AUTOMATED SUSTAINABILITY COMPLIANCE CHECKING PROCESS: PROOF OF CONCEPT

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ABSTRACT: *Building Information Modelling solutions are evolving to achieve effective integration in the construction industry. The emerging approaches of knowledge sharing and data processing push the researchers to re-engineer innovative automated processes for integrated 3D design that complies with regulations and statutory requirements. This paper presents a generic approach for automating BIM compliance checking with standards and best practice with a focus on sustainability related standards. A methodology will be presented to provide a reusable solution for compliance checking within a similar context. The proposed approach is generic in nature thus allowing implementation in different fields of engineering including; electrical engineering, energy, water and electronic engineering. It is anticipated that the findings of this research will promote a fundamentally innovative BIM-based compliance checking for a variety of industry standards. In this approach, the RASE methodology is utilised to extract requirements from sustainability based regulations, with the goal of converting them into compiled coded rules for execution by a rule engine*

KEYWORDS: *BIM; Integrated design; IFC Extension; dynamic sustainability assessment, RASE, Rule engine*

1. INTRODUCTION

Appropriate and efficient methods for designing sustainable and high performance buildings in order to achieve a low carbon footprint are urgently needed by the current construction industry (Everett, Boyle et al. 2012). Professionals throughout the construction industry are increasingly required to use environmental assessment rating systems to evaluate building performance. Several frameworks are currently available to provide environmental assessments (Trusty 2000), but there is still a lack of highly efficient tools that can be used to manage the large amount of relevant data that needs to be collected in order to make an assessment; to consider effectively the nature and number of performance criteria and their influence on different construction project stages. The current practice of conducting environmental assessment manually and at the later stages of construction is not effective, since any improvement in achieving the desired performance has proved to be too expensive and time consuming (Kibert 2008). The construction industry needs to fundamentally innovate in the area of assessment culture and methodology in order to come up with something that could provide the opportunity to preview the overall performance of a project at every stage during a building's lifecycle.

In the remainder of this paper, Section 2 will outline the background of the regulations that are being considered in this work, with a description to existing work in the field of regulatory compliance, focusing specifically on other efforts within the AEC sector. The methodology of the new approach will then be described and, finally, two case studies that have been used for validation will be discussed in Section 4.

2. BACKGROUND

2.1 The Need for Automated Sustainability Compliance Checking

The emergence of Building Information Modelling as an integrated framework to manage building performance during its lifecycle is widely evolving and several researchers have conducted research with aims to integrate BIM with sustainability tools in order to achieve a high performance building (Everett, Boyle et al. 2012). Autodesk, (2005) has indicated that BIM makes an efficient contribution to achieving sustainable construction by "making the information required for sustainable design, analysis and certification routinely available simply as a by-product of the standard design process that can reduce the cost associated with traditional sustainability analysis and can improve energy performance." However, the full benefit of the integration of BIM with sustainability measuring systems still has to be considered in more detail (Dawood, Lord et al. 2009). To conduct

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building performance assessment in the early design and preconstruction stage realistically, access to a comprehensive set of information and knowledge regarding a building's form, behaviour, management system, location, materials, context, and technical systems are required. Therefore, many researchers have investigated the integration between BIM and sustainability tools to overcome the previous difficulties (Biswas and Tsung-Hsien Wang 2008). The evolution of integrated BIM solutions has pushed for a new approach to an automation process assessing building compliance with regulations. The resulting approach reduces the violations to regulations that control the construction process. In the United Kingdom, there are several mandatory regulations that every building is required to comply with such as UK Building Regulations. These regulations basically contain the rules for construction work that every new and altered building need to comply with to improve the overall quality of the buildings, as well as making them safe and accessible with limited environmental damage. To facilitate checking compliance, Building regulations are supported by a statutory approved guidance document providing general guidance, practical examples and solutions to demonstrate how to achieve compliance. Compliance with these regulations is normally conducted manually by collecting and processing the relevant information (Regulation 2010). To assess the sustainability of new constructions of different building types, BREEAM (Building Research Establishment Environmental Assessment Method) was established in the UK in 1990. BREEAM is the first such comprehensive building performance assessment method (Lee and Burnett 2008). The main aim of introducing BREEAM was to mitigate the impact of buildings on the environment and to increase the recognition of buildings according to their environmental benefits (Global 2008). With the similarity to the approach of BREEAM assessment process, The Code for Sustainable Homes (CSH) has been introduced as the national standard for assessing, rating and certifying the sustainability performance of design and construction of new homes. These standards aim to encourage continuous improvement in sustainable construction design and to promote higher standards over the current standards set out by building regulation (McManus, Gaterell et al. 2010). BREEAM and CSH certification coupled with compliance with Building Regulation is a highly complex, rigorous and costly process; the huge amounts of data at every stage of the project make it difficult to conduct assessment and compliance checking continuously and accurately. In particular, when the assessment is considered at a later stage, it reduces the influence that these regulations can have on a project and may result in a desired rating being unobtainable or being obtainable only through additional investment.

