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10th – 12th September

New Delhi India

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The Construction, Building and Real Estate Research Conference of the Royal Institution of Chartered Surveyors

Held in New Delhi, India in association with the University of Ulster and IIT Delhi

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Peer review process

All papers submitted to COBRA were subjected to a peer review refereeing process.

Referees were drawn from an expert panel, representing respected academics from the construction and building research community. The conference organisers wish to extend their appreciation to the following members of the panel for their work, which is invaluable to the success of COBRA.

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AN OBJECT MODEL DEVELOPMENT FOR THE UK AUTOMATED COMPLIANCE CHECKING

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ABSTRACT

Approving building designs against existing UK building regulations manually is a time consuming and tedious process. As the architecture engineering construction (AEC) industry moves from 2D CAD drawings to more semantically rich building information models (BIM), the development of automated compliance checking systems for building regulations becomes achievable. The Industry Foundation Class (IFC) has been accepted worldwide as an inter-operability standard and is a well suited format for automated compliance checking. However, whether the IFC data format can fully support the specialized needs of the UK Building Regulations is still debatable. In order to automate the checking of the building regulations they first need to be interpreted from a human readable free text rule into a set of computer implementable rules. This paper focuses on the analysis of the UK fire safety building regulations for dwellinghouses, to determine and subsequently optimize the potential for automated compliance checking. A UK Building Regulation specific semantically rich object model, appropriate for the requirements of automated compliance checking has been developed.

Keywords: BIM standards, Interoperability, knowledge formalization, object model.

INTRODUCTION

UK Statutory Requirements are published officially by the Royal Institute of British Architects (RIBA) Enterprises in the form of Building Regulation Approved Documents. These documents consist of clauses which are written in a natural language format. They set out the standards to which building works must comply (Hjelseth 2009 Satti and Krawczyk 2004). A few of the characteristics which typify the UK Building Regulations are

- Subjectively complex and prescriptive in nature.
- Inconsistent use of terminologies.
- Complexity of their structuring and inter-relationships.

Due to the above characteristics of the UK building regulation, it is observed that checking of building designs for compliance is very complex and time consuming activity which is prone to human error. It is dependent on the building inspector's experience, judgement and skills. It is argued that the more automated the process is, the more accurate, consistent and expedient it will be (Fenves, et al. 1995). The advent of object oriented BIMs coupled with the Industry Foundation Class (IFC) as an interoperability standard has opened up the possibility of having an automated compliance checking system for the UK building regulations (Eastman, et al. 2009).

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However there are characteristics of the building regulations as mentioned above which make this transition difficult.

BIMs AND IFC

Traditionally, drawings have been created in 2D format with an emphasis on making them graphically and visually as correct as possible to enable professionals to understand and interpret them for necessary building information (Eastman, et al. 2009 Jeong and Lee 2008). From the building regulation compliance checking perspective, the drawings need to contain all the information necessary to measure compliance; however, this is not always the case.

To create a BIM, a modeller uses semantically rich objects to build a virtual prototype. The resulting 3D integrated model is a far more rich representation of a building project than the traditional 2D drawings. The ability to attach "properties" to objects means that the use of BIM is potentially a far more convincing instrument in communicating building designs to get them sanctioned by the rule checking authorities (Holzer 2009 Sullivan 2007 Davies and Raslan 2010). Recent developments in both software and hardware have resulted in a significant sophistication in representing building models. However even today building models do not typically include the detailed level of information required for fully automated rule checking.

The full benefits of BIM will materialize only through sharing of information across organisations, departments, IT systems and databases (Bernstein and Pittman 2004). The IFC standard is the key to facilitating this interoperability cost-effectively and without relying on any particular product or vendor specific file formats (Conover 2009 Solibri 1999). IFC adds a common language for transferring information between different BIM applications while maintaining the meaning of different pieces of information in the transfer (Holzer 2009 Ding, et al. 2006 Eastman, et al. 2009).

The International Alliance for Interoperability's (IAI) IFC standard is implemented in all the major BIM packages, which can consistently export valid IFC data files describing a building design, including the model hierarchy, properties and behaviours of building objects. The IFC is suitable in terms of standardisation, unambiguity, consistency and completeness of description of building designs. IFCs significance is further acknowledged on the basis of its use on existing code checking projects (Eastman, et al. 2009 Khemlani 2004).

THE UK BUILDING REGULATIONS – SUITABILTY

In the UK context, it is important to have building regulations which respond to the opportunities provided by these technical developments. One way of potentially reaping the benefits is by developing methods of converting the UK building regulation knowledge into computer interpretable rules (Hjelseth 2009). However, there are characteristics of the UK Building regulations which make this transition difficult:

Subjectively complex and prescriptive in nature

It is important to acknowledge that building regulations are complex and at times subjective in nature and therefore building regulation experts need to be involved in the conversion to computer interpretable rules to ensure the correct interpretations for the code checking. Software developers should not be expected to deal with the prediction of meaning from building regulations without a framework in place to allow domain experts to check on whether the understanding is correct or not. Such a framework would help to eliminate concern over loss of integrity of intent (Hjelseth 2009). An example demonstrating the need for domain expert input is given below, extracted from Clause 1.11 of Part B1 of the UK Building Regulations Approved Documents (Staff Writer 2010, June).

