A Rule-based Semantic Approach for Automated Regulatory Compliance in the Construction Sector

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Abstract

A key concern for professionals in any industry is ensuring regulatory compliance. Regulations are often complex and require in depth technical knowledge of the domain in which they operate. The level of technical detail and complexity in regulations is a barrier to their automation due to extensive software development time and costs that are involved. In this paper we present a rule-based semantic approach formulated as a methodology to overcome these issues by allowing domain experts to specify their own regulatory compliance systems without the need for extensive software development. Our methodology is based on the key idea that three semantic contexts are needed to fully understand the regulations being automated: the semantics of the target domain, the specific semantics of regulations being considered, and the semantics of the data format that is to be checked for compliance. This approach allows domain experts to create and maintain their own regulatory compliance systems, within a semantic domain that is familiar to them. At the same time, our approach allows for the often diverse nature of semantics within a particular domain by decoupling the specific semantics of regulations from the semantics of the domain itself. This paper demonstrates how our methodology has been validated using a series of regulations automated by professionals within the construction domain. The regulations that have been developed are then in turn validated on real building data stored in an industry specific format (the IFCs). The adoption of this methodology has greatly advanced the process of automating these complex sets of construction regulations, allowing the full automation of the regulation scheme within 18 months. We believe that these positive results show that, by adopting our methodology, the barriers to the building of regulatory compliance systems will be greatly lowered and the adoption of three semantic domains proposed by our methodology provides tangible benefits.

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Highlights

- A Rule-based Semantic Approach for Compliance Checking.
- An ontological framework for regulatory compliance checking.
- Extracting regulations from semantic analysis of textual documents.
- Semantic rules to deliver regulatory compliance checking based on instances of the proposed ontology.
- Semantic mapping of regulations to data file formats.
- Validation on a case study in the construction industry.

1. Introduction

One of the major concerns for professionals in any industry is ensuring compliance of their work against the plethora of statutory, contractual and performance based requirements that govern their disciplines [1, 2, 3]. While the use of computer systems to support regulatory compliance has become increasingly common[4], the effective conversion of often complex and non-binary (True / False) textual regulations, designed to be readable by humans, into computer executable code remains a difficult challenge [5]. Performing this task often requires close co-operation between domain experts with building regulation expertise and software developers [4, 6].

This paper addresses key limitations to the development of IT solutions for regulatory compliance problems; the complex nature of regulations that necessitates a lengthy software development process, more specifically, the complexities involved in communicating the requirements of often industry specific regulations to software developers and, conversely, validating the developed software by domain experts. The output of this process leads to regulatory compliance systems that are often closed and can only be maintained by dedicated software developers[7]. This process is simply not viable in the complex and continuously changing regulatory landscape.

Moreover, existing commercial and academic approaches fall short in addressing effectively the accuracy, scalability, maintainability (including, domain experts ease of use) requirements. We argue that a suitable compliance checking system should provide an end-to-end methodology that (a) understands the semantics of both the regulations, the domain in which they operate, and the data formats related to the domain, (b) allows seamless extraction of regulations from textual documents, (c) provides the ability for integration with industry standard software, and (d) maintains strong links between the extracted regulations and the original text from which they have been generated. Above all our methodology separates the domain expertise from the computing expertise.

This paper focusses on the construction sector which forms a prime candidate for the implementation of our compliance checking methodology. This industry has a complex structure and is facing the major challenge of meeting the need to reduce greenhouse gas emissions from existing and new buildings. This increasing complexity and new government targets have led to a huge appetite within the construction industry for intelligent solutions[8]. A prime example of this, is the need for the impact of existing, often continuously evolving, regulations (in areas such as environmental, energy, waste, and water) to be assessed by specialists to satisfy regulatory compliance, statutory requirements, planning consents, and various public concerns [9].

Additionally, these regulatory and statutory requirements vary between countries and even sometimes between local authorities which renders the compliance checking process ever more complex. In addition, the construction sector presents additional unique challenges [9]:

- Traditional industry practices need continuous adaptation and integration to suit local conditions, new materials and frequently changing stakeholder relationships.
- Concerns for quality, timely, and to budget delivery against the threat of financial penalties are causing the major industry players to reduce their circle of specialists and sub-contractors.
- Project data management and coordination often follows ad-hoc approaches [10]. Data within the construction sector is still often stored in a series of incompatible proprietary data formats for application such as AutoDesk Revit [11] and Bentley Systems Micro-station [12]. Currently only one open data standard exists - The IFCs[13], and the implementation of this standard varies[10].
- Semantics within the target domain are not standardised and many regulations utilise different semantics. For example one regulation standard refers to the area in which a building is being developed as a "Development Site"[14], and another refers to it simply as "site"[15], these regulations are described in more detail in Section 4.

The aim of the paper is to develop, test and validate a generic rule-based semantic regulatory compliance checking methodology, with an application in the construction sector. We foresee two key emerging advantages as a result of the adoption of our methodology: (a) the ability of domain experts to understand and update the regulations within an open software architecture. This vastly improves the maintainability of the system, and (b) the increased understanding of what the regulatory compliance system is actually checking. This allows validation of the system to be conducted with a far higher level of certainty.

Following this introduction, the related work section summarizes existing work in the field of regulatory compliance. The architecture of our system and its components are then elaborated in Section 3. Next, the case study section provides a detailed description of our case study in the construction sector and its results. The final section (Chapter 5) discusses our results and provides concluding remarks as well as directions for future research.

2. Related Work

There has been considerable efforts in the past towards performing automated regulation checking, with various approaches being adopted [16, 1, 2, 6].

Giblin et al [16] describe their developments in the use of regulations expressed as logical models, with a focus on the regulation of business activities. This work importantly identifies the key requirements of a conceptual model, that describes the domain in which the regulations lie. This work is expanded further by Cheng et al [1], who perform regulatory compliance checking by explicitly mapping the terminology of regulations onto an industry specific taxonomy, recognising, importantly, that the semantics of a particular regulation do not always map onto the general semantics of the domain in which it operates. Other related work includes the REGNET system developed by Law et al [4]. The REGNET system aims to develop an infrastructure to facilitate access and analysis of government regulations. Their approach requires the addition of meta-data to requirements documents, while maintaining strong links between the logical structure generated from the process of adding metadata to the requirements. The limits of this REGNET system are that, mainly due to the nature of the legislation that it targets, there is no scope for targeting industry specific data file formats. Within their current work, the authors instead focus on an approach that largely guides the users through the regulations using a web-based system.

Several authors have attempted to tackle the problem of extracting regulatory information from textual documents. Dinesh et al's [3] work focuses on designing a logical representation of legislative regulations which they named ReFL logic. One of the most interesting aspects of their work is their focus on handling the referencing between laws in the complex, and often interlinked legal structures that exist today. Hassan eta al [17] also adopt an approach in which their UML Governance extraction Model to extract legal and enterprise requirements. The work by Kharbili [2] surveys approaches related to the compliance checking of business processes, and the formalising of the regulations put upon business processes so they can be compared against the already formalised business process modelling language. Liu [6] conducted similar work utilising a business process specification language that captures regulatory compliance of business processes. This language is then translated to linear temporal logic. An automated approach in a related domain is taken by by Yeung et al[18], this work, while not focused on compliance checking, outlines an approach for extracting semantic information from narratives in the construction sector, using natural language processing techniques. This is important work as their approach attempts to automate the process of extracting domain semantics from text.

