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# Development of an object model for automated compliance checking

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ABSTRACT

Building designs in countries such as the United Kingdom are currently checked manually against a frequently changing and increasingly complex set of building regulations. This is a major task for designers and those bodies that are charged with enforcing the building regulations. As a result this can often lead to ambiguity, inconsistency in assessments and delays in the overall construction process. As the Architecture, Engineering and Construction (AEC) industry moves from 2D Computer Aided Design (CAD) drawings to more semantically rich Building Information Models (BIMs), the development of automated compliance checking systems for building regulations becomes achievable. A format well suited to the automation of compliance checking is that based upon Industry Foundation Class (IFC). IFC has been accepted worldwide as an inter-operability standard. However, whether the IFC data format can fully support the specialised needs of the England and Wales Building Regulations is still debatable. In order to automate their checking, building regulations first need to be interpreted from human-readable free text rules into a set of computer-implementable rules. This paper reviews previous research into automated code compliance-checking, identifies the key issues for future development, and focuses on the analysis of the England and Wales Building Regulations that relate to fire safety for dwelling houses, to determine and subsequently optimize the potential for automated compliance checking. Subsequently, a Building Regulation-specific, semantically rich object model, appropriate for the requirements of automated compliance checking has been developed for England and Wales.



## 1. Introduction

With the arrival of Building Information Modelling (BIM) software, automated compliance checking of building designs using model checking software (MCS) is becoming a realistic prospect [1]. It is likely that in the near future BIMs will become important digital assets that are not only key instruments in communicating design, but also in obtaining approval from statutory bodies [2]. However, automated compliance checking requires the application of software tools (which are normally generic and international) to codes and regulations (which are specific and local). To date, the strategy adopted in most compliance-checking initiatives has been to convert proprietary BIM models into the international standard format, namely, Industry Foundation Class (IFC), and then to author bespoke compliance rules that can be executed using this model.

One of the problems with this approach is that often BIM tools are not designed to populate these IFC models with all the data required for checking compliance; BIM tools normally target and cater for an international and general customer base and therefore struggle to accommodate the nuances of specific and local building codes and regulations. In addition, there are many basic concepts within the Building Regulations, such as the space classification “habitable room” which exist in complete isolation from established classification standards such as Uniclass and Omniclass. It may therefore be impractical to expect the authors of BIMs to explicitly define all the information required to check for compliance, particularly where this information is only relevant to the Building Regulations. Thus, for reliable compliance checking, it is likely that additional data will need to be provided by the design team as a separate activity.

Against this contextual backdrop, this paper defines, within the IFC model, a domain extension for the England and Wales[1] Building Regulations building on the existing work of the buildingSMART International [3]. Working with the National Building Specification organisation (the official publishers of England and Wales's Statutory Requirements, in the form of the Building Regulation Approved Documents) concepts, objects and properties that are entrained in the Building Regulations (England and Wales) have been identified and formal syntaxes for the creation of the requisite rules are explored.

The England and Wales Building Regulations ‘Approved Documents’ consist of clauses that are written in a natural linguistic format. They set out the standards that ensure building works are compliant [4,5].

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[1] It should be noted that England and Wales have different building regulations to those established in Scotland and Northern Ireland.

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Examples of the characteristics that typify these Building Regulations include:

- Their subjective complexity;
- Their inconsistent use of terminologies; and
- The complexity of their structuring and inter-relationships.

The above characteristics make the checking of building designs for compliance a complex and time consuming activity, prone to human error and dependent on the building inspector's experience, judgement and skills. They also, by their nature, make the transition to automated compliance checking a difficult process. Thus, details of the development of a Building Regulation-specific semantically rich object model, appropriate for the requirements of automated compliance checking, through leveraging object oriented BIMs coupled with the IFC as an interoperability standard, are presented within this paper.

## 2. BIMs and IFC

To create a BIM, a modeller uses semantically rich objects to build a virtual prototype. Recent developments in both software and hardware have resulted in significantly increased sophistication in representing building models. The resulting object-oriented models have a key advantage over traditional 2D drawings, in that they are computer interpretable. This, coupled with the ability to attach an extensible set of “properties” to objects means that the use of BIM is potentially a far more convincing instrument in communicating building designs in terms of obtaining sanction from the rule-checking authorities [7]. However more often than not a building model does not typically include the detailed level of information required for fully automated rule checking.

