Semantic Encoding of Construction Regulations

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Abstract. In recent years increased attention in the built environment research community has been given to the implementation of automatic compliance checking systems. Specifying, managing and subsequently executing these regulations is a challenging task, with a wide variety of experts involved. These experts range from experts in the regulations themselves, to specialists in BIM data formats and software engineers, all of whom are required to manage the automatic execute of a single regulation set. This paper demonstrates how an ontology can be used to encode construction regulations, acting as the single source for both human and machine readable regulations. The structure of the ontology will be described, along with how regulations can be encoded, and subsequently executed. This will be demonstrated on case studies using a proof-of-concept user interface that has been developed to abstract the generation of the ontological encoding.

Keywords: regulatory compliance, linked data mapping, reasoning

1 Introduction

While the use of ICT to automate compliance checking has become common [1], the effective conversion of complex textual regulations, readable by humans, into computer executable code remains a difficult challenge [2]. This process requires continual close co-operation between domain experts with building regulation expertise, software developers and those experienced in BIM data storage standards [3,4]. The reason for this is that; (a) semantics within construction regulations are not standardised and many regulations utilise differing semantics [3], (b) there are a variety of data storage standards utilized in the construction sector (such as the IFCs, and proprietary standards from major software vendors) and (c) construction regulations are frequently updated. All of this means that automating regulatory compliance in the construction sector requires a large team and has become non-scalable resource and financially intensive task. Moreover, it is our view that any approach that attempts to automate regulations must do more than simply automate the execution of regulations but also provide for full management of the regulations incorporating specification viewing, modification, storage and execution. This is supported by the recent BuildingSMART regulatory room report that recommends the specification and creation of a generic regulatory compliance management tool [5].

The adoption of semantic approaches to storage of built environment data [6] has now paved the way for the use of semantics for regulatory compliance and the use of ontologies to model regulations has already achieved success [3]. Building on these facts, this paper will demonstrate how an ontology can be used to encode construction regulations, acting as the single source for both human and machine readable regulations. To achieve this an ontology will be utilized to model regulations that are specified using a defined methodology for specifying regulations. Additionally, improved ways of mapping between the semantics of a domain and IFCOwl will be described. This will all be demonstrated on two case study regulations using a proof-of-concept user interface.

In the remainder of this paper, Section 2 will describe relevant related work, Section 3 will describe our approach to semantically encoding construction regulations, Section 4 will demonstrate this approach through two case studies and, finally, Section 5 will conclude the paper.

2 Related Work

There have been several examples of automated compliance checking in the construction sector. One of the earliest successful examples was targeted at Singapore's Building Regulations [7]. This focused on the processing of rules in relation to industry standard data formats, namely IFCs, rather than the management of regulations. More recently, authors raised concerns about the different types of data formats used in the construction sector and they also described initial work in embedding meta-data relating to the IFC format directly into building regulations [8]. This strengthens the need for management of regulations as there are distinct differences between the semantics of the regulations and the semantics of data files. Other related work has used and aligned two ontologies to perform compliance checking based a series of rules that have been extracted from a regulation based on SPARQL queries [9]. This was expanded upon to define a more comprehensive approach to constructing a rule checking environment utilising semantic and a SWRL-based rule engine [10]. Other work has focused on specific building types, such as high-rise and complex buildings [11]. In this work, the authors have specified the regulations in a way that tightly couples them to the IFCs. Key issues faced by regulatory compliance checking in the construction domain has also been identified this includes inconsistent terminology between regulations, and even within the same set of regulations [12]. Semantic approaches to regulation checking within the construction sector are also becoming more common [13], however, this work only proposed a simple IFC to RDF converter - no consideration is made for semantic differences between the regulations and data file format. Other regulatory compliance systems have utilized natural language processing [14] to extract regulations from documents, however these automatically extracted regulations will still require extensive review so that domain experts can have confidence in their correctness. Work is also being undertaken to define semantic representations of constructions regulations [15], however it is our view that future work must look beyond the specification of the initial set of regulations, but also consider the future modification and review to ensure maintainability and confidence in automated regulatory compliance.