Specifically, within the construction sector, there has been several examples of the utilising of intelligent systems to aid decision making [19]. Recent work by Hajdasz focuses on building decision support systems to aid with repetitive tasks within the construction site. In the domain of compliance checking Liebich et al [20] provide one of the earliest successful examples of the implementation of a compliance checking system. This particular work was targeted at Singapore's Building Regulations. However, their system focusses mainly on the processing of rules in relation to industry standard data formats, namely IFCs, rather than the critical aspect of rules extraction from regulation documents. This work has, however, been one of the most successful to date in terms of actual use within industry.

Yang et al [21] expand on the idea of compliance checking by utilising an object orientated approach to model requirements. Their approach allows the extraction of entities from within building regulations; however from the descriptions presented by the authors, their approach seems a largely manual process of extracting rules in the form of computerised code directly from the regulations document. More recently, Eastman et al [22] outlined the architecture that a building compliance checking must take and summarised existing efforts within the industry, including various approaches for extracting regulatory information from human readable documents. In their work the 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 object based format directly into building regulations. This is especially important in understanding the differences between the semantics of the regulations and the semantics of domain specific data file format.

Other related work includes Yurchyshyna et al[23] who have defined an entirely semantic approach for compliance checking. In this work the authors use and align two ontologies to perform the conformance checking based a series of rules that have been extracted from a regulation, their approach however was based on SPARQL[24] queries. Pauwels et al [25] then take this work further by defining a more comprehensive approach to constructing a rule checking environment utilising semantic an SWRL-based semantic rule engine[26]. Zhong et al[27] present, a semantic approach to regulation checking within the construction sector. However, the authors work, while among some of the most advanced in the field, only considers the specific semantics of the type of regulations they are checking and propose linking to industry standard data file formats via only a simple IFC to RDF converter - no consideration is made for semantic differences between the regulations and data file format.

The work of these authors is especially important as they are one of the few examples of the consideration of semantic issues. However, while the issues they consider are specific to the construction industry, it is our view that they are equally prevalent in related domains. In our opinion Pauwels[25] approach to overcoming these issues is to generate an ontology using the semantic underpinnings of the IFCs. This is a good first step as it provides a semantic representation of the domain, however, the semantics of many regulations within the industry do not map well to the often implicit semantics embedded within the IFC data model.

Choi et al[28] have developed an approach to regulation checking for high-rise and complex buildings. In their work the authors have specified the regulations in a way that tightly couples them to the industry standard representation of data, the IFCs[13]. This means that implicitly the IFCs have been utilised as the underlying semantics of the model. The key problem with this approach arises if the semantics of the regulations do not match these semantics. Other related work includes the work by Malsane et al[29]. In this work the authors take a purely object orientated view upon the regulations and building, as a result, a complete object orientated model of two parts of the UK Building regulations is built. In the process of conducting this work the authors also identify some of the key issues faced by regulatory compliance checking in the construction domain - inconsistent terminology between regulations, and even within the same set of regulations.

In terms of commercial products within the construction sector, the main compliance checking product currently on the market for the construction sector is the Solibri Model Checker [7]. The Solibri model checker enables users to perform several common pieces of regulatory checking, e.g. the distance between a given room and the nearest evacuation point in the context of fire engineering. However, one major problem with the Solibri system is that the regulations within the application are closed; users cannot edit them or add new regulations. The only way in which new regulations are added is when Solibri updates the software. This is a critical problem given the vast variety and inter-national differences between regulations in the construction sector.

This section has reviewed the related work in the field of regulatory compliance checking, considering both general research in the field and domain specific research within the construction sector. While it has been found that there has been a large amount of research considering the extraction of regulations from textual documents [3, 17] and the implementation of formal logical methods from this data [6, 16], and the semantic underpinnings required for this functionality[28, 23, 16], however, no work yet incorporates these approaches into an overarching methodology, considering all the underpinning semantic domains. While several key pieces of work relate the regulations to a semantic underpinning within the domain [16, 28, 23, 25], in our view a complete consideration of all the related semantics must include the semantics of the regulations, the semantics of the domain itself, and the semantics of the data formats used within that domain. This is especially important within the construction domain, as there is an emerging trend toward reverse engineering the semantics of the domain from its primary data storage format, the IFCs. In our view this is sub-optimal due to the fact that the IFCs were designed as a data storage mechanism and do not necessarily represent the correct set of semantics for the construction domain. The integration of three key semantic domains is the main contribution of our methodology compared to work presented in this section and constitutes a real progress beyond state of the art. We believe that this contribution to the field will provide many advantages to implementers of regulatory compliance systems.

3. A Methodology for Automated Compliance Checking

Our proposed methodology for automated compliance checking is informed by its semantic underpinning and further refined by extensive requirement capture work in collaboration with our industrial partners. The key goal in developing our methodology is that the process of developing the rules used for compliance checking should be kept as close as possible to the domain specialists; the people that understand the regulations and the people that understand the industry specific data formats. To describe this methodology it is sensible to consider two specific elements; (a) the creation of the regulations (shown in Figure 1 and (b) the use of the created regulations in industry processes (shown in Figure 2.

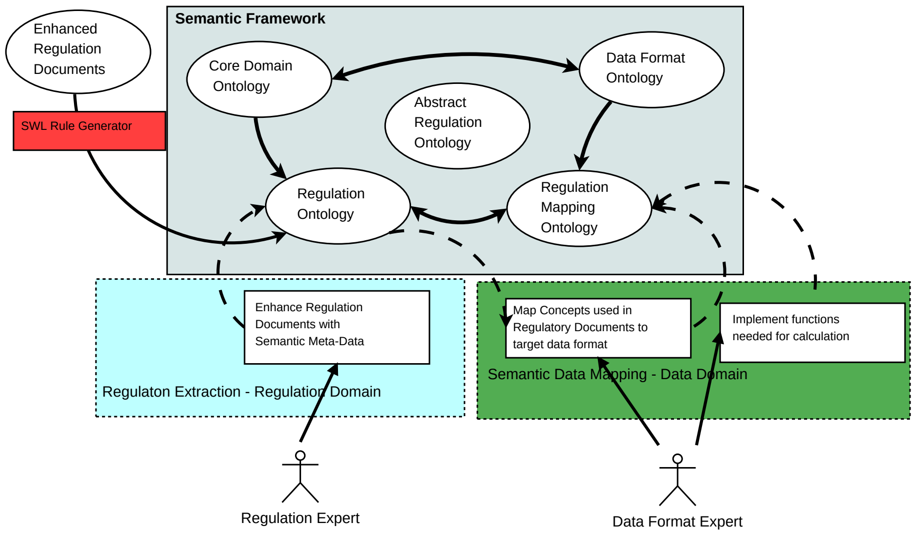


Figure 1: Generation of Compliance Regulations

Figure 1 illustrates three distinct processes within our architecture: (a) The semantic framework that underpins the system (b) Regulation Extraction and (c) Semantic Data Mapping:

Semantic Framework - The semantic framework that underpins the system consists of a series of related ontologies that are either prebuilt or built as part of the regulation extraction process. These pre-built T-Box ontologies are: (a) An abstract ontology that represents key concepts within the abstract area of regulation checking and semantic mapping, (b) A core domain ontology, created to outline key concepts within the target domain for the regulations, and (c) A data format ontology describing the semantics of the data format that data files on which the regulatory compliance system will be executed will be stored in. The final two ontologies shown in Figure 1 are initially blank but will be built as part of the regulation extraction that is described below. This is described in more detail in Section 3.1.

