and the emerging services and data sources. Hoang and Torma [14] developed an open-source Java based IFC2RDF tool that performs multilayer conversion from IFC schemas developed in EXPRESS into OWL2 ontologies [26] and IFC data from STEP physical file format (SPFF) into RDF graphs aligned with the ontologies. Through the multi-layer model, users can 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. There is another tool named IFC-to-RDF-converter developed by Internet & Data lab at Aalto University and Ghent University [15]. They provide with an EXPRESS-to-OWL and IFC-to-RDF conversion service. The converter can be accessed in a

number of ways: using a command line tool (written in Java), using a RESTful Web interface, or using a Graphical User Interface (GUI).

Besides these projects that build an ontology for the IFC, recent years revealed some contributions based on Semantic Web technologies. SWOP-PMO project is one of recent contributions that use formal methodology based on the Semantic Web standards and technologies [16]. 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 has to be remodeled in accordance with the rules of OWL/RDF. There are some other works for the semantic enrichment of ontologies in the construction and building domain. Emani et al. proposed a framework for generating an OWL Description Logic (DL) expression of a given concept from its natural language definition automatically [17]. Their framework also takes into account IFC ontology and the resultant DL expression is built by using the existing IFC entities.

Pauwels and Zhang [18] listed three ways for the conformance checking of IFC models. First, we have the hard coded rule checking, which is similar to the approach adopted by Solibri Model Checker [19]. This tool loads a BIM model, considers rules stored natively in the application and performs rule checking against BIM for the architectural design validations. This approach is fast as rules are integrated inside the application, but there is no flexibility or customization possible as rules are not available outside the actual application. Another solution, the traditional approach of compliance checking is with the IfcDoc tool developed by buildingSMART International for generating MVDXML rules through a graphical interface [20]. It is based on the MVDXML specification to improve the consistent and computer-interpretable definition of Model View Definitions as true subsets of the IFC Specification with enhanced definition of concepts. This tool is widely used as AEC specific platform in the construction industry.

The second approach is ‘rule checking’ by querying the IFC model. In this approach, BIM is interrogated by rules, which are formalized directly into SPARQL queries. As an example, K. R. Bouzidi et al. [21] proposed this approach to ease regulation compliance checking in the construction industry. They reformulated the regulatory requirements written in the natural language via SBVR, and then, SPARQL queries perform the conformance checking of IFC models.

The third is a semantic rule checking approach with dedicated rule languages such as SWRL, Jess [27] or N3Logic [28]. There are few projects in AEC industries that use this approach for the formal rule-checking, job hazard analysis and regulation compliance checking. H. Wicaksono et al. [22] built an intelligent energy management system for the building domain by using RDF representation of a construction model. Then, they formulated SWRL rules to infer anomalies over the ontological model. Later, they also developed SPARQL interface to query the results of rules. Pauwels et al. [23] built acoustic regulation compliance checking for BIM models based on N3Logic rules. They use

N3logic rules with an ontology to reason whether a construction model is compliant or not with the European acoustic regulations. Another project that was built on the ontological framework for the rule-based inspection of eeBIM-systems was developed by M. Kadolsky et al. [24]. They used rules to query an IfcOWL ontology that captured a building.

IV. VALIDATION OF CONSTRUCTION MODELS VIA IFCDOC AND SWRL

The validation of IFC building models is vital in the BIM-based collaboration processes. The aim of validating Models 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. We have adopted two methods for the verification of rules. Firstly, we use IfcDoc tool (MVDXML checker) which performs three step automatic control sequence. The IfcDoc engine loads the IFC file and MVD files, and then 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 IFC-to-RDF-Converter. 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 present a comparison between two technologies MVDXML and SWRL side by side.

A. 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 1 shows the MVDXML template and Figure 2 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 2 also illustrates how the names of IfcSpaces are obtained with the help of built-in ordered function (sqwrl:orderBy).