2.2 Currently Available Solutions for Compliance Checking

The emergence of a rule checking environment has open the doors for researches to automate assessing the features and characteristics of a building design based on the information available in BIM model. The methodology applies a set of procedures to the information model and examines the compliance of a design, plan, action or performance with applicable codes and regulations and eventually results in a 'pass', 'fail' or 'unknown' warning messages for the assessed features (Nguyen and Asa 2006). There are several on-going studies that have been undertaken to automate compliance checking of building models against applicable laws and regulations. Pauwels, Van Deursen et al. 2011, have suggested four major software platforms which have been developed to support implementation aspects of rule checking systems. These are Solibri Model Checker, Jotne EDModelChecker, FORNAX and SMARTcodes. All these systems apply rules to Industry Foundation Classes (IFC) building model data. According to the approach followed for the indicated systems, the rule checking process is separated into four phases; these are a rule interpretation phase, a building model preparation phase, a rule execution phase, and a rule check reporting phase. These approaches are widely applicable and there are several application examples that have been stated by Eastman, Lee et al. 2009, such as CORENET-Singapore, Norwegian Statsbygg's design rule checking efforts, International Code Council (ICC) and General services administration design rule checking. Practically, these systems still have limitations in terms of interoperability (Tan, Hammad et al. 2010). Information for compliance checking requirements are not compatible with the information within the IFC file or in many cases some compliance checking requirements are not even available within the information model. The methodology applied in the previous approaches was to create IFC models with one of the BIM software such as Autodesk Revit architecture, Bentley, Google Sketch Up or ArchiCAD and then process the IFC files with SMC (State Machine Compiler), a java-based desktop platform to facilitate information access and processing (Salama and El-Gohary 2011). SMC has limitations such that any editing, modifications of existing rules, or addition of new rules have to be done by editing the original code by a person with knowledge of computer science. Most of the previous developments focus on the architectural and structural design domain, where efforts were exploited only to examine compliance with relatively simple form of rules such as dealing with geometrical or special attributes. For example, checking access dimensions, doors sizes, or wall thickness (Yang and Xu 2004). Automated compliance checking of performance and construction operations has only received little attention due to the complexity of the structure of performance related data. Existing tools lack the capability of performing logical compliance checking such as checking compliance with contractual requirement, quality control and construction's safety procedures where the information is not semantically represented in the BIM model.

3. SYSTEM OVERVIEW

The framework introduced in this paper is aimed at achieving an intelligent and integrated solution to make better decisions for sustainable construction, whilst achieving the desired building environmental performance with minimal errors and omissions. BREEAM, CSH and Building Regulations are considered in the current research. On this research, RASE methodology (Hjelseth and Nisbet 2010) has been utilized to convert standards and best practices into complied coded rules and to summarise data requirements for compliance checking as a possible enhancement of IFC for sustainability performance checking. The approach involved comparing the information within the IFC with the information needed for check and assessment. Once mapping occurs, new entities are added to the IFC. Figure 1 shows an overview of the current approach for automated compliance checking vs. the traditional manual approach.