Regulation Extraction - This domain focuses on the process of enhancing regulation documents with metadata by a regulation expert. This will result in the necessary semantic data being added to regulation documents to enable them to be utilised for automatic regulatory compliance and in the building of the regulation ontology, which will describe the semantics of the specific view that the target regulations have upon the domain and the relationship between these semantics and the core semantics of the domain itself. This is described in more detail in Section 3.2.

Semantic Data Mapping - This domain focuses on the processes an expert in the appropriate industry standard data file format would undertake. This involves specifying the semantic mappings between the semantics of the regulation ontology and the semantics of the data format. This involves building the regulation mapping ontology, by specifying relationships between the classes in the regulation ontology and the data format ontology. Secondly, the relationship between properties must also be specified. This final process is where most of the complexity lies, as properties required within the regulation ontology may need to be computed in a procedural way. This results in the data format expert generating a series of procedural functions in addition to the semantic mappings. This process is described in more detail in Section 3.3.

Figure 2 shows the how this semantic framework is now deployed to achieve regulatory compliance checking. This figure shows that the user performing the compliance checking will need to perform a series of tasks.

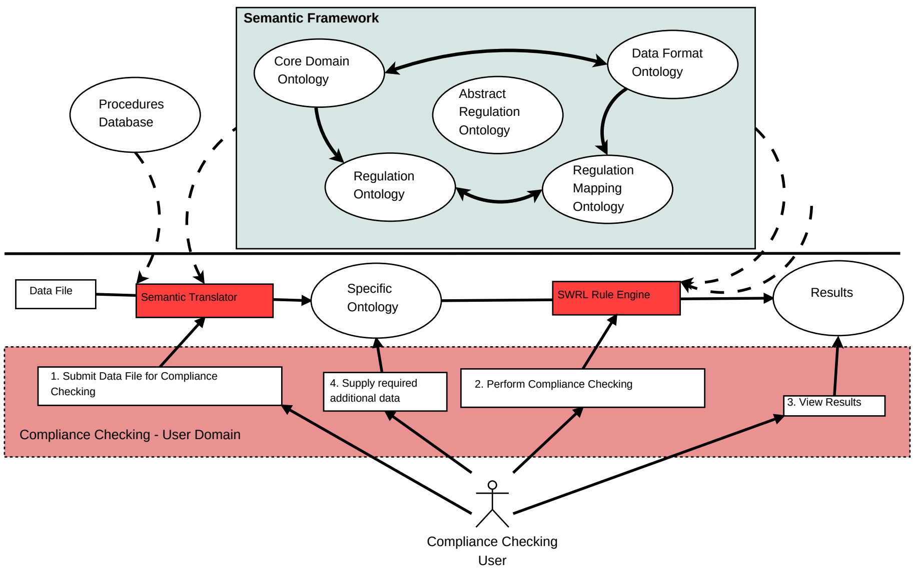


Figure 2: Execution of Compliance Checking

Firstly, the user will submit a data file for compliance checking. This data file will then be translated using a semantic translator component into an A-Box ontology using the semantics of the predefined regulation ontology. This process involves the use of the regulation mapping ontology and the database of procedures that have been built previously. Secondly, the compliance checking process will be executed. This requires the execution of a series of SWRL (Semantic Web Rule Language)[26] rules, which have been generated as part of the process of enhancing the regulatory documents. Thirdly, the user will view the results of this execution and then, finally, the user may wish to manually add additional data to the A-Box ontology. This is especially useful in circumstances where insufficient data is available in a data file to perform full compliance checking. This entire process is described in more detail as part of our case study in Section 4.

Our methodology makes use of several software components that have been developed:

- A user interface allowing the regulation experts to add semantic data to regulation documents, resulting in the building of the regulation ontology.
- A user interface allowing the industry data experts to specify data mappings, resulting in the building of the regulation mapping ontology.
- An SWRL rule generator that creates SWRL rules from the metadata specified in the enhanced regulatory documents. This will be described further in Section 3.3.1.
- A semantic translator that, by using the semantic framework that has been developed, and the procedures database, is able to translate the data within the industry standard data file into a A-Box ontology that uses the semantics of the existing regulation ontology.

The following sections will describe in more detail how our methodology is deployed within our case study. We firstly describe how the rules are extracted from regulation documents, then how these rules are mapped onto an industry standard data model, and finally how the output from these processes enable the execution of regulatory compliance checking.

3.1. Semantic Framework

As described previously, it is our view that regulatory compliance checking can only be undertaken using a semantic framework that consists of three key elements: (a) an understanding of the semantics of the domain (b) the semantics of the regulations and (c) the semantics of the related data file formats. The semantic framework that underpins our regulatory compliance methodology consists of five related ontologies:

Abstract Regulation Ontology: This T-Box ontology describes a set of generic semantics utilised by the system. This ontology includes: the semantics of the regulations themselves, the semantics for recording results from regulations and a taxonomy of the relationships between objects and properties that will be utilised in the regulation mapping phase describe in Section 3.3.

Core Domain Ontology: The core ontology is a high level abstraction of the key components within the domain that the regulations are targeting. It is increasingly common that ontologies for many domains are already in existence, and in reality it is anticipated that such ontologies can be used a core ontology within our methodology. An extract from the core ontology of our system targeted at the Building domain is shown in Figure 3.