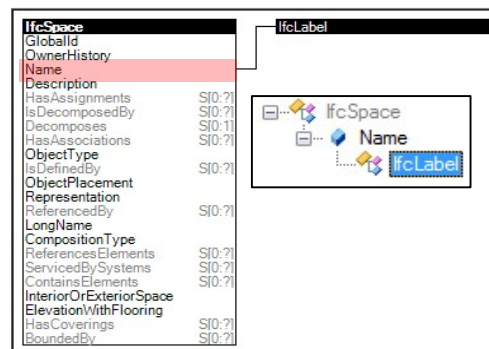


Figure 1. Accessing attribute of IfcSpace in IfcDoc

```

    → IfcSpace(?x) ∧ name(?x, ?y) → sqwrl:select(?x, ?y)
    → IfcSpace(?x) ∧ name(?x, ?y) → sqwrl:select(?x, ?y) ∧ sqwrl:orderBy(?y)
    
```

Figure 2. Accessing attribute of IfcSpace in SWRL

B. Verify the presence of an Element

When there is a need to restrict the relation between the elements of IFC, we can use the IfcRelAggregates relation in MVDXML to specify relating objects. For example, Figure 3 illustrates when we want to check IfcProject should contain an IfcBuilding as represented by the cardinality involved between IFC objects. On the other hand, 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 4. 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.

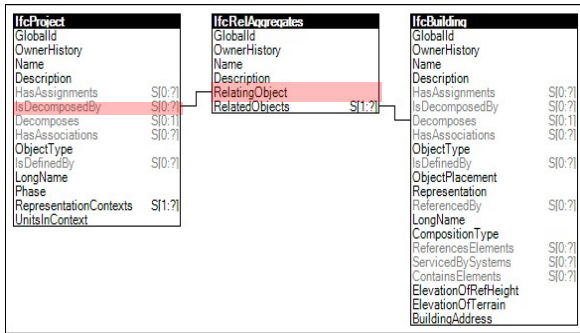


Figure 3. Verify the presence of an element in IfcDoc

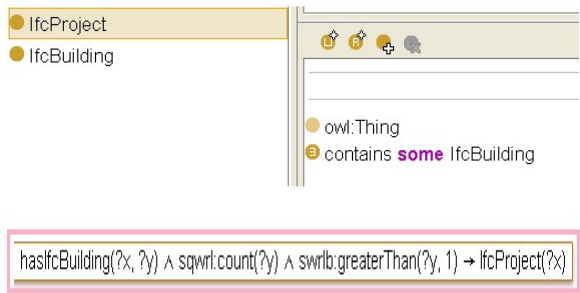


Figure 4. Verify the presence of an element in SWRL

C. 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, consider a case when we need to check the value of overAllWidth attribute of a door to be greater than 0.8. Figures 5 and 6 illustrate how we can verify this in these technologies. Both technologies support a lot of operators

for the implementation of conditions (such as: =, ≠, <, >, ≤, ≥).

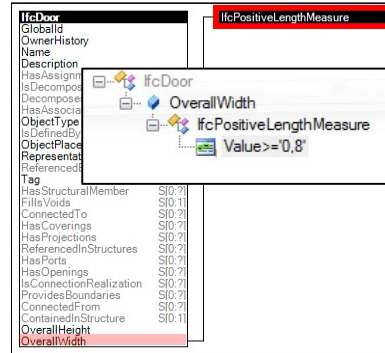


Figure 5. Condition on OverAllWidth attribute of an IfcDoor in IfcDoc

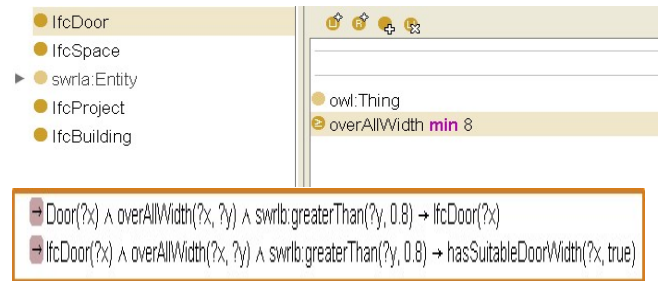
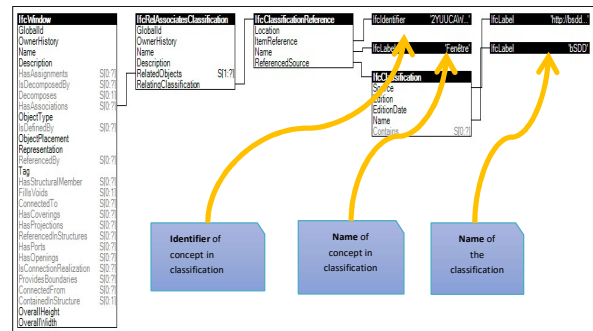


