Aligning IFC and SRI domains for BIM supported SRI assessement

Calin Boje
Environmental Research and Innovation
Luxembourg Institute of Science and Technology
Esch/Alzette, Luxembourg
calin.boje@list.lu

Sylvain Kubicki
Environmental Research and Innovation
Luxembourg Institute of Science and Technology
Esch/Alzette, Luxembourg
sylvain.kubicki@list.lu

Annie Guerriero
Environmental Research and Innovation
Luxembourg Institute of Science and Technology
Esch/Alzette, Luxembourg
annie.guerriero@list.lu

Sebastien Thomas
Environmental Research and Innovation
Luxembourg Institute of Science and Technology
Esch/Alzette, Luxembourg
sebastien.thomas@list.lu

***Abstract*—Although more assessment and certification schemes aimed at buildings appear on the market, professionals always face the same challenges: information scarcity and data flow interruptions. It therefore becomes crucial to rigorously assess the information workflows associated with built assets in order to help deliver the subsequent assessment services and certification schemes. The Smart Readiness Indicator is a new assessment scheme directed at harmonizing the smartness levels of buildings and intelligent installations at a European level. While the European Union defines the Smart Readiness Indicator scope and assessment methodology towards new regulations with the member states, the availability of data should strategically rely on existing sources such as the Building Information Model in order to automate and simplify the efforts of assessors. This paper explores the potential of Building Information Model data, more specifically relying on the Industry Foundation Classes schema, to support assessors with more automatic extraction of relevant information on the building and its equipment. The adopted methodology looks at the semantic alignment between the two domains. An initial alignment of concepts from several versions of the Industry Foundation Classes is proposed. This alignment was implemented using several rules, which were tested on the architectural and mechanical models of the same building. The study shows the convenience of employing such a methodology, the usefulness of data from existing building models, but also their limitations in correctly identifying relevant concepts.**

Keywords—BIM, Smart Readiness Indicator, IFC, ontology alignment, semantics, smart building

I. Introduction

The emergence of smart buildings and smart cities supporting energy performance objectives has led to the need to measure the smartness of buildings, for both are ensuring high performance design and reflect on operational energy performance. The Smartness Readiness Indicator (SRI) is a new tool introduced under the tutelage of the European Commission to standardize the evaluation of smart buildings [1]. As defined by the EU in the new Energy Performance of Building Directive (EU) 2018/844: "The smart readiness indicator should be used to measure the capacity of buildings to use information and communication technologies and electronic systems to adapt the operation of buildings to the needs of the occupants and the grid and to improve the energy efficiency and overall performance of building".

The SRI allows a robust, yet flexible assessment of smart services present within a building. It is robust in the sense that it considers several evaluation domains, ranging from energy to human comfort and electric vehicle charging. This aligns the framework with new potential research and development avenues around smart grids under the green energy agenda. The SRI is flexible in the sense that it allows each member EU country to evaluate building smartness according to their own circumstances, by using several weighting factors for each domain. Therefore, this design approach to the SRI assessment permits an EU level standardization of data collection, evaluation and comparisons between regions.

The SRI framework itself is still quite new, with few assessments having been conducted to date, but this is expected to catch up alongside the Energy Performance Certification (EPC) for buildings. For the time being, the SRI is optional for member states. Even if the European Commission adopted the legal acts associated with the SRI in October 2020, the methodology and related documentation is still under development and deployed for testing by EU member states. Several research works have examined the deployment of the SRI methodology [2] [3], most notably in order to assess how it will impact the energy performance of buildings [4] or studying the link with the next generation of EPC [5].

The role of Building Information Modelling (BIM) is increasingly associated with information automation. Seen as a reliable source of building rich data under many real-time applications, and seen as a vital component for the employment of construction sector digital twins [6]. BIM is regarded as the primary source for geometric information at building level in many applications across the industry. The real potential lies in contextualizing the geometric shape and layout of a building with supplementary semantics - such as element specific types, properties and attributes. This level of information may prove vital to supporting a more accurate evaluation of SRIs. The Industry Foundation Classes (IFC) schema allows a very detailed semantic description of our building projects, ranging from the structural and architectural domains to the mechanical, electrical and plumbing (MEP) services. The schema also includes very comprehensive definitions for sensor and actuator networks, key components for smart buildings. The main issue remains the quality of data within BIM models, which is often lacking. However, once present, it is a reliable source of data which can support the evaluation of several types of certifications such as EPC or SRI.