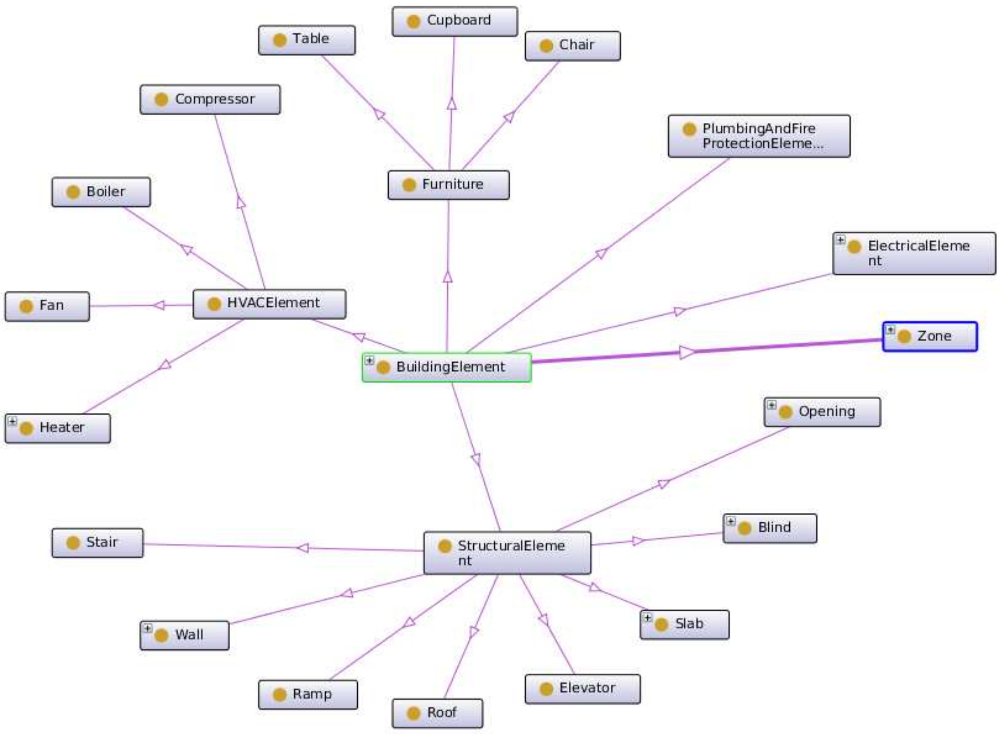


Figure 3: Core Ontology

Data Format Ontology: The data format ontology represents the semantics of the data file format in which the data to be checked for compliance is to be passed to the system. In many sectors of industry there are standard (or several standard) data file formats. In the construction there is a variety of standards, however, the one open standard is the IFCs[13]. For our system an ontology known as IFC-OWL[30] was utilised and enhanced to include recent

IFC model construct addition, to provide our data format ontology.

Regulation Ontology: The regulation ontology is formed as part of the process of extracting rules from regulatory documents. At the conclusion of this process, this T-Box ontology will represent the semantics used by the regulations and the relationships to the semantics within the core ontology, thus providing a full set of semantics representing the often unique view that a particular set of semantics has upon the core semantics of the domain itself. This will be discussed further in Section 3.2.

Regulation Mapping Ontology: When initially automating a set of regulations, this A-Box ontology is initially blank, and is populated within the semantic mapping process within our methodology. This process, described in more detail in Section 3.3, leads to this ontology being populated with a series of relationships describing how the semantics within the regulation domain are mapped to those within the data format ontology.

3.2. Extracting Rules from Regulatory Documents

This section will describe the overall process of extracting rules from preexisting regulatory documents, describing the RASE[31] method of adding semantic data to regulation documents, how we expanded the method to meet our requirements and how this method results in the population of our semantic framework. The process of extracting computable rules from the regulation documents has been undertaken by the addition of meta-data to the regulation documents. In order to do this we adopted and expanded the RASE methodology [31], which has been used previously to add semantic data to requirement documents. RASE itself was selected for two key reasons[31]; its foundations in boolean logic and its previous use in similar projects including some within the construction sector[20].

At its core, our method involves adding XML tags to documents. These tags use the four concepts from RASE: 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).

Each of these four concepts have a well defined logical meaning. In short, Application, Selection and Exception define the scope of the decision and the Requirements define the decision itself. This is shown in the Venn Diagram in Figure 4, which shows that only what is applicable, selected and not an exception is considered in scope.

Our methodology allows the addition of these concepts to a regulatory document at the block level (i.e paragraph level) and inline (i.e. individual words or groups of words). At the block level, a series of nested boxes are used to surround paragraphs (or groups of paragraphs) enabling the expression of complex and/or nested groupings. Each box normally represents one decision, which contains one or more inline tags which define what this decision is.

When adding these RASE tags to a document the regulations expert will also specify additional metadata items, via a convenient user interface. This

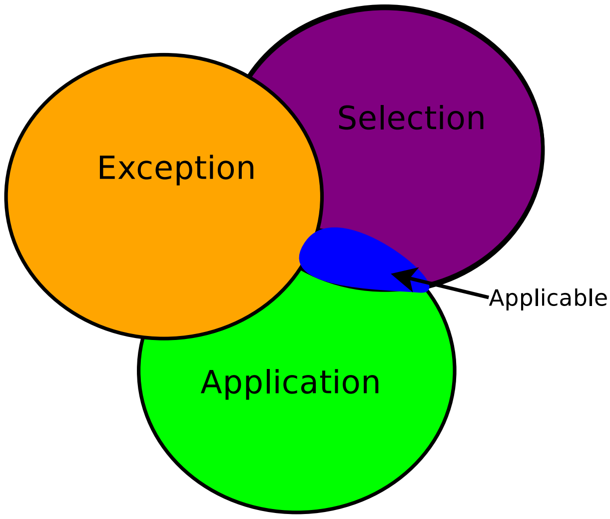


Figure 4: Defining the Scope

second type of metadata that is added takes the form of detailed information about each inline RASE element. This metadata takes the form of:

- The abstract object i.e. *Window, Door.*
- The specific object i.e *Fire Door, External Door.*
- The property i.e. *type, width, height.*
- The comparison i.e. $=$, $>$, $<$
- The value.
- The Unit i.e *m, cm, litres.*

The three key items of data that have an influence semantically are the related object, the specific object and the property. When populating metadata for a specific tag the domain expert would undertake the following workflow: (1) Select an abstract object, which is drawn from the core ontology, (2) Optionally select a specific object, which the user must type in or select from the set of specific objects that have already been used within these regulations, (3) specify a property by either selecting from a list of pre-used list of properties or typing in a new property and (4) complete the remaining items of metadata.

This workflow has implications within the underpinning semantic model of the regulations. If a specific object it specified, this will be created as a class within the regulation ontology, a subclass relationship will then be formed with the abstraction object and, finally, the property will be created as a data property and related to the specific class specified earlier. This process is absolutely critical in gaining a detailed understanding of the semantic structure of the regulations. The second effect of this process is to begin building an understanding of the structure of the regulation. This also populates the regulation ontology with individuals - using the semantics pre-defined in the abstract regulation ontology.

One important final consideration that has to be taken into account is that many regulations do not simply work in a pass or fail manner. Many regulations, including many within our construction case study, give numeric scores for various sections of their regulations. These scores are generally then computed to give an overall final score.

In order to deal with these types of regulations the RASE terminology needed to be expanded to include the concepts of *total* and *output*. These two additions to RASE functionality operate by giving each set of points that can be awarded a unique identifier.

Totals are needed to represent in order to assign a total to each set of points and **Output** is needed to allow us to model the amount of points awarded. These two pieces concepts allow us to model that, for example, a specific part of a regulation may award 1 out of 2 points. Figure 5 shows our previous example now amended with the new concepts.

These new tags have been designed to be fully integrated with the rest of the RASE tags allowing them to be nested inside boxes. This nesting allows for these tags to be used to allow varying number of points to be awarded or to varying the total number of points available based on the outcome of part of a regulation. The ability to allow a total not be set is especially interesting, as it allows the modelling where sections of a regulation are not applicable and the points they award will then disappear.

An example of the type of situation where this is important would be a regulation that stated *"If bicycle racks are present then all bicycle racks must be within 10m of the main entrance of the building - Award 1 credit"*. The correct interpretation of this is that if a building does not have bicycle racks then the credit would not exist - and the designer would not be penalised for not including bicycle racks.

