Don't Shoehorn, but Link Compliance Checking Data

Ruben Kruiper[1,2,*], Ioannis Konstas[1], Alasdair J.G. Gray[1], Farhad Sadeghineko[2], Richard Watson[2] and Bimal Kumar[2]

[1]School of Mathematics and Computer Sciences Heriot-Watt University, Edinburgh, United Kingdom
[2]Department of Architecture and Built Environment Northumbria University, Newcastle, United Kingdom

Abstract
Wouldn't it be great if we could automatically check whether a Building Information Model (BIM) complies with all the relevant building regulations? Despite a plethora of motivations and a long history of research, the Automated Compliance Checking (ACC) problem is far from solved. We argue that a general solution to ACC may not be feasible based on three fundamental difficulties: (1) semantic parsing of regulatory texts, (2) a mismatch in requirements for representing a building project and representing the building elements that ACC rules refer to, and (3) the lack of a strategy to align ACC rules to each other and to building representations. We identify the need for tools that support the use building regulations for their diverse group of users, e.g., not only during Compliance Checking. Our conclusion is that a Linked Data approach is particularly suited to the development of such support tools.

Keywords
Automated Compliance Checking, Linked Data, Building Regulations

1. Introduction

Building regulations – we use '*building regulations*' to refer to any statutory regulations, guidance and associated standards – play a vital role in the design, construction, and use of the buildings we live and work in, e.g., their safety, efficiency, and accessibility [1]. Automatically checking whether a Building Information Model (BIM) complies with regulations may reduce the difficulty, time, cost and number of human errors made during manual compliance checking [2, 3], and, as a byproduct, Automated Compliance Checking (ACC) could reduce the threshold to customisation and innovation in the building sector [4]. Unsurprisingly, there has been a lot of research on ACC over the past 4 decades [2, 5]. But ACC remains an open research problem.

This paper examines three fundamental difficulties that complicate ACC; converting regulations to rules, aligning rules to building information, and a strategy to integrate research on ACC. Section 2 provides a detailed overview of these challenges and illustrates how complicated ACC is. A more feasible approach may be to support manual compliance checking by, e.g., improving regulatory search, suggesting rule templates for regulations, tracking a compliance audit trail. In Section 3 we argue for the development of such intelligent Regulatory Compliance

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*Corresponding author.
r.kruiper@northumbria.ac.uk (R. Kruiper)
0000-0002-2288-3743 (R. Kruiper); 0000-0002-6720-4425 (I. Konstas); 0000-0002-5711-4872 (A. J.G. Gray); 0000-0002-9359-6493 (F. Sadeghineko); 0000-0002-3868-8088 (R. Watson); 0000-0002-2539-4902 (B. Kumar)

(iReC) tools, rather than focusing on ACC. We argue that research in this domain should follow a Linked Data (LD) [6] approach. Reasons include is the re-use of a large variety of existing resources, and enabling new ways of analysing building regulations.

2. Fundamental issues with Automated Compliance Checking

ACC may seem relatively straightforward. First, one converts the building regulations to a set of computer-processable rules and criteria. Second, one takes the digital representation of a building project or product, e.g., a BIM. Third, using the computer-processable rules one may automatically check whether each of the elements in the building project or product complies. Unfortunately, however, these three steps are incredibly hard to implement – we aim to illustrate this in Sections 2.1, 2.2 and 2.3.

2.1. Converting regulations to rules

Automatically converting regulatory texts to a set of rules requires semantic parsing; this is the term used in the field of Natural Language Processing (NLP) to describe the task of converting text to a computer-executable logic form [8, 9]. Due to the complexity of semantic parsing, existing ACC research focuses on simplified sub-tasks [10, 11]. An example is the conversion of only quantitative rules in a specific section or set of texts that revolve around one topic. The reasons that semantic parsing for ACC is so complicated include, but are not limited to:

- Most of the building regulations are licensed and restrict sharing of data that either includes or is derived from their contents. Even the regulations found in open-access guidance documents, such as the UK Merged Approved Documents, contain many references to information that is found only in licensed documents, e.g. British Standards.
- Building regulations are fragmented over many documents. Integrating the rules from these different documents will be a daunting task, see also Section 2.3. One complication is the existence of conflicting criteria. Figure 1 provides an example of such a conflict

ADA Accessibility Guidelines
4.7.2: Slope
Slopes of curb ramps shall comply with 4.8.2. The slope shall be measured as shown in Figure 11. Transitions from ramps to walks, gutters, or streets shall be **flush** and **free of abrupt changes**. Maximum slopes of adjoining gutters, road surface immediately adjacent to the curb ramp, or accessible route shall not exceed 1:20.