3 Semantic Building Regulation Management System

Figure 1 shows the overall architecture of our approach to managing construction regulations using semantics. The process of automating a construction regulation consists of several phases; (a) encoding the regulations – populating the regulation ontology with data representing the encoding of the construction regulation being considered (based on the semantics within the regulation structure ontology), (b) alignment – populating the data mappings ontology, this is deliberately separate from the regulation ontology to promote re-use between different regulations as applicable, (c) execution of regulations, (d) modification of regulations/mappings, (e) generation of human readable documentation.

Based on these phases three distinct user interfaces have been developed to enable the complexities of semantic modelling to be abstracted; (a) rule specification, (b) data mapping and (c) rule execution. Each of these will be described in more detail in the following subsection, along with how encoded regulations can be utilized to generate human readable documents will also be described.

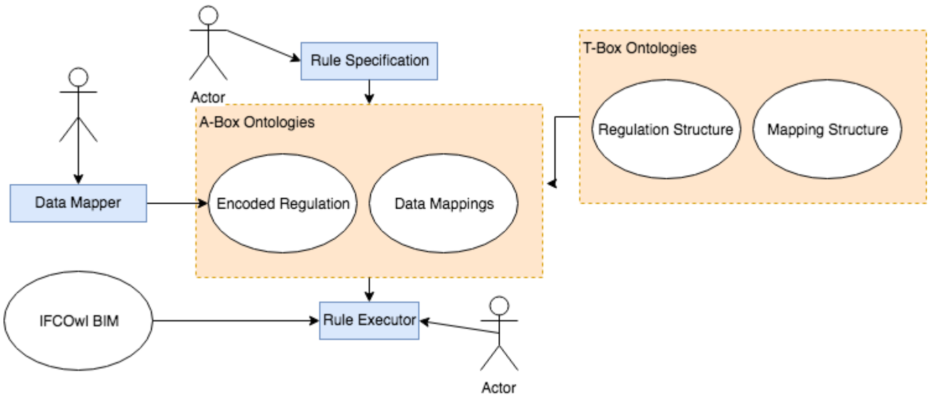

Fig. 1. Architecture of a Regulation Management System

3.1 Encoding Regulations

Encoding construction regulations involves transforming human readable regulations into a semantic model, based on the semantics defined in the regulation structure ontology. The process of encoding requires regulations authors to use user interface shown in Figure 2, this process is described below:

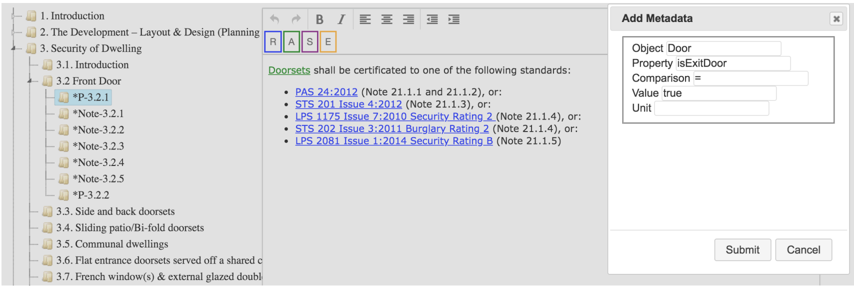

Fig. 2. Rule Specification Interface

Structuring regulations into a hierarchy: regulation authors will structure their regulations into a series of hierarchical paragraphs – normally in line with the original document structure. As part of this process authors must define whether each paragraph should produce a true/false result (i.e. if the individual regulations within it are met). If a paragraph does have a true/false result, it should be defined how a set of sub-paragraphs contribute to the result of its parent paragraph (i.e. or/and).

Encoding individual regulation paragraphs: Once the paragraph hierarchy has been created each individual regulation is tagged using RASE [16,3]. RASE is utilized because it allows the specification of how a regulation should be evaluated in a user-friendly way using a set of understandable tags, each possessing a well-defined logical meaning. More specifically, RASE specifies four tags; Application (which restricts the Scope), Selection (which increases the Scope), Exception (which allows the specification of exceptions to the rule being specified), and Requirement (which specifies the definitive requirements that must be met).