Within this paper we aim to explore the potential of BIM in supporting the SRI evaluation process. More specifically, the IFC schema is analyzed on its potential alignment with SRI concepts. The rationale behind the alignments is shown and discussed from a semantic web world view, which is demonstrated by implementing a knowledge base with appropriate alignment rules. The initial alignment process is tested on a sample IFC model, attempting to highlight the utility and limitations of the IFC schema. The IFC2x3 and IFC4 schema versions are both discussed.

II. Background

The SRI evaluation method is not an automatic process, which requires several steps from a human technician, as well as several types of building information [2] [3]. [7] have proposed an algorithm for an automatic estimation of the SRI, but not based on a BIM approach. Within this section we will introduce the SRI technical domains and their potential links to BIM.

A. *SRI technical domains*

The SRI evaluation and main criteria are summarized in Fig. 1. The final scores are classed under 7 impact categories which affect several criteria such as energy efficiency, comfort, convenience, information to occupants etc.

The impact categories scores are automatically calculated based on the evaluation of the underlying technical domains: heating (1), cooling (2), domestic hot water (3), ventilation (4), lighting (5), dynamic building envelope (6), electricity (7), monitoring and control (8) and electric vehicle charging (9). Some technical domains may contribute to all impact categories, whilst some do not. For more information on the exact terminology and connections between these concepts, the reader is referred to the official report [8]. Within the scope of this study, we believe that the 9 aforementioned SRI technical domains are logically related to the BIM of a building, which can be leveraged to aid the SRI evaluation.

B. *BIM and IFC*

BIM as a process defines the management and creation of construction models and their associated data. BIM models are regarded as a source of information on several nearby domains, ranging from GIS applications to cost analysis, energy simulation software and more recently are seen as a main provider of data for digital twins [6]. The BIM models themselves come in different shapes and sizes when it comes to their data models, but at large, the research and industry communities look to the IFC schemas (in various formats and versions) as a meta model for organizing the information about construction projects, and implicitly buildings. IFC provides simple definitions for most building elements (structure, mechanical, plumbing, electric, etc.), including those associated to smart buildings (sensors, actuators). More importantly, the IFC schema provides semantic mechanisms to model interrelationships between various types of elements, such as: hierarchies, connections, aggregations, etc. Therefore, the IFC domain is arguably the most complete ontology model to feed into SRI evaluation and support.

In practice however, the main aim of IFC is to foster interoperability and the communication of information models. The scope of the transferred data is often restricted (and for good reason). The IFC is mostly used to transfer information from on construction practitioner to another through the use of IFC exporters, making use of Model View Definitions (MVD), which define the boundaries of exported information as a sub-set of the IFC schema. For example, a structural engineer is not interested in cluttering his model with electrical component information. Thus, the majority of IFC format BIM models will represent a sub-set of building information, with no MVD dedicated for smart buildings. As a result, the concepts available in BIM models may prove to be incomplete or insufficient to assess an SRI fully automatically. Still, the IFC schema is the best option for representing complex building information, and can be used to support human evaluators in accessing and evaluating BIM information more easily.

C. *SRI as a data collection process*

Conventionally, assessing the smartness level of a building requires data that has to be collected, analyzed and inserted into a dedicated calculation spreadsheet in Microsoft Excel. The accuracy of final score depends largely of the quality of data and its interpretation.

The SRI method is undergoing several pilot testing phases between 2021 and 2030 in Austria, Czechia, France and Denmark [9], where experts are testing the data collection process. The training of assessors is not yet subjected to certification nor exams, but some training material is now openly available[1]. During these test phases, it is expected that the data gathering process will improve and align the SRI certification with the EPC one, as they have several overlapping criteria and responsibilities, most notably the energy aspects.

Compared to the EPC assessment, the data collection is more oriented on identifying the presence of devices instead of metrics linked to the performance (e.g. U value for walls). A first round consists in indicating the presence or absence of a type of device. A second-round deals with evaluating the capabilities of devices and systems installed (e.g. 2-way controlled electric vehicle charging including desired departure time and grid signals for optimization). However, the criteria assessed and data to be handled are arguably quite different from the current EPC assessor expertise. With regards to the existing data collection methodology, there are several drawbacks. A largely manual process which relies on a human expert filling out a complex excel spreadsheet clearly shows a need for more integration with existing data sources. The process assumes that the evaluator has good knowledge of the buildings services and their spatial configuration. The SRI spreadsheet includes a list of pre-defined types of services which are associated with several of the SRI domains, but these are analyzed in turn by the human evaluator, which needs to rely on external documents and building specifications.