An example of this entire process is shown in Figure 5, this figure also shows the semantic data that has been specified. Figure 6 shows the state of the regulation ontology after the addition of these tags to the regulatory documents, with an example individual added to show the data properties. We can see from this figure that the concept contractor has been defined in the main regulation ontology. We can also see that the structure of the regulations has been defined. The three regulations defined in Figure 5 (one regulation for each box, and one overall regulation) have been defined along with the number of credits they award, the total and the relationship between these regulations.

3.3. Semantic Mapping of Rules to an OWL enhanced Industry Standard Data Format

Once the task of enhancing the regulatory documents with metadata and building the regulation ontology has been completed, the next challenge is to

If there is a principal contractor - awards a total of 2 credits

Where the principal contractor achieves compliance with the criteria of a compliant scheme, CCS score between 32 and 35.5 Award 2 Credits

Or

Where the principal contractor achieves compliance with the criteria of a compliant scheme, CCS score between 24 and 31.5 Award 1 Credit

Object	Property	Comparison	Value	Unit
Contractor	role	=	principal	
Contractor	ccs score	≥	32	
Contractor	ccs score	≤	35.5	
Contractor	ccs score	≥	24	
Contractor	ccs score	≤	31.5	

Figure 5: Adding MetaData to Regulation Documents

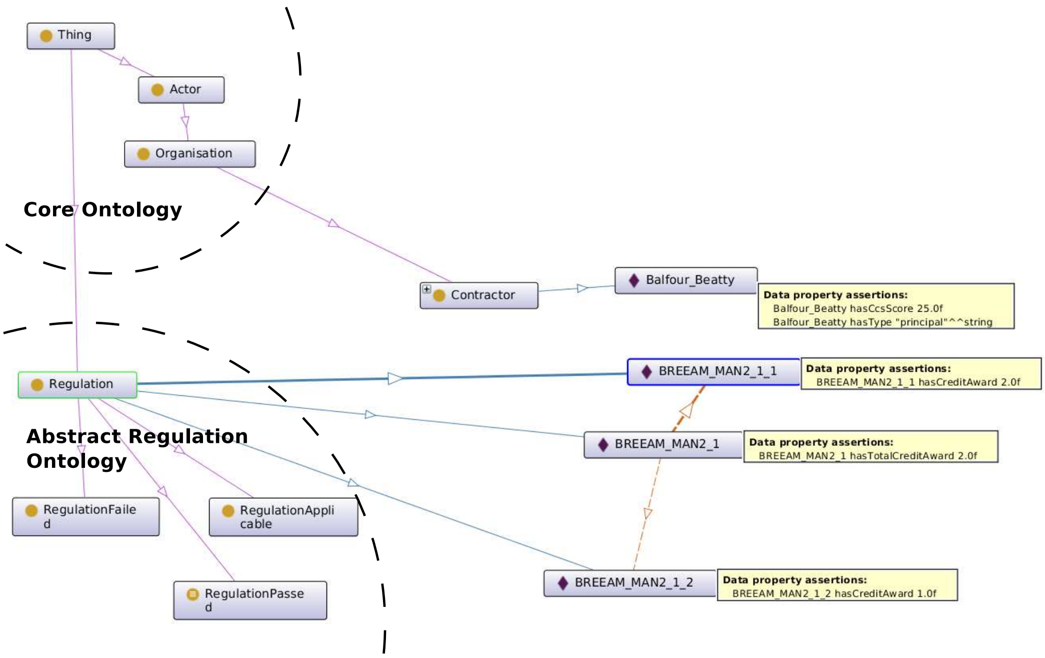


Figure 6: Semantics of Regulation Checking

perform a mapping of the semantics in the regulation ontology into the semantics of the data format ontology. This process is performed by use of data mapping user interface that has been developed.

This generally falls into two discrete tasks: class level mappings and property level mappings. Class level mappings involve specifying 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. This is overcome by also specifying that this relationship is restricted to only certain instances of the class in the data format domain.

The second stage is the specification of property level mappings. In general two types of property level mappings are available, firstly a standard one to one property mapping and a one to many property mapping. In this second case one value in the regulation domain must be computed from multiple data items in the data format domain.

Figure 7 shows an example of the mappings established related to the Contractor class. This contractor class is mapped to an IfcActor class, in the data format domain but only to objects of this class where a specific property is set to "Contractor".

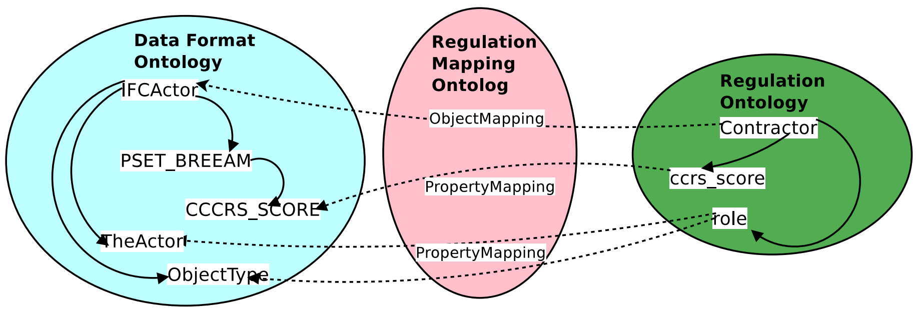


Figure 7: Data Mapping

Figure 7 also shows how the properties are mapped. Currently in these mappings we have defined that the role property in the regulation domain maps to both the "TheActor" and "ObjectType" properties in the data format domain. In order to compute this value, a function will need to be defined. These functions form part of the procedures database described earlier, and a example of a procedure is shown below. These procedures can be used for a variety of purposes. The most common is to perform a calculation that cannot easily be represented within the data mappings, and to use the procedure to marshal the execution of an external program.

```
@Regulation(class="Contractor",property="ccs_score")
public static Double role(DataModel model,
Object properties[], String currentObjectUid) {
.....
.....
}
```

In this example, the method is annotated with a class name and a property name from the regulation ontology, this allows the components of the regulatory compliance system to call these procedures dynamically. These procedures also have a standard set of parameters including the id of the object being considered, a list of properties specified in the mappings and a representation of the entire data model to allow the procedure to perform more detailed queries of the data model if necessary.

The final possible scenario encountered in the course of performing the mapping is if the data needed cannot be retrieved from the data file, or calculated using a known procedure. In this circumstance no mapping can be established. If this occurs and a compliance check is executed the user will be asked to provide this information via the compliance system's interface. In these circumstances this extra data is saved in a second data file, which is then federated together with the original data file to perform the compliance check. This decision was taken to allow users to update the main datafile without deleting any data that was previously supplied by the user. A second reason to separate these two types of data, is that data that is supplied directly by the user could be seen as less authoritative than data that is calculated or extracted directly from a data file. This was an important consideration for our case study and will be discussed further in Section 4.