Additionally, when adding RASE tags the user-interface will prompt the author to specify metadata; (a) object i.e Fire Door, External Door, (b) property i.e. type, width, height, (c) comparison i.e. =, > , <, (d) value to be compared against and (e) unit i.e m, cm, litres. This metadata will be used to automatically build an ontology, that models explicitly the semantics utilized within the regulation being considered. This phase deliberately does not follow any existing building ontology, but rather lets the regulation author specify the semantics explicitly through the interface. This is because we have found that many regulations utilize subtly different semantics and, thus, the only way to be sure of getting these semantics correct is to make the regulation author specify them.

The result of this process will be an ontology fully populated with data regarding the regulation being considered. This ontology will utilize the semantics defined in the regulation structure ontology, (extracts of the semantics of which are shown in Figure 3, please note that for brevity data properties and inverse relationships are not shown). Secondly, this process will result in a fully populated ontology encoding the regulations along with the ontology explicitly defining the semantics of the regulation.

It should be noted that the user interface is equally suited for the encoding of a new regulation (one that has not previously been automated) and for modifying a previous encoded regulation. This enables the scalable introduction of additional regulations as standards and legislation changes. Additionally, this encoding process could easily be extended to support language localization, where each paragraph shares the same RASE encoding, but has versions of its text available in multiple languages. This allows the support for regulations from other countries and multi-national regulations.

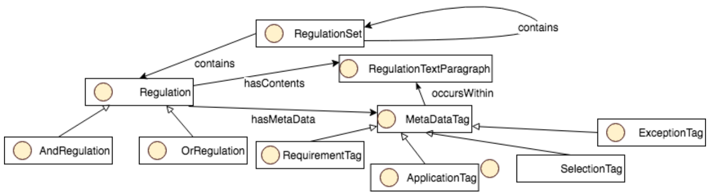

Fig. 3. Regulation Structure Ontology

3.2 Alignment of BIM standards to Regulations

The process of aligning the semantics of a regulation to a BIM data format is performed by mapping how data from the BIM data format can be translated into an ontology based on the semantic of the given regulation. This is done using a user interface that guides the user in mapping each object and property defined in the encoded regulation ontology to the BIM data format. This process firstly consists of performing class level mappings that specify a one to one relationship between a class in the regulation ontology and a class in the data format ontology. In many cases the class in the data format ontology will be less specific than is required (i.e. IfcDoor as opposed to a specific type of door). To overcome this, the interface possesses functionality to allow this relationship to be restricted with filters, limitation the relationship to only certain instances of this class in the data format domain. The second stage is the specification of property level mappings. This process maps properties from the regulation ontology onto properties in the data format ontology. In this case, the user interface has been designed with convenience functionality for the use of ifcOWL (i.e. abstracting the complexity of property and quantity sets) but the use of any target data format is possible.

These mapping are subsequently stored in the data mappings ontology, the semantics of which are illustrated in Figure 4. These semantics, based on [17] model the SPARQL queries required to extract the needed data for each object/property, but it is important to note that the user interface abstracts the complexity of SPARQL away from the individual performing the mapping.

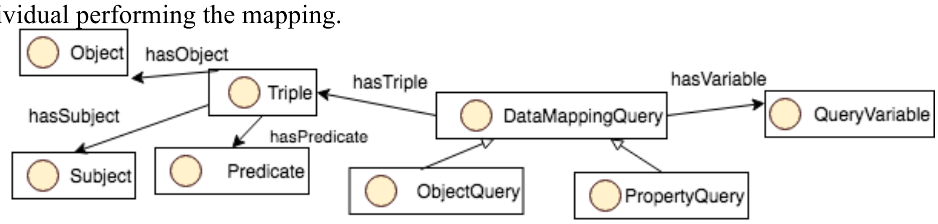

Fig. 4. Alignment Ontology

This phase of the regulatory compliance process raises two issues; (a) lack of data present in BIM models, and (b) unit conversions. Firstly, in many cases, the data required by regulations is simply not present in a BIM model, currently this approach deals with this in one of two ways; (a) if the data can be calculated from the standard data available in a BIM, then a function can be defined in a java like language to calculate it or (b) the user can simply be asked to specify the data manually when the regulation is executed. This approach is also utilized to deal with unit conversions, with functions defined to convert between units. However, this approach is limited in the current IfcOWL implementation by the fact that the IFC specification does not stipulate units for each property.