Figure 6. Condition on OverAllWidth attribute of an IfcDoor in SWRL

D. Verify Attributes of Element relative to the Classification

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



```

    → IfcWindow(?x) ∧ hasIfcClassificationReference(?x, ?y) ∧ hasIdentifier(?y, ?z) → sqwrl:select(?x, ?z)
    → IfcWindow(?x) ∧ hasIfcClassificationReference(?x, ?y) ∧ hasIdentifier(?y, "fenetre") → sqwrl:select(?x)
    → IfcWindow(?x) ∧ hasIfcClassificationReference(?x, ?y) ∧ hasLabel(?y, "2YUUCAWJqHu000025QrESV") → sqwrl:select(?x)
    
```

Figure 7. Selection of the concept by 'Fenêtre' in (a) IfcDoc (b) SWRL

E. Verify the cardinality of an Element

Both MVXML and OWL schema allow verifying the cardinality of an element. For an example, they allow to verify whether IfcGroup has two WCs. Figures 8 and 9 illustrate how these technologies support the verification of the cardinality of an element. There can be many ways to perform this semantically, as depicted in the Figure 9.

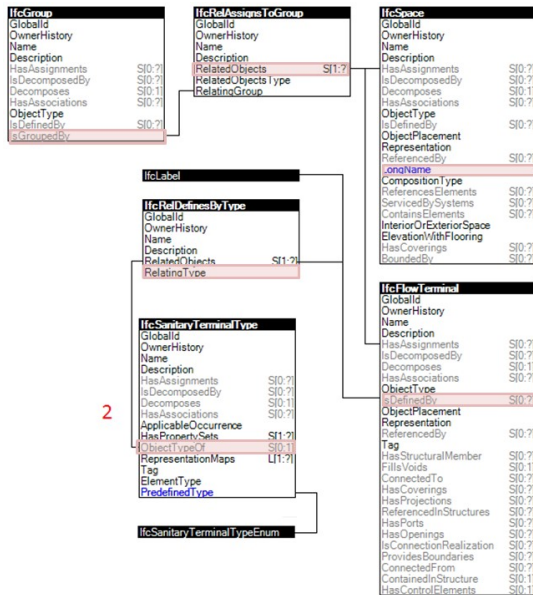


Figure 8. Verifying IfcGroup should have two WC in IfcDoc

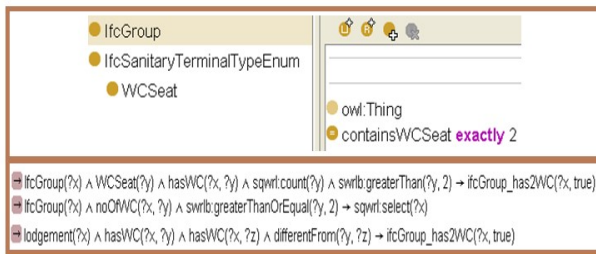


Figure 9. Verifying IfcGroup should have two WC in SWRL

F. Composition of Simple Rule to build complex rules

MVXML and SWRL allow building complex rules which are formed from basic rules. We can concatenate simple rules with operators to form more complex rules. Figures 10 and 11 show an example of building complex rules with the composition of simple rules.

```
<Concept name="Nombre de WC dans le logement">
  <Template ref="1" /><!-- vers le Template : WC séparé-->
  <Template ref="2" /><!-- vers le Template : 2 WC-->
  <TemplateRules operator="and" />
</Concept>
```

Figure 10. Composition of complex rules based on simple rules in IfcDoc

```
logdement(?x) ^ hasWC(?x, ?y) ^ hasWC(?x, ?z) ^ differentFrom(?y, ?z) -> hasSeparateWC(?x, true)
logdement(?x) ^ containsWCSeat(?x, ?y) ^ sqwrt.count(?y) ^ swrlb.greaterThan(?y, 2) -> has2WC(?x, true)
hasSeparateWC(?x, true) ^ has2WC(?x, true) -> hasAppropriateWCLodgement(?x, true)
```