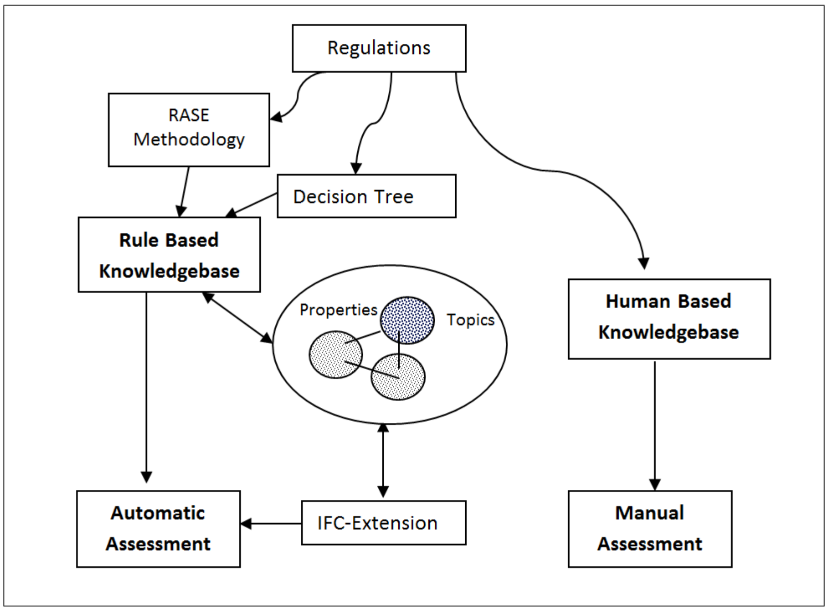

Fig. 1: System Overview

3.1 Automated Sustainability Compliance Checking Process VS Traditional Assessment Approach

The process of automated sustainability compliance checking is slightly different from the traditional manual approach. The proposed automated process relies on fastened records of project information presented in digital format rather than manual collection and re-organizing the accessible project data. Table 1 gives a summary of some of the pros and cons of the two approaches. Achieving an integrated automated compliance checking process is the field of interest of many researchers and stake holders however; the detailed coordinated workflow has not been precisely defined. The assessment procedure comprises different activities conducted by different parties. For example, energy efficiency performance measures, building element properties assessment and design aspects characteristics evaluation.

These actions require a coordinated work flow to address configuration of activities, roles of actors involved and packages of information exchange to achieve the optimum design that complies with sustainability standards. It is not within the scope of this paper to explain the full process, however, the context of the process is summarised in figure 2. The figure demonstrates exchange scenario between well-defined roles for a specific purpose within a particular stage of a project's life cycle. That can be abbreviated by what is known as "Use Case". Basically, a life cycle of the project is a series of use cases composed of detailed process parts. Every use case has a set of information that is exchanged between the involved actors (A1, A2, etc.). These sets of information represent exchange models (EM).

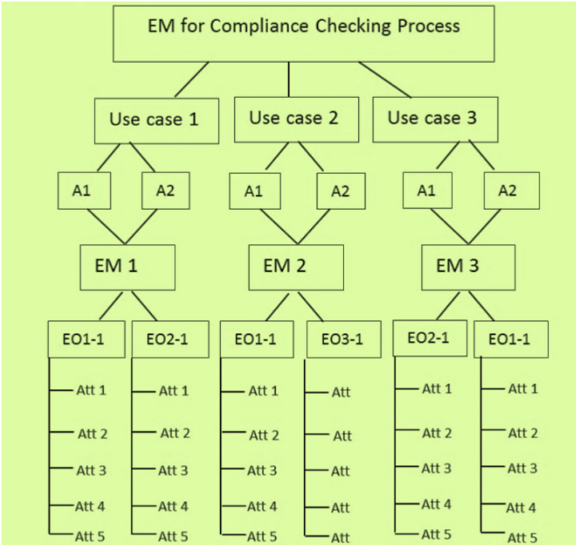

Fig. 2: Exchange requirement scenario

An exchange model comprises a list of exchange objects (EO) that encapsulates definitions of attributes for the exchange functional requirements. For example, a *building type* has several attributes that requires to be checked for compliance as shown in figure 4.

Generally, the process starts when the designer creates a BIM model for a proposed design in a BIM Authoring application, designers then save BIM as an IFC BIM. The IFC file should be comprehensive including sustainability related requirements. The compliance checking is completed by running the rule engine. Every object in the model should be checked for compliance with sustainability related standards (BREEAM, Building Regs and CSH) and generates a report and/or annotations in the model about issues of non-conformance with sustainability standards requirements. The automated process allows designers to be able to change the design such that it meets standards requirements and to satisfy the failed code requirements. The designer repeats the process until the design is fully conformant with these standards requirements.