[1] https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/smart-readiness-indicator/sri-implementation_en

Fig. 1. The seven SRI impact categories. Source: [9]

There is a need for better data aggregation to speed up the process and implicitly increase the quality of the assessment. The use of BIM is therefore an opportunity for improving the effectiveness of the SRI assessment framework.

D. Semantic web ontologies and rules

The semantic web tools and technologies are used to formalize knowledge and represent information using graph data structures. The Web Ontology Language (OWL) allows very complex definitions for abstract models and real-world things on top of the Resource Description Framework Schema (RDFS). At their core, these are sophisticated, scalable tools which allow us to formalize data models and leverage them for reasoning and inference, all on the web. Semantic web ontology graphs have become widely used in linking data and formally aligning semantic models from various domains within the construction and building sectors [10]. The use of OWL and RDFS allows data models from adjacent domains to be mapped, and therefore connected to various degrees, depending on their structure and domain semantic proximity, resulting is a semantic alignment. The mapping of two schemas can be done by formalizing knowledge alignment rules. By defining rules in a language such as the Semantic Web Rules Language (SWRL), these can be integrated with the two aligned schemas within a knowledge base which uses reasoners to infer the connections. As a result, a query to the knowledge base (usually done in the SPARQL query language) about a domain concept, would also yield results from the mapped domains. This is a powerful tool in connecting models such as BIM and their data to other adjacent domains.

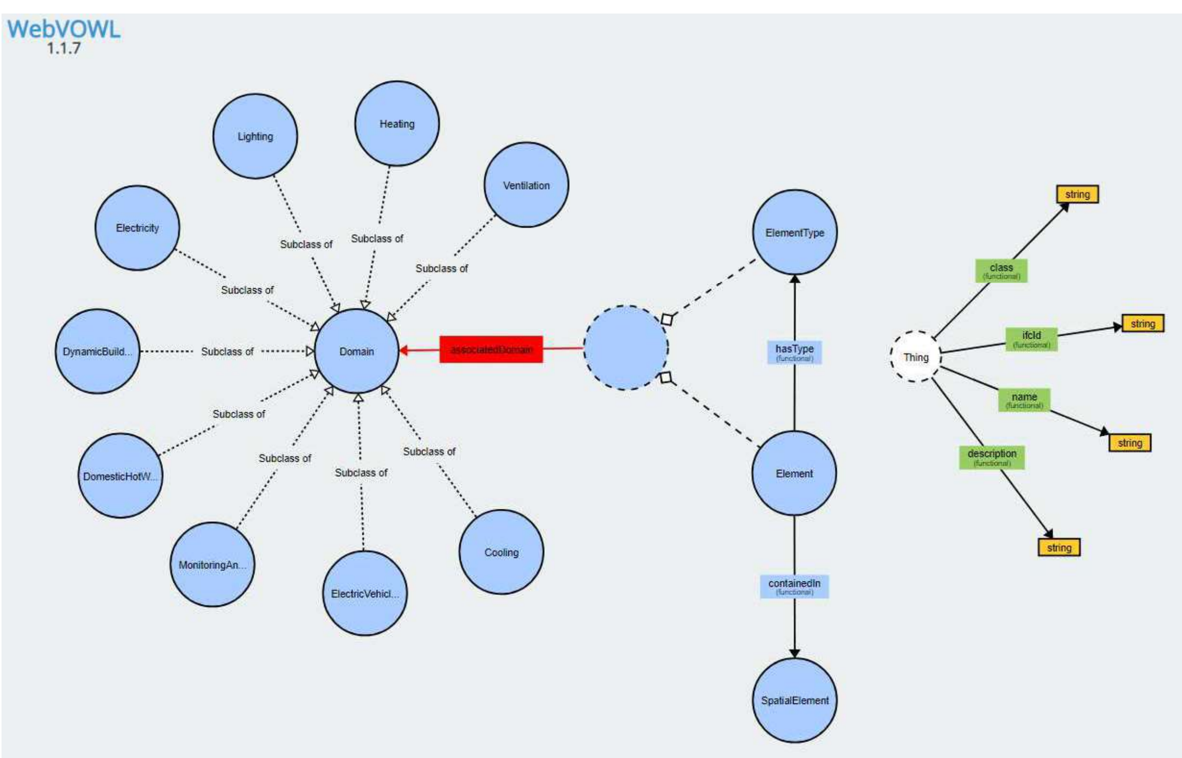

Fig. 2. A visual representation of an ontology for modelling SRI domains and relevant BIM sourced object information