3.3 Executing Regulations and Generation of Human Readable Regulation Documents

Once the ontologies have been populated, the regulations are able to be executed. Firstly, a set of simple SWRL rules are generated automatically from the regulation ontology. Then, the SPARQL queries modeled in the alignment ontology are executed to load data from the BIM into an ontology that represents this data in the semantics of the regulation being executed. This is done in a just in time fashion, so that a query is only invoked when a rule needing specific data is executed. An example of rule execution is shown in Figure 5. This rule execution follows a bottom up approach taking each encoded regulation paragraph in turn. For each paragraph, the Application, Exception and Selection encoding is firstly evaluated, to determine if the paragraph is in scope (i.e. if a paragraph only applies to a hospital, do not apply this paragraph to an office building). For all paragraphs that are in scope, the requirement encoding is then evaluated, determining if the paragraph has passed or failed. The results of these paragraphs are subsequently utilized to determine results for the rest of the regulation hierarchy.

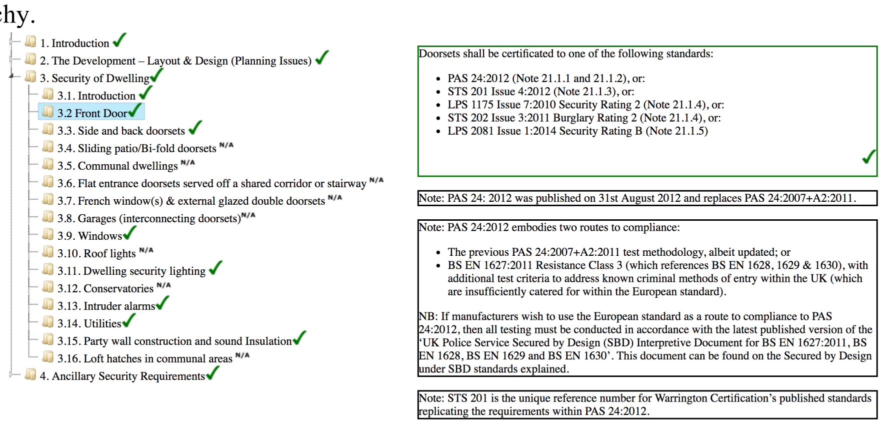

Fig. 5. Rule Execution Results.

In addition to rule execution, human readable regulation documents can also be generated, by outputting latex that can then be compiled into a PDF. An example of this is shown in Figure 6.

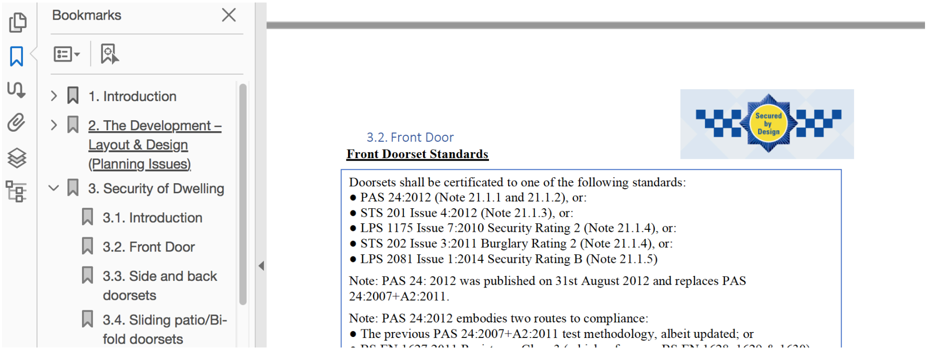

Fig. 6. Human Readable Document

4 Case Studies

Our approach has so far been tested on two exemplar regulations, the UK Building Regulations Part L [17] and the Secured by Design standard [18]. To conduct initial trials of the system, these regulations were encoded by undergraduate students with separate students performing the data mapping. This demonstrated that, given training, those skilled in civil engineering, but not in computer programming, or semantic modelling were able to successfully encode regulations. An example of the process of encoding elements of the secure by design standard was shown in Figure 1, and Figure 7 shows an encoding for Part L. Once these regulations were encoded and mapped, they were tested with data gathered as part of previous work [3], this enabled the functionality and correctness of the rule execution to be tested, an example of this is shown in Figure 5. Subsequently Figure 8(left) shows an example of a SPARQL query generated from the data mapping ontology and an exemplar SWRL generated from the regulation ontology.