Smoke alarms should normally be positioned in the circulation spaces between sleeping spaces and places where fires are most likely to start (e.g. kitchens and living rooms) to pick up smoke in the early stages of a fire.

It's clear to see that there is potential for different interpretations here particularly in reference to "where fires are most likely to start". This could lead to errors during automated compliance checking, due to the complexities involved in extracting the parameters.

Inconsistent use of terminologies

An overview of the UK building regulations by the authors suggests, entities or objectified concepts are terminologically inconsistent both within an Approved Document and across Approved Documents. Hence, knowledge formalisation becomes vital to ensure consistent terminology throughout all the sections of the UK building regulations helping to make automation much more efficient and robust.

An example demonstrating the inconsistent use of terminologies is given below using section-1; fire detection and fire alarm system of Part B1 of the UK Building Regulations. Entities referred to in the section -1 clauses, include alarm, units, smoke alarm, detector, smoke detector, heat alarm, detection equipment, alarm receiving centre, heat detector, wall mounted unit and ceiling mounted unit. All of the above are used inconsistently, sometimes within the same clause, and all refer to the same general concept, but it is unclear what differentiates them.

Complexity of their structuring and inter-relationships

The UK building regulations are composed of 14 different parts and they get updated frequently and independently due to reasons such as, changes in the law, consultation processes, and extraordinary events (Greenwood, et al. 2010). Since these 14 parts represent different specialised domains, they each get updated from the respective subject specialist. This has resulted in a situation, where occasionally the desired continuity and the consistency across these UK building regulations' parts is missing from the code compliance point of view. Because of the need for the Building Regulations to respond to external events, the maintenance of an automated rule base needs to be kept separate from, and independent of, any proprietary software updates.

AN OBJECT ORIENTED APPROACH

Building regulations are created and managed by people. They are represented in human language formats typically in the form of lengthy subjective text, numerical tables and sometimes in equations (Bell, et al. 2009). As more and more consultants are producing semantically rich object oriented building models (Jones 2010) the need for a shift in authoring practice, bringing consistently defined building objects with associated properties to the forefront, becomes apparent. If the UK building clauses are object centric, with consistently defined properties, it will be easier for architects to reflect that information into building models.

In the UK, RIBA Enterprises have made progress in relation to the context mentioned above by creating an elemental view of the building regulations. This elemental view helps in understanding the impact of clauses on individual building objects and is maintained via a complex matrix showing building objects and their relationship to building regulations clauses and the classification system UNICLASS (Staff Writer

2010, June).

Knowledge formalisation such as the above provides suitable, significant and required data for the development of the UK Building Regulation specific object modelling.

KNOWLEDGE FORMALISATION

The basic aim of knowledge formalisation in the context of the UK automated compliance checking is to interpret a body of building regulation knowledge and convert it into a set of rules that can be processed by a computer application (Hjelseth 2009). The formalisation of building regulations in the UK context is achieved in three steps

- Selecting an appropriate building regulation sample belonging to a specific building related aspect.
- Classifying building regulation clauses into those which are computer interpretable (declarative) and those which are not (informative).
- Decomposition of the declarative and informative clauses to extract semantics.

KNOWLEDGE FORMALISATION EXECUTION

The UK Fire Safety Regulation Part B1 was selected as a sample for this research. Part B1 was chosen, as it had been updated recently, was well-documented and involved clauses that are used regularly in practice. It deals with UK dwelling houses, has eleven different sub sections, comprising 137 clauses. Knowledge formalisation began with section-1, which has 24 clauses. Figure -1 shows the number of clauses (sample size B1) considered for the knowledge formalisation out of the total UK clauses.

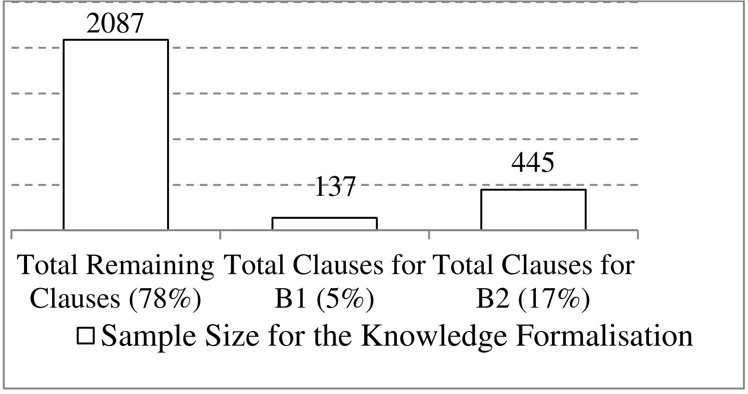

Figure 1; Total number of clauses (sample size) considered for the knowledge formalisation

Use of Data Filtering System for classifying the building clauses

A filter system was then used, to determine whether the regulations are computer interpretable or not (Jeong and Lee 2008). Only checkable provisions filtered from the system are taken into consideration for code compliance for the purpose of this research. Every entity featuring in these checkable regulations is then identified and extracted.