III. METHODOLOGY

The main contribution of this study is to highlight the semantic alignments between the IFC schema concepts and the SRI technical domains. In order to achieve this aim, we have adopted a standard ontological alignment process [11]. By analyzing the formal definitions of the IFC schema, we can associate each concept to one or more technical domains as part of the SRI. In terms of a practical implementation we adopted a semantic web approach using the Web Ontology Language (OWL) to formally represent the two distinct domains. The alignment between the domains can be achieved in several ways, from explicit mapping between concepts to the formalization of rules. We recommend the latter using the Semantic Web Rules Language (SWRL) standard. To analyze the potential of the proposed alignment, we tested this on two openly available IFC models which are extracted, analyzed and discussed.

IV. IFC AND SRI SEMANTIC ALIGNMENT

E. An initial SRI ontology model

Using the Protégé tool[2], we have modelled a simple ontology describing the SRI domains, as shown in Fig. 2. The ontology is still under development and may change in the future. The purpose of this model is to offer a way to quickly identify BIM-sourced objects associated with SRI domains. Thus, the classes labelled “Element”, “SpatialElement” and “ElementType” in Fig. 2 denote three distinct object types extracted or sourced from a BIM model. These should have several key data attached to it explicitly in order to allow subsequent reasoning rules to function. These are modeled as data properties for containing the following data types from an IFC model:

- ifcId – an identifier to distinguish between distinct IFC instances
- class – the type of object class in IFC (used for reasoning)
- name & description – used to label the elements and help users distinguish between them (informative purposes)

Looking at the SRI documentation, we can observe that apart from building components, spatial containers (e.g. levels, spaces) are also needed for the evaluation. These are used in identifying the location of elements within the building, as well as the coverage of services across the building spatial structure. The SRI specifically denotes a service as covering a percentage of the building functional space, which means that the value area of spaces is also important in calculating this. Thus the class “SpatialElement” is a generalization of a spatial container, in which a building “Element” is placed within the BIM.

By considering both the IFC2x3 and IFC2x4 major versions of the schema[3], we selected several concepts to review their definitions and scopes under the SRI domains. Most notably, the uppermost abstract classes for IFC objects were IfcProduct – objects with an associated geometric representation in the IFC model. Following the hierarchy, the IfcProduct contains IfcElement and IfcSpatialElement which are needed to identify real building components and the buildings spatial delimitations.

A more in depth analysis ofr concepts related to smart buildings, we can associate most smart building services to the mechanical, electrical and plumping elements. Therefore, the IfcDistributionElement is arguably the more useful super-class which one can align its subclasses to the SRI domain. Under the IFC2x4 version, the IfcDistributionElement has a total of 76 sub-classes, whereas under the IFC2x3 version these are only 12, but to compensate it also adds the 67 equivalent types under these 12 classes. The reason behind this is that IFC2x4 included several new types of elements (previously under IfcTypeObject), which were considered as special types for the 12 classes in IFC2x3. For example, the concept for IfcActuator did not exist in IFC2x3, but instead it was classed as an IfcDistributionControlElement with an associated IfcActuatorType. This was changed by adding the explicit class IfcActuator in IFC2x4, which is a direct subclass of IfcDistributionControlElement.

Disregarding the schema version discrepancies, from the concepts under the IfcDistributionElement, 11 of these could not be attributed to any specific SRI domain. For example: IfcTank, IfcWasteTerminal, IfcFilter, etc. The other associations are summarized in Table I.

It should be noted that some concepts could belong to more than one SRI domain. For example: IfcBoiler can be associated to both Domestic Hot Water, but also Heating. Here is an example of the definition for the IfcBurner “A burner is a device that converts fuel into heat through combustion. It includes gas, oil, and wood burners.” - we can therefore assume that this type of class is always associated with Heating, as the purpose of this device within a building is to provide heat. However, this heat can be transferred to the heating system, but also to the domestic hot water via other complementary installations. Therefore, we can safely assume that this type of class can be associated with two distinct SRI domains: Heating and Domestic Hot Water. The context of each instance BIM model will dictate which one domain is actually used in practice for each building.