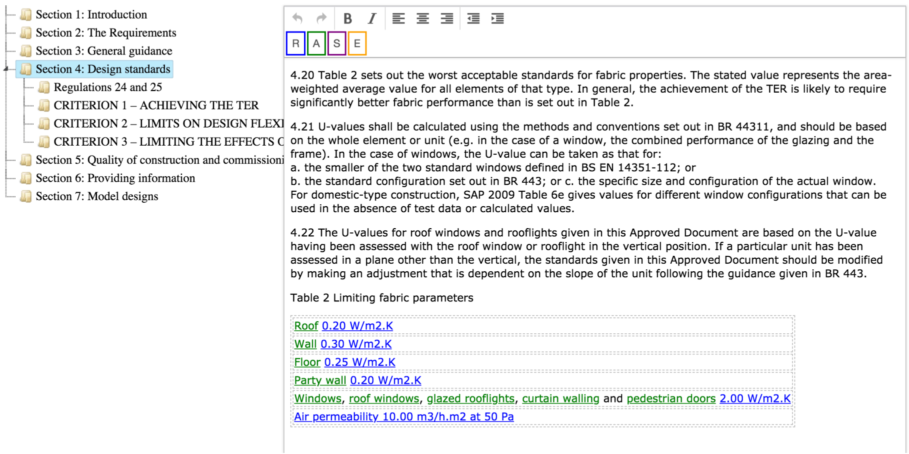

Fig. 7. Part L Regulations

```
Door(?c) , isExitDoor(?c,true) -> RegulationApplicable(P-3.2.1)

Door(?c) , isExitDoor(?c,true) , compliantWithPAS24_2012(?c,true)
->RegulationPass(P-3.2.1)

Door(?c), isExitDoor(?c,true) , compliantWithPAS24_2012(?c,false),
compliantWithSTS201Issue4(?c,false),
compliantWithLPS1175Issue7(?c,false),
compliantWithSTS201Issue3(?c,false),
compliantWithLPS2081Issue1(?c,false),
->RegulationFail(P-3.2.1)
```

```
select ?result WHERE {
?result rdf:type ifc:IfcDoor.
?result ifc:IsDefinedBy ?rel.
?rel rdf:type ifc:IfcRelDefinesByProperties.
?rel ifc:RelatingPropertySetDefinition ?pset.
?pset rdf:type ifc:IfcPropertySet.
?pset ifc:HasProperties ?p.
.....
```

Fig. 8. Extracts from generated SPARQL Queries and SWRL Rules

Finally, the generation of human readable documents was also tested and reviewed by the students who encoded the regulations, an example of a human readable document for secured by design was shown in Figure 6.

In conclusion, while each of these were successfully executed, it was found that the characteristics of these two regulations were slightly different, thus presenting different challenges. The secured by design regulation contains many more prescriptive regulations (i.e. widths of doors), meaning that more of the data required was present in the BIM model. However, Part L has many less prescriptive regulations. These regulations often do not have the required data present within BIM models. This means, that for Part L, there was a far greater need to specify functions to calculate needed results, or to ask for user input.

5 Conclusion

This paper has presented how an ontology can be used to encode construction regulations, acting as the single source for both human and machine readable regulations, and, based on this, how a management system for regulatory compliance can be created around this ontology. This has been demonstrated through two case studies that, while in the early stages and utilizing student users, have shown that users with no expertise in rule languages, programming or semantics are able to, specify and manage regulations. Additionally, this trial has shown that this ontology can also be used as a basis for executing regulations, and generating human readable documents.

This approach has the potential to overcome the key issue of the scalability of automating regulations, which is caused by the required close co-operation between domain experts with building regulation expertise, software developers and those experienced in BIM data storage. Thus, it is our view that, in the future, having a single source from which both human readable, and computer executable code can be generated is the best way to create and, perhaps more importantly, maintain automated regulations checking in the construction sector.

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