Table 1: Comparison between traditional and automated compliance checking

Traditional sustainability assessment process	BIM based compliance checking
Required information is fragmented, needs to be gathered and re-organized to facilitate compliance checking	The BIM platform assembles Fasten record of information represented in digital format ready for the automated assessment process
Objects related attributes are not precisely attached but need to be collected separately	Objects are richly described with items such as a manufacturer's product code, or cost, or date of last service
Errors are likely to occur due to a lack or constrains of information representation	The model holds all information in a single repository ensuring consistency, accuracy and accessibility of data to reduce errors and omissions of assessment
There is no linkage between the data created.	The BIM platform assembles all the required data for compliance checking into one location and cross-links that data among associated objects
The traditional assessment can assess all aspects of compliance checking	Some aspects cannot be assessed automatically when information cannot be represented in digital

	logical format
The assessor or compliance checker required to be an expert with wide knowledge of both assessment process and regulations requirements	The assessment can be conducted with a person with fair knowledge of the assessment process
Time consuming process	Faster and more effective processes information is more easily shared, it can be value-added and reused
Required hard human based efforts	Automatic compliance check relies on rule engine process
The assessment depends on available information and assessors experience	Depends on the information embedded within BIM model
Assessment Data is fragmented over the life cycle of the project	BIM model supports data over the complete project lifecycle from conception to demolition
The compliance check conducted after completion of the project	Can be conducted numerous times during the project stages for a better design
Human based documentation exposed to errors and omissions	Better production of quality documentation, output is flexible and exploits automation
Predictable assessment cost could not be reliable	Controlled predictable compliance checking cost
Any change of the design for better performance is time consuming and require further investment	Achieve optimized design that complies with standards and best practice.
Decreased implementation with the emergence of new technologies	Ultimately, a more effective and competitive industry

3.2 Extracting Compliance Requirements from Regulatory Documents

To define the main objects and their related attributes that are required to be checked for compliance, RASE methodology (Hjelseth and Nisbet 2010) has been utilized. The main objective of utilizing RASE is to convert text representation of compliance requirements from standards and best practices into complied coded rules. The principle behind the RASE concept is to add meta-data to human reading regulation documents. This is done using a mark-up based on the four operators; requirement (R), applicabilities (A), selection (S) and exceptions (E). See figure 3 (Hjelseth and Nisbet 2011). By deploying this method, the data requirements and the logical relationship between these requirements have been extracted by using the RASE tags. The assessment criteria have been imported into a software tool "Require 1" from AEC3 (Hjelseth and Nisbet 2010) and the data requirements have been fully extracted from the issues in the documents. This has enabled the required information for each issue to be summarized. Some text has been reformatted to facilitate this extraction. This is only required in a few issues where information is nested in a way that prevented the easy extraction of information. However, the vast majority of issues do not require any reformatting.