The Electricity SRI domain is a particular domain in the sense that many services are in reality connected to other electric devices, and implicitly to the power grid. Therefore, our alignment rationale here was to restrict this domain to IFC concepts which deal exclusively with electric power generation, its conduction or control. For example, IfcBoiler can be electric powered, but its application scope is to heat fluids and thereby provide heating or domestic hot water. By contrast, IfcElectricGenerator and IfcMotor both deal with power generation, and therefore are aligned to electricity.

The Dynamic Building Elements SRI domain is the more hard to identify, and we believe walls are too generic. Some candidates here would be IfcShadingDevice, as these can be monitored and controlled via sensors and will impact the indoor air quality, air flow and solar gains. However, this concept only exists under the IFC2x4 schema. Doors and windows are also plausible candidates, but these are only relevant if they have sensing devices and/or are operated automatically, such as automatic sliding doors for example.

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[2] https://protege.stanford.edu/

[3] https://technical.buildingsmart.org/standards/ifc/ifc-schema-specifications/

The same would apply for IfcCurtainWall related concepts, which may be considered for future alignments.

The alignment of the Electrical Vehicle Charging domain by contrast is not evident, and no concepts were identified in IFC. Apart from usual electrical domain components, one cannot infer if these are associated with this domain.

V. ANALYSIS ON IFC MODELS

In order to test theory in practice, we have chosen the Duplex House[4] open model to extract the relevant SRI information from the BIM model. We have tested both the MEP model, which contains most elements under the IfcDistributionElement class, as well as the corresponding architectural model for a complete alignment process. The architectural elements included most structural and functional façade elements, as well as including several furnishing elements, within a 2.3 MB file.

The MEP version only contains mechanical, electric and plumbing elements within a 10.6 MB file. Both models were exported via Autodesk Revit under the IFC 2x3 schema. A visualization of the models is shown in Fig. 3. Following the requirements of the alignment as discussed in the previous section, we have used the xBIM[5] set of libraries to parse the IFC models and extract only the information needed. The parsed files extracted instances for all the Element, ElementType and SpatialElement classes and their corresponding data attributes, according to the implemented ontology (Fig 2). Table II below shows a complete view of the types of classes and objects available in a typical BIM model in the IFC2x3 schema. The extraction of concepts from the BIM model shown above is an analysis on the viability of our methodological approach, as the actual mapping rules which achieve the proposed alignment have not all been tested.

In the process of using alignment to support the SRI evaluation, the extracted data would be updated to a triple knowledge store in tandem with the SRI domain ontology. Along with the definition of SWRL rules for each type or class, this would in effect allow an expert to query the knowledge base for identifying the actual BIM elements associated with each domain.

To show how this would work in practice, we have defined the follow alignment rule in SWRL for identifying which elements belong to the Lighting domain:

```
sri:Element(?e) ^
sri:class(?e, ?c) ^
swrlb:matches(?c, "IfcLightFixture")
-> sri:associatedDomain (?e, sri:Lighting)
```

The above rule is a standard example of string matching the element instance class (?c) to be identified as a Lighting domain instance, denoted here by the string "IfcLightFixture". There are other ways to define the rules, but this has the advantage of being a relatively simple process, and would also be suitable for scaling this approach beyond IFC classes and types. The downside is that this would result in the creation and maintenance of several dozen rules (as many as alignment classes and types in the previous section).

The rule reasoning would be triggered by querying the triple knowledge store using a very simple SPARQL query, such as:

```
SELECT DISTICT ?s ?p ?o
WHERE {
        o? rdf:type sri:Lighting
        }
```

This would result in a list of triples which would show each element instance associated with the SRI domain for Lighting. Their identification would further permit BIM support applications to exercise various operations, such as visualization on the actual BIM model, for an immediate feedback to the expert user which carries out the evaluation.