California Building Code
1127B.5.5: Beveled lip
The lower end of each curb ramp shall have **a ½ inch (13mm) lip beveled at 45 degrees** as a detectable way-finding edge for persons with visual impairments.

Figure 1: This example, taken from [7], illustrates how the fragmentation of regulations over many documents can easily lead to conflicting criteria.

[7]. An ACC system has to detect these conflicts, and a strategy should be determined to resolve each of them.

- Many criteria refer to other documents and sections – see Figure 2. Such references may simply state that all the criteria in the specified documents or sections should be met. Reasoning over these coreferent criteria requires defeasible logic representations that allow conclusions to be defeated on the basis of subsequent information [12] – adding an additional layer of complexity to how ACC rules may be captured and represented.
- A substantial amount of regulations are formulated as a performance requirement or may even be open to interpretation, such as '*as far as reasonably practicable*'. It may be impossible to convert such text to unambiguous rules for ACC. A related issue is the disambiguation of generic terms found in the regulations, e.g., does '*area*' refer to a region or a surface area?
- Regulations apply to specific countries or regions, and sometimes focus on a specific environment. This can complicate the reuse and application of such criteria in a other environments [13]. An ACC system, thus, may need adjustment before being useful in other regions and has to be aware of the local requirements of building works.

The reasons listed above are domain-bound, ergo they complicate specifically the conversion of building regulations to rules. It is also worth noting that building regulations are constantly amended, so an ACC system will require frequent updates. More generally, semantic parsing is complex regardless of the domain, which makes it difficult and costly to collect training data for Machine Learning approaches [15, 16].

In summary, it makes sense that the scope of parsing the regulations is heavily reduced. One might argue that by focusing on a small part of the puzzle the overall task of ACC can be achieved incrementally. However, even when the scope of ACC research is drastically reduced, the developed solutions will have to fit into a general strategy, e.g. [5]. Furthermore, many

4.3.2 Unprotected members

A hot finished rolled or hollow section member which has a load ratio $R \leqslant 0.6$ (see **4.4.2.2** and **4.4.2.3**) may be assumed to have an inherent fire resistance of 30 minutes without any fire protection, provided that it has a section factor H_p/A not exceeding the appropriate maximum value given in Table 4.

4.3.3 Protected members

4.3.3.1 *Required thickness.* The required thickness of fire protection materials for the required period of fire resistance should be determined from fire tests in accordance with BS 476-20 and BS 476-21.

NOTE Further information on the appraisal of fire test data may be obtained from [2] and [3].

Figure 2: This example, taken from [14], illustrates how references to other documents complicate capturing the regulations as logical rules. Additional challenges include determining the '*appropriate maximum value*' from a Table, as well as determining the '*required thickness*' and '*required period*' of fire resistance based on two entire documents.

studies do not make their code or data publicly available or reusable. If we are to piece together ACC from various studies, these studies should follow the FAIR principles to ensure Findability, Accessibility, Interoperability and Reusability [17].

2.2. Representing a building project

Figure 3 visualises how the information extracted from regulations has to be matched with the information captured in building data. A standardised representation format for building projects and products, such as those used in openBIM[1], would considerably simplify this matching process. BIM and the underlying Industry Foundation Classes (IFC) data model[2], aim to enable interoperability between data that was created in various software packages [18, 19]. Examples of research on improving BIM interoperability include [20, 21, 22, 23, 24]. In this section we consider what it would mean for an ACC system if they focus on checking standardised BIMs. Note that:

- One might want to apply ACC on other types of data than BIMs, such as technical product specifications in PDF format.
- BIMs that were created in line with the building regulations, may not necessarily contain all the information required for ACC.

The primary approach to avoid miscommunication between BIMs is through using strict definitions for all possible constituent components, which are captured in ontologies. An ontology is a formal and explicit specification of a shared conceptualisation of some area of interest [26, 27]. In the case of ACC, a *conceptualisation* is the set of classes and properties needed to compose ACC rules. The *explicit specification* indicates that all elements of the conceptualisation have to be defined, and *formal* refers to the need for definitions to be machine-understandable. Ergo, the definitions should be captured in a formal language, such as description logic. *Shared* indicates that the building and construction community should agree on the conceptualisation and its explicit formal definitions. One use-case for an ontology is to check the internal consistency of a classification scheme [28], which is not necessarily relevant to ACC.

