Delivering the Infrastructure for Digital Building Regulations

James H. Garrett Jr., F.ASCE

Dean, College of Engineering, Thomas Lord Professor of Civil and Environmental Engineering, Carnegie Mellon Univ., 5000 Forbes Avenue, Pittsburgh, PA 15213-3890 (corresponding author). E-mail: garrett@cmu.edu

Mark E. Palmer

Leader, Process Engineering Group, Engineering Laboratory, National Institute of Standards and Technology, Gaithersburg, MD 20899.

Salih Demir

CEO and Co-Founder, TEC Company, Istanbul, Turkey.

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The building industry uses numerous engineering standards, building codes, specifications, and regulations (henceforth, all are referred to as "regulations" for the purposes of brevity), and a diverse set of industry vocabularies to describe, assess, and deliver constructed facilities. These building regulations are available as hardcopy and searchable digital documents. Some building design software applications (e.g., building-energy analysis and fire-egress assessment) are available that include computer-interpretable representations of the logic and rules from relevant building regulations. As part of the expanding use of building information modeling and new types of software applications, building and regulatory stakeholders and their software suppliers are recognizing the value of combining building models with rule sets for multidomain analyses, optimization, and assessing regulatory compliance. The availability of validated representations of building regulations for use by model-checking applications will streamline and shorten the building process, reduce inefficiencies and errors in the process, and enable new capabilities for optimizing designs and for automating the regulations-compliance assessment process.

There has been a significant amount of research on this topic, and some of these results have been published in this journal during the past three decades. There are now a number of very important initiatives [e.g., by Associated General Contractors of America (AGC); American Institute of Steel Construction (AISC); American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE); Fiatech: Industry Consortium to Advance Innovation (ICAI); International Code Council (ICC); National Institute of Building Sciences (NIBS); and the United States Army Corps of Engineers (USACE)] to develop standardized representational approaches for building regulations so that they can be applied and checked automatically against building information models and standardized data-exchange representations, such as the Industry Foundation Classes (IFCs). Numerous fields of engineering, particularly those that rely on interdisciplinary collaboration, are adopting vocabulary-management and ontology-development software tools as part of the process of transitioning to computer-interpretable standards for engineering. Building-systems engineering, sustainable manufacturing (Lechevalier et al. 2013), and biomedical engineering are using these semantic tools to develop the needed infrastructure for a new generation of computer-interpretable engineering standards.

With this editorial, we provide recommendations for broadening the support and coordination of these initiatives, which are needed and timely, and present a set of issues derived from research and prototyping that is related to development and industry deployment of formal computable representations of building regulations. We hope that these recommendations and deployment challenges will be taken up, either in the short-term or over the long-term, by everyone involved in the digitization of building regulations and the building industry, as we move to using building regulations as computer-interpretable resources for model-based engineering in the architecture, engineering, and construction (AEC) industry.

What are the Main Issues that Drive Us toward Digital Building Regulations?

There are a variety of types of regulations for which a building is required to be designed, assessed, and operated. Some regulations are collections of simple limits and relationships that are enforced as design rules, whereas others are the result of extensive deliberation and are crafted as text-based documents to be read and interpreted by those applying them. Thus, a great deal of flexibility is needed in the representation and encoding of the semantics and logic of building regulations to support the many different types of documents and decisions needed for the design, analysis, and approval of building plans and models. To further complicate this issue, building regulations are used in design processes and checked for compliance by a wide range of domain experts, each possibly using different software tools and vocabularies for design and analysis, and each able to make their own interpretations of potentially ambiguous provisions in these regulations. Although the modeling and analysis (structural, energy, and lighting) of building designs has continued to become more sophisticated, there is still no standard, generalized approach for formally representing building regulations in a digital format that would facilitate a variety of forms of reasoning about those codes in combination with digital building information models.

Given the fragmented nature of the building and construction industry and the challenges of transforming existing industry standards and glossaries into data dictionaries and multidomain vocabularies, early efforts to transform building regulations into computer-interpretable logic and rules did not progress beyond the proof-of-concept stage [National Conference of States on Building Codes and Standards (NCSBCS) 2003; Wibble 2004]. Fortunately, many of the lessons learned from these early prototypes are being leveraged in current efforts to automate and streamline building regulatory compliance assessment processes. It is important for these efforts to coordinate their work and insights so that the building industry can achieve essential transformations of the building design, review, and approval processes.