TABLE I. AN OVERVIEW OF INITIAL ALIGNMENT PROPOSAL BETWEEN IFC CLASSES AND TYPES UNDER SRI DOMAINS

SRI domains	concept numbers	IFC2x3	IFC2x4
Heating	10	IfcBoilerType, IfcCondenserType, IfcPumpType, IfcSpaceHeaterType	IfcBoiler, IfcCondener, IfcPump, IfcSpaceHeater
Domestic Hot Water	7	IfcBoilerType, IfcBurnerType, IfcPumpType, IfcPipeSegmentType	IfcBoiler, IfcBurner, IfcPump, IfcPipeSegment
Cooling	12	IfcCompressorType, IfcEvaporatorType, IfcChillerType	IfcCompressor, IfcEvaporator, IfcChiller
Ventilation	9	IfcDuctSegmentType, IfcAirTerminalType, IfcDamperType, IfcFanType	IfcDuctSegment, IfcAirTerminal, IfcDamper, IfcFan
Lighting	2	IfcLampType, IfcLightFixtureType	IfcLamp, IfcLightFixture
Electricity	16	IfcElectricGeneratorType, IfcTransformerType, IfcElectricDistributionBoardType, IfcOutletType	IfcElectricGenerator, IfcTransformer, IfcElectricDistributionBoard, IfcOutlet
Monitoring and Control	15	All types for IfcDistributionControlElement and IfcFlowController	All subclasses for IfcDistributionControl and IfcFlowController
Dynamic Building Envelope	2 and 3	IfcWindow, IfcDoor	IfcShadingDevice, IfcWindow, IfcDoor
Electric Vehicle Charging	0	-	-

[4] http://openifcmodel.cs.auckland.ac.nz/Model/Details/274

[5] https://docs.xbim.net/

TABLE II. EXTRACTED CONCEPTS FROM THE DUPLEX HOUSE OPEN BIM MODELS AS PER THE PROPOSED SRI ONTOLOGY

BIM model	Extracted concepts					
	SpatialElement		***Element***		***ElementType***	
	Class	***no***	***Class***	***no***	***Class***	***no***
A	IfcBuildingStorey	3	IfcDoor	14	IfcDoorStyle	6
	IfcSpace	21	IfcWindow	24	IfcWindowStyle	6
	Total	**24**	**Total**	**38**	**Total**	**12**
MEP	IfcBuildingStorey	3	IfcEnergyConversionDevice	16	IfcHeatExchangerType	6
	IfcSpace	42			IfcBoilerType	1
			IfcFlowController	14	IfcValveType	3
					IfcProtectiveDeviceType	1
			IfcFlowFitting	358	IfcPipeFittingType	59
					IfcDuctFittingType	1
			IfcFlowMovingDevice	4	IfcFanType	2
					IfcPumpType	1
			IfcFlowSegment	427	IfcDuctSegmentType	2
					IfcPipeSegmentType	407
					IfcCableSegmentType	12
			IfcFlowTerminal	105	IfcLightFixtureType	3
					IfcElectricApplianceType	7
					IfcSanitaryTerminalType	6
					IfcOutletType	1
			IfcDistributionControlElement	2	IfcControllerType	1
	Total	**45**	**Total**	**926**	**Total**	**513**

VI. DISCUSSION

Considering the multitude of IFC classes and types from the proposed alignment method, as well as the identification of several hundred instances of IFC objects within the tested models, the study shows that there are clear associations between the SRI and IFC domains. By extent, the use of BIM could greatly benefit the exploration and identification of relevant building information. However, this assumes a relatively good quality of exported IFC models. The fully or even semi-automatic extrapolation of BIM objects to procure an SRI evaluation is still far from reach, and may not be something feasible simply due to the fact that the scopes of the BIM and SRI domains are too different. The SRI evaluation was envisaged to be carried out by a human expert, where the BIM can play a key role in helping the expert find, visualize and confirm building information. With basic inference using rules, we have shown to what extent BIM objects can feed into a BIM-supported evaluation of the SRI.

One of the key challenges in validating the alignment was finding suitable, complete BIM models of smart buildings. Our testing results were carried out on two relatively known IFC files for the construction community, which has very complex definitions of systems (piping, lighting, electric), but still lacked any objects related to sensors, actuators, with only 2 distribution control devices which are in fact basic electric components. The association with the SRI domains remains feasible and technically relatively easy to implement with several rules. However, the presence of services for existing BIMs are still at a very basic level, providing little vital information in evaluating the level of smartness for the lighting elements for example.