To exemplify the use of an ontology for ACC, we will consider how one might (1) automatically determine the appropriate '*U-value*' when calculating the '*dwelling primary energy rate*' (DER) and (2) what it means for a BIM object of the class '*IfcWall.SOLIDWALL*' to be a '*party wall*' –

[1]https://www.buildingsmart.org/about/openbim/

[2]https://www.buildingsmart.org/standards/bsi-standards/industry-foundation-classes/

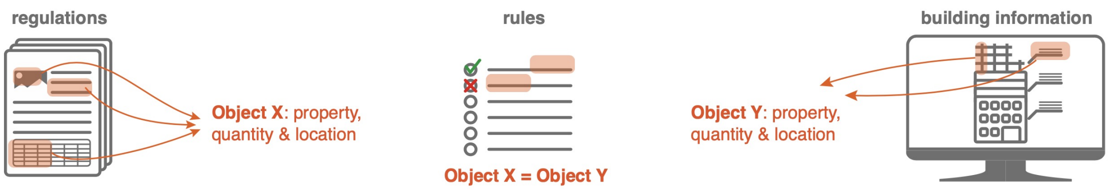

Figure 3: Parsing the regulations to a set of rules requires identifying which real-world objects are being regulated. To apply a rule, the elements of the rules have to be mapped to elements of some building or building product representation.

Party walls

2.14 When calculating the dwelling primary energy rate, dwelling emission rate and dwelling fabric energy efficiency rate, a party wall U-value for the type of construction adopted should be applied as set out in Table 2.1.

Table 2.1 U-values for party walls

Party wall construction	U-value W/(m²·K)
Solid	0.0
Unfilled cavity with no effective edge sealing	0.5
Unfilled cavity with effective sealing around all exposed edges and in alignment with insulation layers in abutting elements[1]	0.2
A fully filled cavity with effective sealing at all exposed edges and in alignment with insulation layers in abutting elements[1]	0.0

NOTE:
1. It is necessary to show that the edge sealing is likely to be robust under normal site conditions.

Figure 4: Example regulation involving the concept of a '*party wall*' [25]

see Figure 4. This would require at least the following:

- The regulation in Figure 4 was captured as a set of rules in the ontology, e.g., along the lines of: if any '*party wall*' is a '*solid wall*' then the '*U-value*' for calculating the DER is 0.0, and if the '*party wall*' has an '*unfilled cavity*' without '*effective edge sealing*' then it would be 0.5, and so on.
- Each of the classes and properties that occur in the rules are captured in the ontology. E.g., '*party wall*' is any instance of '*IfcWall*' (or an instance of some specified set of wall sub-types) that separates two instances of '*dwelling*', potentially captured using the classes '*bot:Zone*' and '*bot:adjacentZone*'.
- The BIM model has to provide the required and expected information. As an example, the system would break if our (inferred) '*party wall*' object has a '*cavity*' that is not specified as '*filled*' or '*unfilled*'.

Determining the '*U-value*' is a relatively small step in the overall DER computation. Yet, it requires formally defining a number of new rules, classes and properties. Even when all the required definitions are captured in an ontology, the ACC system will be unable to reach any conclusion for BIMs that do not provide exactly the expected information.

The '*party wall*' example illustrates the complexity of using an ontology for ACC to some extent. More complicated cases exist, such as the fire resistance requirements of walls that rely on, e.g., building use, wall height, topology of spaces and other factors. With the large amount of object types and numerous interactions, accurately defining or inferring all classes and properties for ACC is difficult – if not impossible. And as more diverse stakeholders share and define their knowledge, a geometrical increase in complexity arises w.r.t. resolving inevitable terminological and conceptual incompatibilities [29].

In order to avoid case-by-case resolution of any conceptual differences, one could consider using a common reference ontology [29]. The use of a so-called upper-level ontology that only covers widely agreed-upon terms, is the strategy that has been adopted for BIM interoperability – the Building Topology Ontology (BOT) [20], but an ontology for ACC will have to cover terms and concepts used by, e.g., regulatory bodies, building product manufacturers and BIM software vendors. The conceptualisation would have to cover spaces, topology, geometry, activities as well as building products that are mentioned in regulations ranging from energy efficiency to fire resistance, and from structural to accessibility requirements. While some new concepts may be defined in terms of existing ontology classes [30], ACC may require a conceptualisation that is several orders of magnitude larger than the current set of classes found in BOT and other building ontologies.

In summary, the ontology approach may make sense in achieving BIM interoperability. But formally and comprehensively defining all ACC classes, properties and rules will be a Herculean task – compounded by the constant change of regulations. Generally, the ontology approach is not suited to a large and ill-defined set of concepts that is used by many people who aren't necessarily familiar with knowledge engineering [31, 28]. We believe that the representation of building projects should not be dictated by terminology found in regulations, and rather a mapping between terms should be provided to enable ACC over existing representation formats.