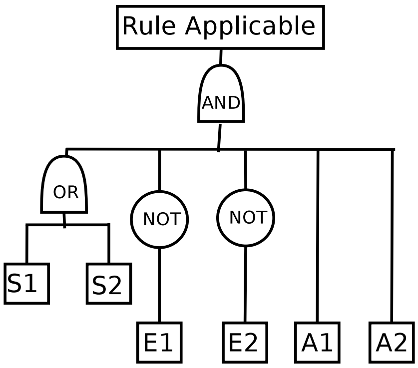
3.3.1. Generating SWRL Rules

The RASE tags added to the regulation documents contain an implicit logical structure. In order to convert this structure into a format that is computable they must be converted into SWRL[26] (Semantic Web Rule Language). This is done using a rule converter that has been developed. All the SWRL examples in this section are shown using the more informal SWRL abstract syntax [32].

This process of converting the RASE into SWRL is done by utilising a series of logical formulas based on the RASE tags[31]. Generally speaking, each block level tag is converted into a set of rules in SWRL, these rules will determine if the regulation is in scope and, then, if it is true or false.

Figure 8 shows the logical formula used to determine if a rule is within scope. Within this Figure *S1,S2* represents the Select Tags - *E1,E2* represent Exception tags and *A1,A2* represent the applicable tags. This means, that in order for a rule to be applicable: All the exceptions must not be met (i.e. are false), all the applicabilities must be met and at least one selection must be met. Figure 8 also shows an example of the SWRL code that is generated. It is important to note that due to the open world assumption taken by OWL[33], a rule is deemed to not be within scope unless it can be determined that it is in scope. This is important as in many cases it cannot be assumed that just because a rule is not in scope that it is out of scope. This approach was taken as it was not desirable to adopt an approach of assuming the rule was true (or applicable) just because it did not fail. The reason for this is to enable the system to handle situations where information may be missing from data files and enable us to give us the valid outcome of "unknown".

More specifically the SWRL in Figure 8 show how it is determined if a particular rule is in scope by checking if a contractor object exists with the data property type set to principal. If there is such a contractor object the rule will




```
Contractor(?c) , hasType(?c,"principal")
->
RegulationApplicable(BREEAM_MAN2_1_1)

Contractor(?c) , hasType(?c,"principal")
->
RegulationApplicable(BREEAM_MAN2_1_2)

Contractor(?c) , hasType(?c,"principal")
->
RegulationApplicable(BREEAM_MAN2_1)
```

Figure 8: Rule Logic

be flagged as applicable. The results of these rules are recorded using the Regulation, RegulationApplicable, RegulationFailed and RegulationPassed concepts that are defined in the abstract regulation ontology described previously. In this case the individuals are asserted to be of the type RegulationApplicable.

Once it has been determined if a rule is in scope it must then be determined if it has passed or failed. This is done using the second formula shown in Figure 9. This figure shows that in order for a rule to be failed it must be in scope and there must exist one item of data that fails at least one of its requirements.

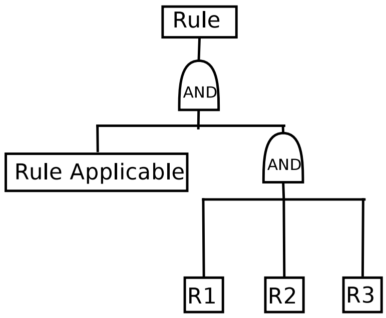


Figure 9: Rule Logic

The SWRL in Figure 10 shows that in order to fail a rule a Contractor object needs to fail its requirements i.e. have a CCS score lower than 24 or above 31.5. A second implication of this rule is that a property is added to all objects that fail a regulation. This enables the tracking of the specific object that caused a regulation to fail. It is important to note that the SWRL only tests if a rule has failed. In order to calculate the final credit score of the regulation the state of the ontology after the SWRL rules have been executed is examined and the result of each credit is calculated using the algorithm described in Figure 11.

```
RegulationApplicable(BREEAM_MAN2_1_1), Contractor(?c),
hasType(?c,"principal") , hasCcs_score(?c,?v1),
swrlb:lessThan(?v1,32))
->
RegulationFailed(BREEAM_MAN2_1_1),
hasFailedRegulation(?c,"BREEAM_MAN2_1_1")


RegulationApplicable(BREEAM_MAN2_1_1), Contractor(?c),
hasType(?c,"principal") , hasCcs_score(?c,?v1),
swrlb:greaterThan(?v1,35.5)
->
RegulationFailed(BREEAM_MAN2_1_1),
hasFailedRegulation(?c,"BREEAM_MAN2_1_1")


RegulationApplicable(BREEAM_MAN2_1_2), Contractor(?c),
hasType(?c,"principal") , hasCcs_score(?c,?v1),
swrlb:lessThan(?v1,24))
->
RegulationFailed(BREEAM_MAN2_1_2),
hasFailedRegulation(?c,"BREEAM_MAN2_1_2")


RegulationApplicable(BREEAM_MAN2_1_2), Contractor(?c),
hasType(?c,"principal") , hasCcs_score(?c,?v1),
swrlb:greaterThan(?v1,31.5)
->
RegulationFailed(BREEAM_MAN2_1_2),
hasFailedRegulation(?c,"BREEAM_MAN2_1_2")

RegulationApplicable(BREEAM_MAN2_1),
RegulationFailed(BREEAM_MAN2_1_1),
RegulationFailed(BREEAM_MAN2_1_2)
->
RegulationFailed(BREEAM_MAN2_1)
```

Figure 10: SWRL Rules

This ensures that credits are only awarded when the regulation is in score - and are

(1) For each regulation individual that has a total score assigned to it:
  (2) If regulation is not asserted to be RegulationApplicable then skip this regulation
  (3) Perform a pre-order traversal of the sub-regulations tree stopping whenever a fail is located.
  (4) Examine all nodes that did not fail and awarded credits.
  (5) If multiple credits awards are found use the highest award is used.

Figure 11: Result Calculation Algorithm

4. Case Study Evaluation

In order to validate our methodology we have conducted a full scale case study within the construction sector involving industrial partners. As mentioned previously the construction sector was selected as a good test of our methodology due to the complex nature of the regulations that exist within it.

Within this case study we will show how our methodology meets its key objectives by:

- Enabling domain experts from the BRE (Building Research Establishment) and LABC (Local Authority Building Control) to specify the regulations within the system.
- Enable the specification of the system utilising the construction sector's only open standard, the IFCs, but still allowing the freedom to map to another data standard.
- Show how strong links can be retained between the rules and the textual documents from which they originate.
- Showing how the domain expertise has been separated from the computing expertise.
- Showing the developed regulatory compliance system is accurate compared to manual assessment.
- Showing how the developed system can be maintained by domain experts from the construction industry.
- Showing how the user interface has been integrated into an industry standard piece of software from the construction industry.

This section will firstly describe the background of the regulations examined within our case study in section 4.1, then describe how our methodology was deployed in Section 4.2 and finally describe our results in Section 4.3.

4.1. Background - Our Case Study

Prescriptive national building standards were first introduced in the UK in 1965. Since then, and with increasing focus on low carbon initiatives and sustainability, additional regulations have been added. Two of the most common performance based regulations are the Code For Sustainable Homes (CSH) [15] and BREEAM (BRE Environmental Assessment Method) [14]. These two regulations are optional, but their use is often stipulated by clients when purchasing buildings. Both of these regulations are termed balanced scorecard methodologies, meaning that each section of the regulations award a set number of points (also called credits) and the credit total is used to provide an overall rating.