Filter one and two (refer to figure 2) is applied to the selected data sample to sort out clauses into 3 categories: declarative, informative and clauses not suitable for automated compliance checking. Using the first filter, 27 declarative clauses have been filtered out (refer to figure 2).

<u>Examples;</u>

- Smoke alarm should not be fixed next to or directly above heaters or air conditioning outlets.
- There should be at least one smoke alarm on every storey of a dwelling house.

Clauses extracted using filter two have been termed as Informative Clauses as they possess subjective information relating to building regulations. They don't deliver a very direct meaning and only contain data partially suitable for interpretation into computer processable rules. Fire Regulation Part B1 features 64 such Informative Clauses (refer to figure-3 below)

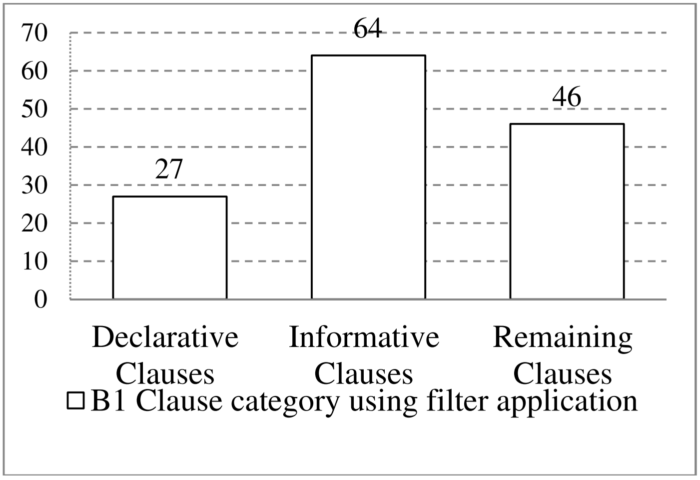

Figure 2; Sorting out of clauses into different categories.

Examples:

- ◦ There should be routes of sufficient number and capacity.
- ◦ There should be appropriate means of escape in case of fire from the building.

By applying filter one and two, 27+64 clauses are extracted as mentioned above. The remaining 46 clauses (refer to figure number 8.3) from the fire safety part B1 are such that they are not suitable for automated compliance checking. The Part B1 clauses are classified into different categories as shown in figure-2 and table-1.

Clause Semantic Filter Level	**Clause Semantic Filter Brief**	**B-Reg**	**Clause Numbers**
First Semantic Filter	Computer interpretable, Information obvious as checkable/can influence project parameters, simple geometrical rules.	Part-B1	1.1,1.3,1.4,1.5,1.6,1.8,1.10,1.11,1.12,1.13,1.14, 1.15,1.16,1.17, 1.18, 1.20, 2.8, 2.14, 5.3, 5.4, 5.7, 5.8, 5.14, 6.1,6.7,7.4,11.2
Second Semantic Filter	Information is not obvious as checkable, Needs interpretation to understand the exact content and meaning, Codes/regulation involves natural language.	Part-B1	1.2, 1.7,1.9, 1.19, 1.21, 2.1,2.2,2.3,2.4,2.5,2.9,2.10,2.11,2.12, 2.13, 2.16,2.17,2.18,2.19, 2.20, 3.1, 3.2,3.5,3.8, 3.9, 3.10, 3.12, 3.14, 4.5, 4.6, 4.7, 4.8, 5.1, 5.2, 5.5, 5.6, 5.9, 5.11, 5.13, 6.5,6.6, 7.2,7.3,7.6,7.7,7.8,7.9, 7.11, 7.12, 8.1,9.1,9.2,9.3,9.4,9.7,9.10,9.13,9.15,9.16, 9.17, 11.1,11.3,11.4,11.5
Remaining Clauses not suitable for compliance checking	Clauses which are not suitable for automated compliance checking.	Part-B1	1.22, 1.23, 1.24, 2.6, 2.7, 2.15, 3.3, 3.4, 3.6, 3.7,3.11, 3.13,4.1, 4.2, 4.3, 4.4, 5.10, 5.12, 6.2, 6.3, 6.4, 6.8, 7.1, 7.5, 7.13, 7.10, 7.13, 7.14, 8.2, 8.3, 8.4, 9.5, 9.6, 9.7, 9.8, 9.9, 9.11, 9.12, 9.14, 10.1,10.2,10.3, 10.4, 10.5,10.6, 10.7, 10.8, 10.9

Table 1; creating clause categories as part of the knowledge formalisation.