Figure 11. Composition of complex rules based on simple rules in SWRL

G. Beyond MVXML – More functionalities in SWRL

As SWRL is a W3C [29] recommendation, a lot more functionality is added to meet the requirements of the real world scenarios. For example, one can perform calculations in SWRL, which we cannot do in MVXML. For instance, volume of a door can be calculated given the length, width and height of a door. In SWRL, we use multiply function to get $LxWxH$ to calculate and display the volume of a door. In addition to a mathematical library (e.g., add, subtract, multiply,...,sin, cos, tan), we have a large number of functions for the string manipulation (e.g., stringConcat, stringLength, substring, normalizeSpace, etc.), and for the DateTime, Duration, URIs and Lists as well. 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 water closet (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 to judge the accessibility of a WC.

V. EXPERIMENTAL ANALYSIS ON IFCDOC AND SPARQL

We also performed experiments via different queries on different sizes of IFC models by the traditional approach via IFCDoc and the ontology-based approach via SPARQL. We have used IFC-to-RDF-Converter developed by Pauwels and Orskari [15]. The IFC file needs to follow the IFC4_ADD1, IFC4, IFC2X3_TC1, or IFC2X3_Final schema. Once IFC document is converted into RDF, then we stored it into the Stardog triple store. Stardog is the enterprise knowledge graph used for querying, searching, and analyzing enterprise data, wherever it is, using scalable, cutting-edge knowledge graph technology. We found that SPARQL queries are flexible for retrieving data and do the validation in an optimized way giving better run-time as compared to the traditional approach. But conversion from IFC to RDF and then storage of triples into stardog takes time. But, once the stardog triple store is loaded with the data, it is much faster querying and validation of IFC document. SPARQL queries and SWRL rules can be modified easily with the new or customized conditions and constraints for the conformance checking against the stored triple store. Besides flexibility, reasoning is another advantage of Semantic Web technology, as the IfcDoc tool does not provide any justification. With

queries and rules, we can identify the reason of inconsistency and anomalies. Therefore, each approach has its own pros and cons. The traditional approach is simpler as there are no conversion tasks. On the other hand, Semantic Web technologies require a conversion layer to be integrated for the validation tasks for IFC models. But, it can enable interoperability and fast information retrieval once the triple store is ready. Table 1 summarizes file and schema features of both approaches, where 1 represents the traditional approach via MVDXML and 2 represents the Semantic Web approach via SWRL.

TABLE I. FILE AND SCHEMA FEATURES OF BOTH APPROACHES

	<i>Data File</i>	<i>Rule File</i>	<i>Rule Schema</i>	<i>Data Schema</i>
1	IFC	.mvdXML	.XSD	.step
2	RDF (IFC converted)	.SWRL, .OWL	.OWL	IfcOnt

VI. CONCLUSION AND FUTURE WORK

This paper addresses the need of automatic verification requirements to warn the non-conformities with the associated 3D visualization as a hot challenge. We studied two approaches for the validation of IFC Models, i.e., with IfcDoc and SWRL. Each approach has its own pros and cons and should be used according to requirements of a research project. Some of major points are:

- IfcDoc tool and traditional conformance checking by MVDXML technology is a good candidate for the simple rules on small IFC models. Verification by SWRL requires a prior conversion of the IFC model in to the RDF, which is an extra task to achieve.
- Although IFC is an open standard; its complex nature makes information retrieval from an IFC model difficult as the size of IFC model grows. Querying semantic model is faster and gives a good run-time. One can customize queries easily and according to requirements.
- There is no intermediate state and IfcDoc tool gives no explanation for the reason of non-compliance. Whereas the Semantic Web technology is a good compromise between development efforts and opportunities. The graphical representation of RDF allows rules to be more intuitive and more efficient to reason and execute.

As a future direction, we are going to present a comprehensive quantitative comparison between the two approaches, and also investigate other triple stores which are competitors of stardog for the storage and querying of IFC models.

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