The Code for Sustainable Homes (CSH) [15] is the national standard for assessing, rating and certifying the sustainability performance homes. It aims to encourage continuous improvement in sustainable home design and to promote higher standards over the current statutory requirements. The code provides nine measures for sustainable design; namely: energy, water, materials, surface water runoff, waste, pollution, health and well-being, management and ecology. Each of these sections awards credits and according to the performance in these sections an overall rating is given of between 1 to 6 stars. Code for Sustainable Homes is a voluntary scheme that applies in England, Wales and Northern Ireland.

BREEAM (Building Research Establishment Environmental Assessment Method) [14], established in the UK in 1990, is the first comprehensive building performance assessment method. The main aim of introducing BREEAM was to mitigate the impact of buildings on the environment and to increase recognition of buildings according to their environmental benefits. The basis of the scheme is to grade the individual building according to environmental performance. There are nine different dimensions assessed in BREEAM, namely: management, materials, health and well-being, energy, transport, water, land use and pollution. Each issue is then divided into sub categories which are required to meet certain criteria to achieve a BREEAM rating benchmark [14]. BREEAM certification is awarded on a scale ranging from unclassified, pass, good, very good, excellent and outstanding.

Commonly used data formats include the IFCs [13] which are the only open standard currently used within the construction industry. The IFCs are maintained by BuildingSMART [34]. Other data formats commonly used include proprietary formats from Bentley Systems [12] and AutoDesk [11].

4.2. Deployment and Implementation of Methodology

To deploy our methodology to enable its validation within our case study, the software that has been developed was provided to our industrial partners to enable the creation of a compliance checking system for the Code for Sustainable Homes and BREEAM. The implementation of our methodology was conducted in three stages: a) Addition of Meta-Data to Regulation Documents b) Specifying of semantic mappings c) Implementation of Procedures. Each of these stages was conducted in a collaborative manor, exploiting the way in

Regulation	Total Data Items	Number of Procedures
Code for Sustainable Home	229	64
BREEAM	854	180
Building Regs	239	166

Table 1: Regulation Object Orientated Metadata

which the regulations are divided up to implement a pipeline approach. In total the complete study lasted 18 months.

Addition of Meta-Data to Regulation Documents: To complete this stage of the methodology industry professionals from BRE (for BREEAM), LABC(for Building Regulations) and a researcher in the area sustainable construction(for CfSH) were utilised to add meta-data to our targeted regulations. This process was conducted with support from the authors in the form of workshops and training but the work was primary conducted by the industrial partners.

Construction of data dictionaries: To complete this stage of the methodology researchers(but separate from the authors developing the methodology) from Cardiff University and external consultants AEC3 (a company with expertise in the IFCs) performed the mapping between the terms used within the regulatory documents and the language of the IFCs. The results of this mapping are presented in Table 1.

Implementation of Procedures: The next stage of the process requires the implementation of the procedures that have been identified as required by the semantic mapping process. These procedures range from simple formulas to more complex computations such as a procedure compute the ratio of wall space to window space within a room.

The final element of our case study is validating the rules that have been developed. This was done by exposing the compliance system as a RESTful web service. This interface has been specified to be as generic as possible to cater for different types of regulations. The functionality of this interface includes; the ability to query and update the semantic model, the ability to query the enhanced regulatory documents so as to extract human readable text, the ability to upload data files and, finally, the ability to invoke compliance checking on all, or part of the regulations.

In order to validate the performance of the regulatory compliance system it will be trailed on a real building project. To achieve this the regulatory compliance system will be integrated into a piece of standard construction design software. For our case study, we implemented a plug in for Bentley Microstation[12], a commonly used architectural package in the construction sector. An example of this interface is shown in Figure 12. Further examples of the user interface are shown in Section 4.3. This interface has been developed with the requirements of the construction industry in mind but utilises the Restful web service interface described previously to interface with the regulatory compliance system itself.

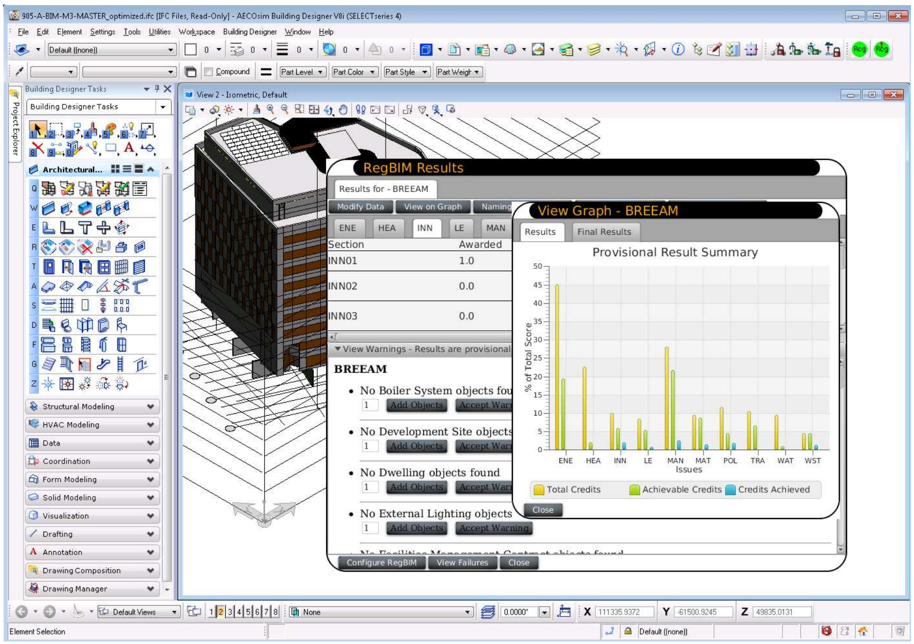


Figure 12: Integration with Bentley Microstation

4.3. Results

Once the construction of the regulatory compliance system has been completed, the developed system was tested on a live building model provided by Skanska (UK). An IFC model of new development in the city of London has been utilized for this purpose. For our case study, the building used is a nine floor construction of 85,000 sq. ft. of offices and 3,000 sq. ft. of ground floor retail accommodation. It is designed to achieve a BREEAM excellent rating and pass UK Building Regulations.

The overall process that has been followed for this validation is that of shadowing the actual process of the building design. This means that our assessments using the regulatory compliance system that has been developed has happened in tandem to those of manual assessment by the standard processes that currently exist within the construction industry. This allows us to compare the results from the regulatory compliance system to the manual assessments.

For our building, the entirety of BREEAM and the Building Regulations have been verified, however, for the purposes of describing the process of the validation this section is based particularly on BREEAM Pollution issue 01 (Impact of refrigerants) as an exemplar.