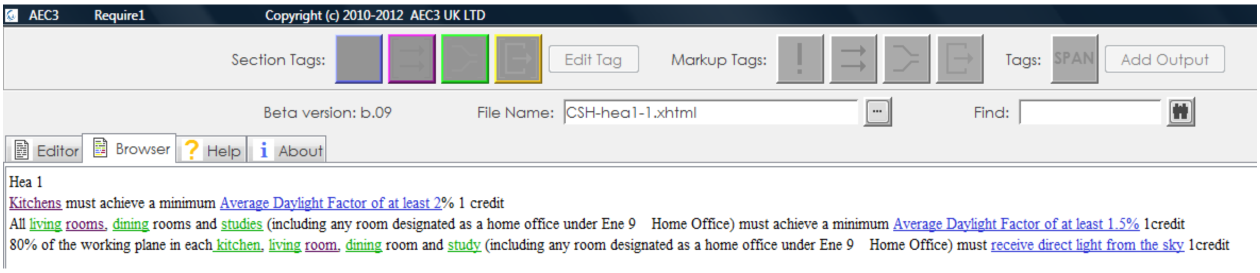

Fig. 3: The use of RASE tags

3.3 IFC for Compliance Checking Requirements

Generally, most of the compliance checking developments utilizes Industry Foundation Classes (IFC) to facilitate data exchange. IFC is the data developed by buildingSMART to facilitate data sharing between different applications for better interoperability (Fazio, He et al. 2007). It is registered by the ISO (International Organization for Standardization) and is currently known as the mainstream standard for BIM (Vanlande, Nicolle et al. 2008). IFC Standard is a complex data standard. It covers nine domains of information such as Building control, structural elements, HVAC, etc. (Eastman 2006). The data structure is based on 3D geometric models and object oriented specification. In spite of its complexity, IFC has efficiently supported software applications for more than 20 venders (Zhiliang, Zhenhua et al. 2011). While the richness of information offered by IFC is evident, there are still tremendous challenges in getting comprehensive representation of performance-specific information ready for extraction for direct compliance checking. By deploying RASE methodology, a list of data requirement for compliance checking has been summarized to append possible enhancement for the IFC. The inference of RASE implementation outlined the terms that occur within the regulation documents. This implementation expedite mapping between the regulation terminology and the terminology that the IFCs perform. Figure 4 shows an example of this. In this figure, the solid arrows represent mappings within the context and the dotted arrows show mappings that the dictionary makes between the terminology used in the regulations and the IFCs. In Figure 4 the object *Building* and its two properties *UsedForFlammableStorage* and *is ShellOnly* that are extracted from the meta-data are added to the BREEAM regulations. These are mapped by our dictionary to their counterparts in the IFC model. "Building" is mapped to *IFCBuilding*; *UsedForFlammableStorage* is mapping to a *FlammableStorage* data item within the *PSET_SpaceFireSafetyRequirements* property-set of an *IFCBuilding*; and *is ShelOnlyl* does not map directly to data within IFCs so it is mapped to a newly added data item within our IFC extensions.

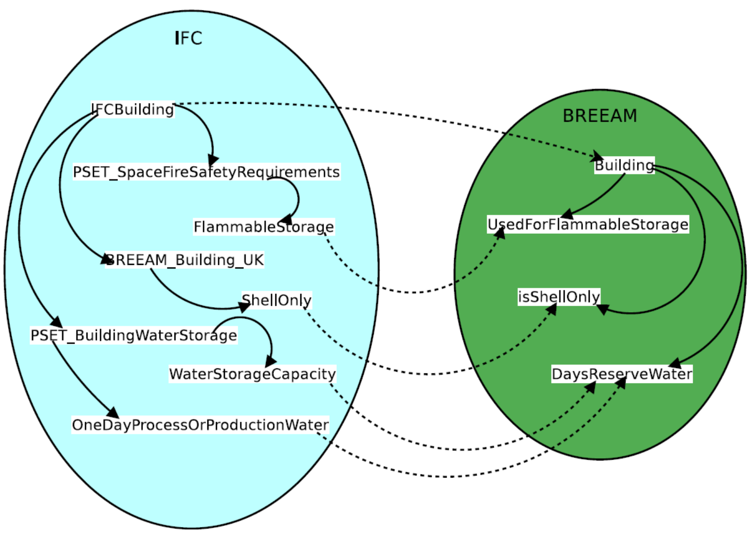

Fig. 4: Mapping Between IFC and BREEAM

3.4 Rule Execution Process

Since there is no satisfactory traditional programming approach to execute the requirement for sustainability compliance checking automation, the decision has been made to use a rule engine, The choice of the rule engine is based on several factors; for example, it must meet the requirements for the executable rules and also the rule engine must be open source and commonly used for similar approaches. Therefore, DROOLS rule engine has been utilised. DROOLS possess interesting features that allows the possible addition of incremental compliance checking features. For successful implementation of the process, it is critical that a checking model is designed with the proper data interface to the rule engine. The mapping process verifies that every set of data occurs within the BIM model/IFC file has a separate, equivalent set of rules within the rule engine system. This is shown in figure 5.