Extracting semantics from the B1 building regulations

Once the declarative and informative clauses were filtered, the physical entities along with their given or derived attributes were extracted. Figure - 3 shows that 122 entities have been extracted.

In total 137 clauses were targeted as a sample and 122 entities were extracted (refer to figure-3) to inform an elemental view of the UK fire safety clauses as part of the knowledge formalisation process.

The above methodology was repeated for the fire safety Part B2. From the 445 clauses in Part B2, 228 entities were extracted (see figure 3).

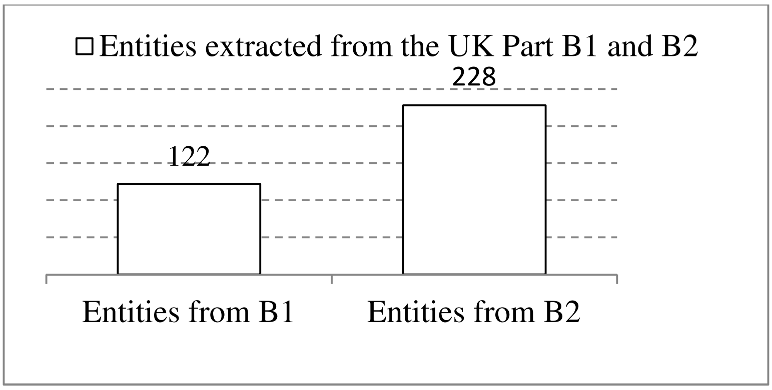

Figure 3; Entities extracted from the UK Part B1, B2.

The above extracted entities formed the basis for the development of an IFC compliant UK building regulation specific data model.

THE UK BUILDING REGULATION SPECIFIC OBJECT MODEL

The entities, once extracted were used as the basis for creating an object based representation of Part B of the building regulations. Initially, this “data model” was created by specifying object classes for each entity and defining each attribute associated with that entity. Attributes were extracted using the same method as above, i.e. on a clause by clause basis, and so each object class developed to give a semantically rich object based view of the Building Regulations. The data model was further enhanced by establishing relationships between the object classes including establishing hierarchical structure. The hierarchical structure was particularly useful for rationalising some of the terminology ambiguities previously mentioned, for example the relationship between smoke alarms, smoke detectors, heat alarms, and detection equipment. The use of enumerations for many of the attributes, extracted from the building regulations, was also very significant for formalising the UK fire safety building regulations context, allowing the model to represent allowable values for non-habitable spaces, for example.

The output of the knowledge formalisation process was disparate objects with their associated attributes. This formalised knowledge was subsequently turned into a data model with the following broad stages, as a framework for building regulation authors and computer programmers to develop for rule authoring:

1) Object Identification 2) Object transformation into classes 3) Defining attributes and enumeration values 4) Establishing semantic relationships.

CONCLUSION

This research concludes that though several open standards exist for building models, the IFC standards are the most comprehensive for the purpose of compliance checking. Without the use of an interoperable open standard format, compliance checking rules would need to be modelled and maintained separately for each proprietary BIM software package, which is not only unsustainable, but could lead to inconsistency of results. With the help of literature review, it is observed that countries such as Singapore, Australia, Sweden and USA have already used the IFC standard for rule checking.

This paper has discussed the difficulties associated with automated compliance of the UK building regulations, but also suggests that many of these can be overcome through knowledge formalisation. Whilst it may not be currently feasible to write computer interpretable rules for 100% compliance, much of the Building Regulations is suitable for automated checking. A focus on automating the process for just the declarative clauses in Part B could have significant benefits for the industry, including:

- Ability for consultants to pre-check applications for completeness of information as well as compliance, at any stage in a project

The analysis of a two parts, B1 and B2, of the UK Building Regulations identified over 350 semantic entities. By inspection it is clear that many of these will have relevance to other parts of the regulations, for example the space model. However, it is clear that creating formalisations of regulatory information will generate many more detailed entity definitions than are currently in the IFC schema. A significant number of these definitions are in reality refinement of IFC definitions, for example “Habitable Space” is a refinement of “IfcSpace”. These refinements can be modelled using Ifcdecorator classes such as IfcClassification, IfcRelationships or the extensible IfcPropertySet mechanism. The terminology that is required to populate this information is reasonably well defined in the regulations and for the most part consistent across the standards. The use of enumerated values based on this terminology and specific to the UK (or any localisation) context could provide a simple and effective mechanism to formalise and localise Building Information Models for compliance checking.

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