Figure 13 shows the interface that has been developed. On this interface we can see how the regulations are presented as a tree structure. This allows

Credits	Rule	Manual Result	Automatic Result
3	Building does not require the use of refrigerant	$\times$	$\times$
2	Air-conditioning or refrigeration systems have a Global Warming Potential < 10	$\times$	$\times$
2	Direct Effect Life Cycle CO2 equivalent emissions of < 100 kgCO2e/kW cooling capacity	$\times$	$\times$
1	Systems in an air tight Enclosure, Using CO2 as a refrigerant, Complies with BS 378, Has a leak detection system installed	$\checkmark$	$\checkmark$

Table 2: Results Summary

the route towards the various levels of compliance to be easily visible to users. We can also see from this figure that for the POL01 issue, the building has been awarded 1 credit. This is a correct result. Figure 13 helps us to validate this score and also shows how rules are presented to the users in a way that related them back to the text in the regulation documents. This aids the user's understanding of how the final score has been generated and allows for much easier validation. In Figure 13 it can be seen that the only way for the building to be awarded the full three credits is for it to have no systems that use refrigerants. This matches the data that exists within the building model. These results and their comparisons to the results from manual assessment are shown Table 2.

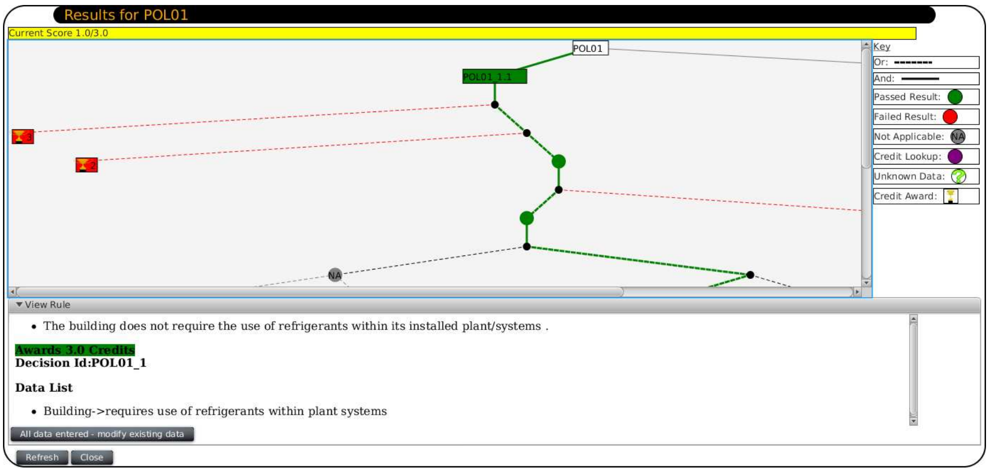


Figure 13: Examining Rules

It can also be seen that there are several circles in Figure 13 that have question marks. This is how the rule engine indicates that there is unknown data. This illustrates one of the key problems that is faced by a regulatory compliance system, missing data. To combat this, the underlying architecture of the system allows the specification of extra data.

Over the course of our validation, missing data within the building model was handled by directly requesting it from the buildings architects. Once clarifications on the missing data have been received, the user would then respond to the rule engine enquiry and then add the missing data. As the missing data has been added, the original IFC model would, gradually, become enriched with the objects and their properties that are needed to complete the compliance checking requirements.

5. Conclusion

In this paper we have outlined our work in developing a semantic methodology for the specification of a regulatory compliance checking system, which we have validated on regulations within the construction sector. Our case study has been used to demonstrate how our methodology allows various domain experts, with experience in the regulations and domain specific data files, create and maintain a regulatory compliance system. The regulatory compliance system that has been developed as part of our case study has successfully and accurately performed compliance checking on building data against BREEAM and Code for Sustainable Homes.

By undertaking our case study we have validated the process by which construction domain experts utilise our methodology and supporting software to (a) specify the regulations without the need for significant software development, and (b) maintain and update the regulations as the standards within the industry change. This process of updating regulations is carried out by simply updating the metadata and dictionary mappings that were developed when the system was specified.

These abilities allow the functionality of the regulations within the system to be changed without prior knowledge of (a) industry data file formats or (b) how the underlying execution of the rules works. Our approach of decoupling the specification of rules, the data formats and the rule execution has proved to be a success, allowing for the development of multiple data file back-ends for the system. This will easily allow, although our initial work within the construction sector has focused on the IFC format, for additional data formats to later be developed.

We believe that the system constructed as part of our case study provides significant advantages over existing approaches as elaborated earlier (Section 2). Currently the only widely used regulation compliance system in the construction sector is Solibri[7]. However, Solibris system currently only provides a small subset of the regulations used by the construction industry. More importantly, the rule system implemented by Solibri is closed, meaning that rule modifications must be made by the company itself. The key advantage of our approach over this product is that the methodology behind it allows the domain experts, who truly understand the regulations, to work together using software tools to produce the computer executable rules. To the best of our knowledge, our proposed approach utilising experts that are familiar with each aspect of the process (regulations and industry specific data formats) is unique within the construction sector.

The work conducted with the construction sectors standard format, the IFCs, has also enabled us to identify additional data items that need to be added to the IFC specifications to enable better support of building compliance checking. These results will be contributed back to BuildingSmart (the standardisation body for the IFCs) in the form of an extension proposal covering regulatory compliance.

It is worth noting that one of our project partners, BRE, is in the process of delivering an online regulatory compliance checking service for the BREEAM standard using our proposed methodology.

Taking a wider view, our proposed methodology, and its semantic underpinnings, is generic and applicable to other industry sectors. It provides key novelty in decoupling of the semantics of the target domain, the regulation specific view upon the domain and specific semantics of data file formats into three distinct semantic domains. This separation of semantics within the system is key as it minimizes the scope of each ontology and promotes re-use of semantic information between regulations within domains, or even across domains. A second key benefit of our methodology is the decoupling of the domain expertise from software development considerations. This presents two key benefits: a) Freedom in expressing regulation rules without software development expertise, and (b) Ease of integration of different data standards, by utilising different data mappings developed by experts in industry specific data file formats.

Due to this extensive testing and the generality of our approach, we have shown how our methodology satisfies the key goals required to be useful to other industries, as it has to the construction industry. The developed methodology provides the separation of domain expertise from computing expertise that is required allowing; a) Domain experts to specify a regulatory compliance system without the need for software development b) The freedom to move between data standards, by utilising different data mappings developed by experts in industry specific data file formats. Specifically within the construction domain it has allowed a single core semantic representation of the domain to be reused in the implementation of multiple regulation systems, it has also provided the ability for the same set of regulations to be deployed to multiple data file formats. Although the IFCs were the chosen format for our case study other formats including Bentley Systems DWG12 and Autodesk Revit[11] have a high level of use within the sector and would increase adoption of regulatory compliance.

In the future, we anticipate the natural language processing and narrative analysis[18] and automatic ontology alignment efforts[35] will result in the semi-automation of various stages within our methodology, especially the mappings between the semantics of regulations and the data format semantics and the semi-automatic extraction of key regulations from within textual documents. It is also envisaged that the semantic resources developed through the use of our methodology will be valuable to industry, we especially see value for various efforts in standardisation of semantics within domains, where multiple regulation ontologies can be analysed together with the core domain ontology to ascertain and explore the semantic differences that have naturally arisen even within the same domain. Finally, it is our vision that, as the importance of having computable regulations grows, and the quantity and complexity of data stored electronically within domains also grows, that regulations should be specified in a structured semantically rich way, where the logical relationships between items is explicitly specified. This complete paradigm shift in the way regulations are written means that from the very start of the design of the regulations they are designed to be automated and the human readable documentation is treated as an output of the automated regulations rather than as an input to create automated compliance checking.

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