The semantic alignment exercise shown within this study remains limited to the basic IFC classes and types, and their immediate association to SRI domains. The association of elements to their spatial container was a first evident step into locating the elements and placing them within a simple context. In simplified terms “Element” would be on the same level as “IfcElement”, but with restrictions on which subclasses to include. “SpatialElement” could in theory be an equivalent of “IfcSpatialStructure”, incorporating any sub-class from: site, building, storey, space or zone for example. However, an exact mapping using OWL or RDF/s on all the IFC schemas would be difficult to maintain. Thus, we chose to extract these types and match them using several basic rules which reflect the alignment at the class and type levels. However, future alignment should consider the connections between elements themselves. Further alignment needs to deal on one side with the generalization between classes and

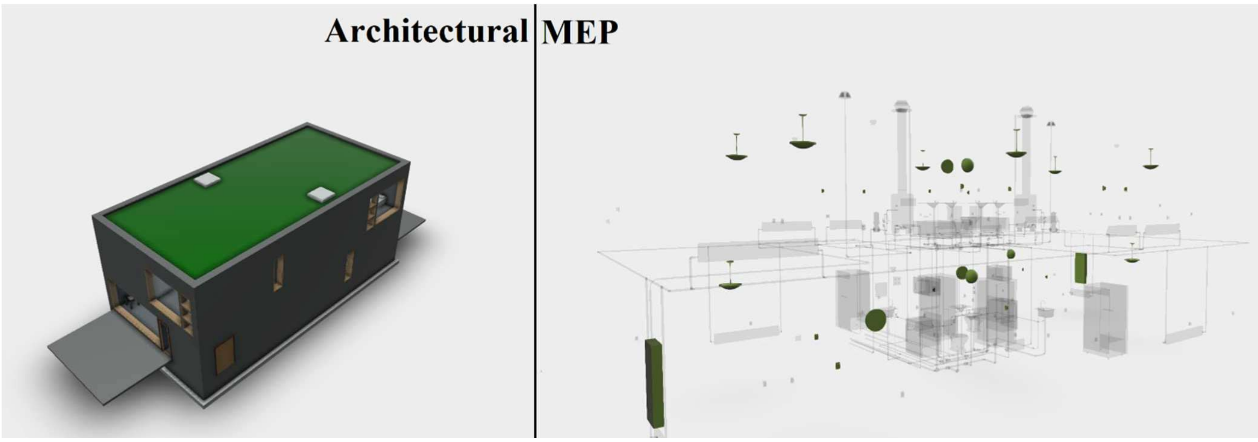

Fig. 3. A visualization of the tested IFC models with the Architectural model on the left, and the MEP model on the right. The elements associated with the Lighting domain are highlighted in green on the MEP models.

types which has shown that can allow multiple elements to be associated with multiple domains. This could be remediated by additional sets of rules which can ascertain if an element belongs to exactly one domain, as opposed to several. For example, in our proposed alignment, we associate IfcPump to both the Cooling and Heating domains. A second set or rules could be defined that check whether the IfcPump is connected to another element which is known to be exclusively associated with Cooling. The inference here would tell us that this particular Pump is indeed only relevant to the Cooling SRI domain.

Where IFC cannot provide sufficient inference, this can be overcome with the addition of classification codes on an object level. However, unlike IFC which is one open standard internationally, classification codes differ by geographical region and application domains. Some worth mentioning candidates for classifications systems are Uniclass, Omniclass, SfB for example, as they are broadly recognized and used across the construction and real-estate sector. However, this also implies that the propose method above needs to incorporate parallel alignment rules for each new classification system to be integrated.

The overall methodological approach would still apply, being easy to incorporate other BIM sourced properties or formats, rather than relying exclusively on IFC schemas, which can in certain circumstances change structure and would require a re-definition of similar rules for future maintenance.

VII. CONCLUSION

Throughout the length of this article we have argued that BIM is a relevant domain for a more precise evaluation of the SRI of a building, with potential avenues for more automatic pipelines. The proposed alignment of IFC schema concepts under the 9 SRI technical domains show the myriad of overlaps of classes and types of objects which even older IFC schema versions can provide. The initial tests on models show which elements would be retrieved from a BIM model. Although the semantic alignment was limited at class and type levels, there are further potential developments which can describe even more precise contexts, as long as this information is available in high-quality and precise BIM models of smart building installations. Nevertheless, the usage or several basic semantic web models and rules show the convenience of linking the two domains to support human technicians in quickly identifying BIM objects of interest along the SRI evaluation process.

In terms of future work, we plan to test our here proposed methodology on several additional more complex BIM models with additional mechanical, plumbing, electrical, but also networked sensing devices, in order to validate and test the initial set of alignment rules. As a second step, we aim to implement some basic user interfaces allowing future assessor visualize the outputs of the ontology knowledge base directly on their 3D BIM models.

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