2.3. Formulating ACC rules

There is currently no shared, open standard to formulating ACC rules [32]. As illustrated by Figures 1, 2, and 4, the regulations often refer to tables, figures and other texts – the latter sometimes in other documents, or even entire documents. Capturing information from tables and figures, by itself, poses a challenge. Additionally, certain types of regulations may simply not be amenable to ACC at all, such as performance criteria that require an '*acceptable solution*' [33]. Besides a missing standardised approach to formulating ACC rules, and some regulations not being amenable to be captured as rules, there is no consensus on the elements that would make up rules; the conceptualisation.

The conceptualisation mediates between representations of building projects/products and the building regulations. It will be necessary to identify which words and groups of words refer to the same concept, in order to avoid ambiguity in ACC rules that involve such concepts [34]. In this section, we consider the extent to which this conceptualisation should cover the variety of surface forms in which the concepts may appear – the form in which concepts occurs verbatim in text. As an example, the class '*party wall*' might be expressed in the regulations as an inflection '*Party walls*' or a synonym '*shared wall*'.

Uniclass [35] is an existing non-formalised conceptualisation that has been proposed as a common reference standard for building terminology [36]. Uniclass is already used by various manufacturers of building products [37], and contains 15K classes that cover a wide range of domain terms. Alignment with ISO standard 12006-2:2015 ensures interoperability of terms with the International Classification for Standards (ICS) [35]. To exemplify the variety of classes, consider the Uniclass terms that contain the term '*party wall*' and their Uniclass subdomains:

- Party wall notices agreeing (Activity: Ac_05_30_60)
- Party wall survey information (Project Management: PM_30_10_60)
- Party wall certificate (Project Management: PM_70_15_60)
- Party wall surveyor (Role: Ro_30_30_60)

However, if UNICLASS were to function as an ACC conceptualisation, terms found verbatim in the regulations would have to manually or automatically be classified into UNICLASS classes. The term '*party wall*' is one example of a term that has to be added – note that adding this term as a class to UNICLASS is significantly easier than formally defining '*party wall*' in an ontology. Similar to the ontology-based approach, the required extension of UNICLASS is likely substantial if an arbitrary mapping of ACC terms is to be avoided. As an example, we will reconsider Figure 2. Candidate terms that should be labelled with a UNICLASS equivalent include '*hot finished rolled member*', '*hollow section member*', '*load ratio*', '*inherent fire resistance*' and so on. UNICLASS contains '*carbon steel hot-finished hollow sections*' (Product: Pr_20_85_07_14) and '*fire resistance performance requirements*' (PM_35_30_28), but these classes barely align with the semantics of the regulations' terminology.

In summary, when it comes to formulating ACC rules, there is both a lack of a recipe (guidelines) and a comprehensive notion of which types of ingredients exist (conceptualisation) – see Figure 5. While UNICLASS has been suggested for labelling elements of building products, its vocabulary does not cover all terms found in the building regulations. Figures 1, 2, and 4 exemplify how domain terms in the regulations may serve as candidates for classes and properties. This prompts the question whether regulatory texts can provide a basis for learning an ACC conceptualisation.

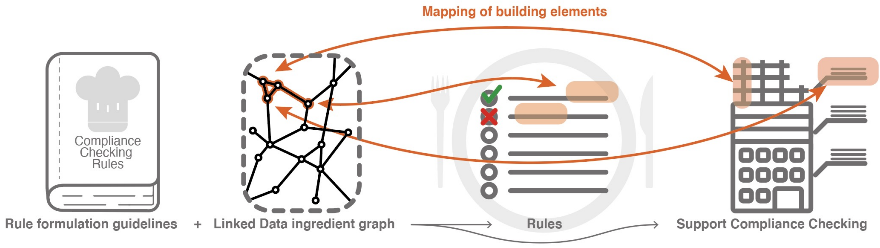

Figure 5: It would be hard to follow a recipe that lacks a set of instructions and a list of ingredients. Similarly, ACC is hard when there are neither guidelines on how to create rules, nor a standardised lexicon. The need is for a standardised approach to formulating CC rules and a standardised representation format that promotes the integration of rules, conceptualisations, and vocabularies.

3. A Linked Open Data approach to Compliance Checking

The previous section provides a grim outlook on the challenges that lie ahead en route to ACC. Despite the complexity, there are a plethora of studies that aim to achieve the monstrous task of ACC [38, 5]. For recent reviews of work in the ACC domain we refer the reader to [32, 33, 39]. For an overview of studies that apply NLP in the ACC domain see [40], and for an overview of rule-checking system see [41].