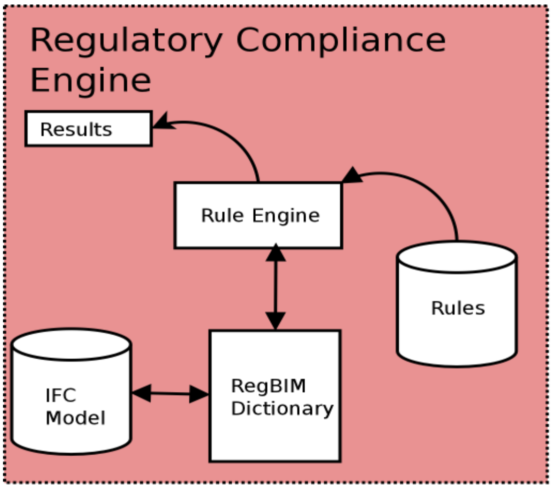

Fig. 5: Rule engine

In order for the DROOLS rule engine to process the meta-data that has been added as RASE to the regulations documents, the RASE tags have been converted into a format understandable by the rule engine, namely DRL (DROOLS Rule Language). This is done by using a rule compiler to apply the logical expansion shown in Figure 6 to the RASE tags that have been applied to the rule (Hjelseth and Nisbet 2010). The DRL is then converted by DROOLS into executable code. New sets of rules can be added to the system with no effect on the existing rules. This, in short, means that in order for a rule to be passed as true at least one of the following must occur:

- The rule is NOT applicable – at least one of the applicabilities (A1, A2 …) is not met.
- The rule meets one of its exception criteria (E1 or E2 are true).
- The rule fails to meet all of its selection criteria (S1 and S2 are both false)
- All requirements within the rule are met (R1, R2 and R3 are true)

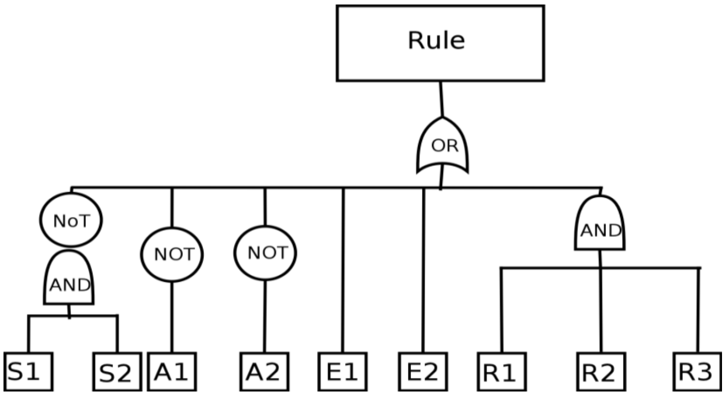

Fig. 6: RASE Logical Expansion

Figure 7 shows a sample clause and the DRL produced by running this clause through the compiler. Examining the clause, we can see that the clause is verifying if the principal contractor has a suitable score from the considerate construction scheme. This clause has one application: that the rule only applies to contractors that are the "principal" contractor and two requirements: that the CCS (Considerate Constructors Scheme) score is greater than 24 and that it is less than 31.5. The DRL shown illustrates that the rule will loop through all contractors that meet the application defined in the clause and check that the CCS score is within the defined limits.

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

```
rule BREEAM_MAN2_1-1
when
        forall ($contractor: Contractor(type=='principal')
                Contractor( this==$contractor, ccs_score >= 24 , ccs_score <=31.5)
        )

then
        results.pass("BREEAM_MAN2_1-1");
end
```

Fig. **7**: An example RASE clause and its translation into DRL

Internally within the rule engine the DRL rules that make the decisions use data stored in a standard object model. In figure 8 we have one object, *Contractor,* which has two properties, *type,* and *ccs_score.* It is important to notice these names are taken directly from the RASE meta-data to form its rules.

4. VALIDATION

Initial trials of the system have taken place and the results have proved very promising. Two case study issues have been tested; ECO5 from Code for Sustainable Homes and MAN2 from BREEAM. ECO5 tests development sites' protection of ecological features and MAN2 tests whether construction sites are managed in an environmentally and socially responsible and accountable manner. To validate both of these issues, a test IFC dataset has been used and the compile rules have been executed by the rule engine and checked by an expert to ensure the results are correct.