Even when semantically rich BIMs are available the full benefits will materialize only through sharing of information contained within them across organisations, departments, information technology systems and databases [8–10] The IFC data model, developed and maintained by buildingSmart International, is the key to facilitating this interoperability in a cost-effective way and without relying on any particular product or vendor-specific file formats [11,12]. IFC adds a common language for transferring information between different BIM applications whilst maintaining the meaning of different pieces of information in the transfer [6,13]. The IFC data model is registered as an International Standard by the International Organization for Standardization (ISO) as ISO/IS 16739 [14] and 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. IFC's significance is further acknowledged on the basis of its use on existing code checking projects [6].

## 3. Existing strategies and approaches to system development

A detailed review of the rule checking systems that have been developed to assess building designs according to various criteria can be found in Eastman et al. [6]. To provide a context for the research reported in this paper, a brief review of the various rule based applications for model checking is presented hereinafter.

### 3.1. Singapore (CORENET)

The ‘BP-Expert’ system has been available in Singapore from as early as 1995 for checking 2D drawings with a view “to reengineer and streamline the fragmented work processes in the construction industry, so as to achieve quantum improvements in turnaround time, quality and productivity” [15]. In 2000 it was replaced by ‘e-PlanCheck’ as part of the Construction and Real Estate NETwork (CORENET) project [16]. CORENET ePlanCheck was one of the first initiatives developed for automated code-checking, and was funded by the Singapore Ministry of National Development and carried out by the Construction and Real Estate Network [16]. This aimed to provide an internet-based electronic submission system for checking and approving building plans. Building proposals were submitted as a combination of existing 2D drawings with additional information provided in supplementary IFC-based files. The system was considered to be ‘cutting edge’ and conceptually strong, yet there is little evidence of continuing work on the specific initiative.

The aim, as before, was to improve performance, increase coverage and check compliance of building data in an IFC format. However, as long as the implementation of the IFC by CAD vendors remained focused on geometry many of the requirements for compliance checking were not available. ePlanCheck addressed this by commissioning an independent platform, FORNAX, which originally sat on top of the already existing Jotne EDModelChecker (EDM Checker), but later evolved to encompass a rule checking engine, which therefore relinquished the need for its use. FORNAX is an object library written in C++. Each object contains all the relevant attributes for the Singapore codes as well as the rules that apply to that object. Each object is designed to be extensible in order to cover the requirements of other countries, and as a result CORENET ePlanCheck was used as the basis for pilot projects in Norway, and New York [17]. Despite ongoing attempts to implement code checking, reported difficulties with verifying data quality [18] and its inability to support the checking of design standards throughout the different design stages of the project (in contrast to systems such as DesignCheck below), ePlanCheck in Singapore is still the only system that is currently operational, albeit currently developing at a very slow pace whilst waiting for the industry to catch up with the use of BIM [13].

### 3.2. Norway (Statsbygg)

The CORENET ePlanCheck work was developed and emulated in Norway with the ByggSok system [19]. This is an e-Government system comprising three modules: an information system, a system for e-submission of building applications and a system for zoning proposals. Driven by the Norwegian Building and Construction industry and supported by Standards Norway and Norwegian BuildingSMART it is heavily based on IFC standards. The work is ongoing and currently focussing on the issues of classification, terminology and standardising rule-checking in construction at an international level.

Building upon their e-PlanCheck pilot projects Norwegian developers Statsbygg have experimented with multiple systems as part of their efforts to extend the use of IFC based BIM to the entire project life cycle. The resulting systems have been piloted on real projects, with data being exchanged through a wide selection of software to suit the various stages/tasks of the project lifecycle. On the HITOS pilot, the code-checking efforts have focused predominately on accessible design. Here the building model data are stored and accessed through the EDM Model Server in IFC format. The accessibility rules are parameterised, mapped to their associated building objects and executed using Solibri Model Checker's ‘Constraint Set Manager’. Solibri communicates directly with building model data in IFC format, but retrieves only the objects it needs — in this case those mapped to the accessibility rules. The rules implemented to date focus predominantly on geometrical constraints and as such the objects and parameters are supported by the IFC data models produced by current BIM packages.

The Statsbygg Solibri system does not support the enhancing of these data models or the export to IFC format, and so cannot currently be used for compliance checking of attributes not supported by the current BIM vendors. The Solibri Constraint Set Manager is implemented in Java and comes with a library of built-in parameterised rules which can be configured by adjusting the parameters. Any new rules, however, must be custom-made in collaboration with the Solibri software developers and, as such, are not easily adapted for other