3.1. Compliance Checking Support

The crux of motivations for developing Compliance Checking systems is to improve the usability – in terms of effectiveness, efficiency and ease-of-use – of the building regulations for the goal of compliance checking. A related strand of Compliance Checking (CC) research specifically focuses on supporting human experts during a compliance audit or even during design [42, 43, 38]. We believe that, in contrast to ACC, such a human-in-the-loop approach to CC is feasible. Examples of tools to improve the usability of regulations one could envision include:

- Metadata associated to the regulation texts makes it possible to keep the following types of tools up to date, even when regulations change:
  - Suggest relevant and current regulations (sections, tables or figures, rather than document-level) based on a set of keywords, or based on a component of a BIM.
  - Grouping current regulations on the same building element to provide a comprehensive overview of various requirements, such as fire safety and energy efficiency.
  - Grouping related regulations to ensure absence of conflicts in the current regulations.
- Provide common templates for CC rules, suggest the most appropriate ones for a given regulation, as well as identifying salients components in the regulation text to populate the rule template – see [44] for an example of recent work in this direction. A LD approach may help identify CC rules that require updates when source regulations change.
- Improve insight in the compliance checking process, e.g., keep track of decisions in a compliance audit trail; which regulations were consulted to reach specific decisions, and so on. LD can ease the collection of data on, e.g., the validity and effectiveness of decisions.

An important first step in developing tools would be to collect insights from various stakeholders and identify their needs, e.g., how they currently use/access the regulatory documents for compliance checking and how this may be improved.

3.2. Towards a Linked Data approach

The use of LD in CC may help overcome some of the difficulties mentioned in section 2. By collecting a comprehensive lexicon as LD, the approach supports semantic parsing as it resolves linking terms found in the regulations (section 2.1) to those found in BIM models (section 2.2) and the classes or terms used in ACC rules (section 2.3). In our other paper submitted to this workshop [45] we present a tool that supports the development of a compliance checking conceptualisation as LD. This section, rather, focuses on three high-level reasons for using LD in compliance checking.

First and foremost, a LD conceptualisation can integrate concepts and labels from (1) formally defined classes and properties, to (2) idiosyncratic labels that may be found in building product specifications – such as marketing terms. Users may easily extend the coverage of the conceptualisation as needed. Where appropriate, mapping relations can be used to identify matching concepts in existing resources. Besides BOT and Uniclass, there are many resources of interest; ontologies such as the Smart Appliances REFerence (SAREF) [46] and the Building Product Ontology (BPO) [47], as well as construction dictionaries such as the buildingSMART Data Dictionary[3]. Additionally, beyond building data, there is a vast amount of relevant open data available online, ranging from geographical information to material properties [20].

This brings us to the second benefit of the LD approach, the ability to link to and between specific building regulations. One could consider defining the geographical regions where a

[3]https://search.bsdd.buildingsmart.org/

regulatory document applies or makes sense. Other applications include linking the regulations to the agencies that authored them, link regulations that refer to each other, link all regulations that mentions a specific concept, link regulations directly to derived ACC rules, link regulations to research that aimed to translate them to ACC rules, and so on. By representing regulations as LD, it becomes easy to analyse regulations in new ways, e.g., compare which regulations prescribe certain materials and which properties these materials have.

Third, LD may ease the identification of opportunities for collaboration between stakeholders with various needs. One example is the identification of a research group that has worked on converting a certain set of regulations to rules. Another example would be identifying companies that produce building products which have to meet a specific set of regulations.

Finally, while reasoning may not be possible to the extent that could be achieved using an ontology, compliance checking rules could be declared on top of LD by other means. One could consider, e.g., validating LD building information through SHACL[4] or ShEx[5].

4. Conclusion

Over recent years the representation of building information has seen a shift towards LD. The LD resources that were developed to, e.g., support BIM interoperability, have thus become of particular interest to ACC. However, these LD resources do not comprehensively cover the terminology found in the regulations. This complicates both the automated and manual formulation of rules for compliance checking. Rather than shoehorning regulations into the existing set of classes, research on ACC should consider ways to extend and link existing vocabularies, ontologies and so on.

Like others, we argue that the overall aim of ACC should focus more broadly on improving the usability of building regulations. An ontology-based approach is not suited to the scale and range of terminology found in the regulations. On the other hand, a LD approach provides both the ability to scale and align to existing resources. Practically, one might expect to build on existing ACC research and existing resources when developing more user-centred CC tools.

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