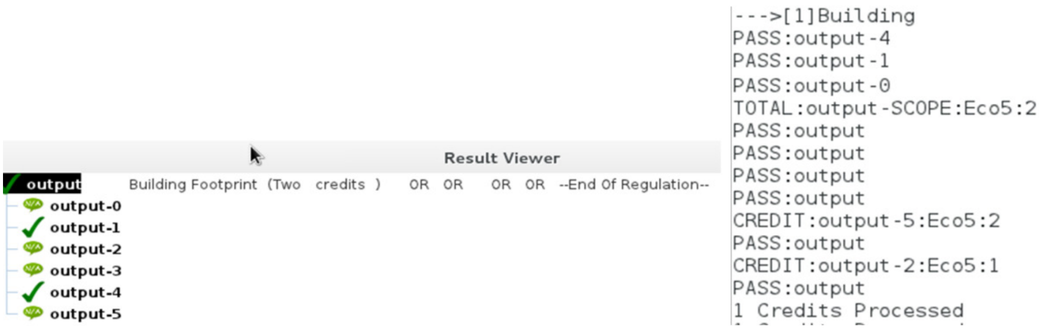

Fig. 8: Visualised Output from Eco5

Figure 8 shows the visualised and raw results from one of the Eco5 tests. We can see from this example that the rule is structured as a single OR with 6 possible options. Two of these options have been passed, meaning that the result is true. The raw result output also shows that credits have also been awarded for each of the options that have been passed. It should be noted that the credits are awarded twice for Eco5, this is because two of the options have passed when only one was required, the post processing, however, understands this possibility and only considers the highest value awarded.

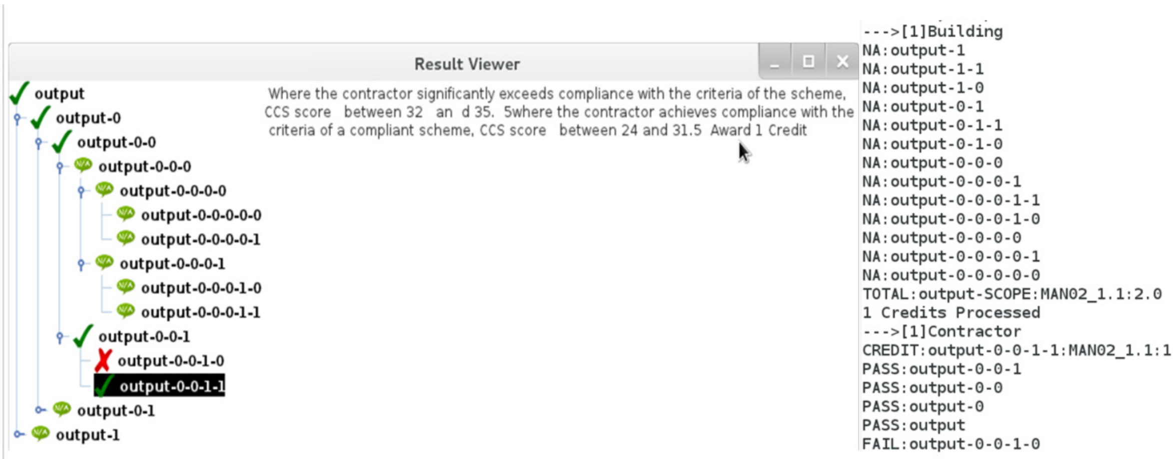

Fig. 9: Visualised Output from Man2

Figure 9 shows an equivalent set of results for the more complex Man2 issue. This issue has a more deeply nested structure of requirements, a large number of which are not applicable in this example. In this particular example, the only particular branch that is applicable is *output-0-0-1*. This is an OR choice between two options in which one fails and the other passes, meaning the regulation itself is true. Once again the raw output shows that credits have been awarded for the pass result.

5. CONCLUSION

This paper introduces a new approach for automated sustainability compliance checking. In contrast, current environmental assessment practice is lacking automatic synchronisation of the domain and rich semantic modelling. It is limited to the simpler querying of the manually maintained model. The rule based compliance checking approach relies on converting standards and best practices into complied coded rules by using a modification of the RASE methodology. This methodology allows the rules to be generated rapidly and extracts the need for manipulation of the compiled rules themselves. This is a critical issue that allows the rules to be in a form understandable by construction domain specialists without needing to understand the industry data file formats or even how the underlying rule engine will work.

On this research, a general overview on sustainability related information available in IFC standard is summarised and a list of data requirements is defined in order to be added to the IFC specification and this will be contributed back to BuildingSmart (the standardisation body for the IFCs) in the form of an extension proposal covering regulatory compliance. While our initial work has focused on the development of a regulatory compliance system for the AEC sector, it is anticipated that our approach is generalizable to many other related industries. However, when adapting the approach modifications may need to be made to the meta-data used to support specific ways in which a particular industry operates. This will be similar to the modifications made to adapt RASE in Section 5.1 to support the balanced-scorecard regulations common in the AEC sector.

Finally, for the validation process, this paper gives preliminary results for two examples of compliance checking on issues extracted from BREEAM and CSH. In future studies, the development will be implemented on a real case study to conduct a comparison between the manual approach and rule based approach for compliance checking. Also, it is promising that the system will be expanded to be integrated closely with an industry standard design package to enable dynamic requirement checking as a designer designs their building.

6. REFERENCES

Biswas, T. and R. K. Tsung-Hsien Wang (2008). "Integrating sustainable building rating systems with building information models."

Dawood, S., R. Lord, et al. (2009). Development of a visual whole life-cycle energy assessment framework for built environment. *Simulation Conference (WSC), Proceedings of the 2009 Winter, IEEE*.

Eastman, C. (2006). "IFC overview." Chuck Eastman.

Eastman, C., J.-m. Lee, et al. (2009). "Automatic rule-based checking of building designs." *Automation in Construction* 18(8): 1011-1033.

Everett, R., G. Boyle, et al. (2012). Energy systems and sustainability: power for a sustainable future, Oxford Univerity Press.

Fazio, P., H. He, et al. (2007). "IFC-based framework for evaluating total performance of building envelopes." Journal of architectural engineering 13(1): 44-53.

Global, B. (2008). "BRE Environment & Sustainability Standard (BES 5055: ISSUE 3.0)." BREEAM Offices

Hjelseth, E. and N. Nisbet (2010). Exploring semantic based model checking. *Proceedings of the 2010 27th CIB W78 International Conference.*

Hjelseth, E. and N. Nisbet (2011). Capturing normative constraints by use of the semantic mark-up (RASE) methodology. *CIB W78 2011 28th International Conference-Applications of IT in the AEC Industry.*

Kibert, C. J. (2008). Sustainable construction: green building design and delivery, wiley.

Lee, W. and J. Burnett (2008). "Benchmarking energy use assessment of HK-BEAM, BREEAM and LEED." Building and Environment 43(11): 1882-1891.

McManus, A., M. Gaterell, et al. (2010). "The potential of the Code for Sustainable Homes to deliver genuine ‘sustainable energy’in the UK social housing sector." Energy Policy 38(4): 2013-2019.

Nguyen, T.-H. and E. Asa (2006). Integrating building code compliance checking into a 3D CAD system. Proc. of Joint International Conference on Computing and Decision Making in Civil and Building Engineering.

Pauwels, P., D. Van Deursen, et al. (2011). "A semantic rule checking environment for building performance checking." *Automation in Construction* 20(5): 506-518.

Regulation, U. B. (2010). Building and Buildings, England and Wales, http://www.legislation.gov.uk/uksi/2010/2214/contents/made. No. 2214.

Salama, D. and N. El-Gohary (2011). Semantic modeling for automated compliance checking. Proc., 2011 ASCE Intl. Workshop on Comput. in Civ. Eng.

Tan, X., A. Hammad, et al. (2010). "Automated code compliance checking for building envelope design." Journal of Computing in Civil Engineering 24(2): 203-211.

Tan, Y., L. Shen, et al. (2011). "Sustainable construction practice and contractors' competitiveness: A preliminary study." Habitat International 35(2): 225-230.

Trusty, W. B. (2000). "Introducing an assessment tool classification system." *Advanced Building Newsletter* 25: 18.

Vanlande, R., C. Nicolle, et al. (2008). "IFC and building lifecycle management." *Automation in Construction* 18(1): 70-78.

Website, D. P. Retrieved February, 2013, from http://www.jboss.org/drools/.

Yang, Q. and X. Xu (2004). "Design knowledge modeling and software implementation for building code compliance checking." Building and Environment 39(6): 689-698.

Zhiliang, M., W. Zhenhua, et al. (2011). "Application and extension of the IFC standard in construction cost estimating for tendering in China." *Automation in Construction* 20(2): 196-204.