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Possible Approaches to Develop Formal Representation of Regulations

For more than 40 years, the formal representation of regulations by information technology has been researched, yielding a wide array of approaches for formally representing and reasoning with building regulations. Space does not permit an extensive discussion of this body of research (Akin 2012). At a high level, these tend to be divided into representations of the logic in the regulation using the following criteria:

- Procedural code,
- Sets of rules or decision tables,
- Objects with attributes and methods associated with those attributes,
- Formal predicate logic expressions,
- Description logic approaches,
- Context-oriented approaches,
- Simulation-based approaches,
- Agent-based approaches, and
- Other hybrid approaches.

The point of briefly mentioning all of these approaches and the extensive research that has been done on these different representations (much of it published in this journal) is to ensure that the industry builds on the findings (successes and lessons) in this body of work.

Guiding Principles

The organizations that are responsible for creating and publishing these regulations will have to recognize the opportunities and stewardship responsibilities for creating and maintaining a computer-interpretable version of the regulations. These organizations will need proven, cost-effective methods and tools to produce and maintain correct, complete coverage of the computer-interpretable versions of the regulations and of the supporting vocabularies as the regulations are updated and expanded. This requires standardized, well-defined components of regulation models and a simple syntax for the representation of vocabulary and logical conditions within the regulations. Hence, there is a need to help organizations develop and maintain the models of their regulations by providing advanced computerized tools (Lechevalier et al. 2013) to support the creation, editing, assessment, and validation of computable models of regulations.

One of the key criteria for such representations is to be independent of any specific model-checker software used to check regulation compliance of building information models. To achieve a model-checker independent, computable representation of regulations, the first step is to create a representation syntax that is simple to understand for building-regulation writers and software developers, and that is sufficiently expressive to support the range of complexity included in regulations. The second step is to provide computerized support to enable regulation organizations to easily develop, test, and maintain these regulation representations. The third step is to test the sufficiency and implementabilty of the digital representations.

To develop these formal, computer-interpretable representations of regulations that are model-checker independent, researchers and stakeholders should consider the following five recommendations identified by projects that examined this topic (Akin 2012):

1. A computable representation of a building regulation should be declared, interpreted, and then applied to a specific building information model using a separate inference engine (such as a model checker). This is a concept that first emerged when knowledge-based systems were explored using explicit declarations of knowledge (possibly in the form of rules) and an inference engine to interpret the rules and apply them to a specific set of variable values. In the case of digital models of regulations, we promote the same concept as the first core requirement for any model. The model of the regulation should be declaratively and explicitly represented, which can then be consistently interpreted by any number of different inference engines (or model checkers) that are able to read this explicitly declared model and perform some process on a building design using that processable model of the regulations. Such processes would include checking the regulation for conflicting or missing requirements, abstracting the detailed regulation model to create a simpler version for use in earlier phases of the design process, and checking a building-information model for conformance to the regulation. The advantage of this approach is that the model can be imported, analyzed, modified, and applied in a variety of ways, which is not possible if the regulation model is embedded within a procedural description (e.g., a specific software application).
2. A computable model of a regulation should be understandable and testable by both the regulation-promulgating organization and the users of the regulation, not just by the implementers of a design system in which the regulation is embedded. In the not too distant future, it will be possible to easily create computable representations of regulations and evaluate a building-information model for compliance with the regulations. Systems exist now that make this possible. It is extremely important that these models of regulations can be inspected and tested by the organizations that create and issue the regulation, often in text form. If the model is in a proprietary format that cannot be easily examined, or in a form that cannot be easily understood or related to the text from which it is derived, many of these computable versions of regulations might go unverified, assumptions will not be understood or managed, and ambiguities may lead to misinterpretations.
3. A computable representation of a regulation and its textual version should be as self-similar (isomorphic) as possible. To make it possible to easily create the initial computer-interpretable representation of a regulation, the computable representation of the text should be interwoven with the text itself. Doing so will also make it possible to maintain the correctness and completeness of subsequent updates to the model of the regulation in response to updates to the text of a regulation. For example, having markup in the text that defines the underlying logical meaning of that text makes it very easy to identify what parts of the digital model need to be modified when the text changes. Several early efforts used this approach, and some current projects are moving in this direction.
4. The domain vocabulary used in the regulations should be defined and explicitly represented so as to be mapped easily to the terms and concepts used in building information models. If this mapping is hard-coded or proprietary, then the ability to check, change, and analyze the correctness and completeness of the computer-interpretable regulation may not be possible. These explicit definitions of the concepts in a regulation (i.e., documented in a data dictionary) should be part of the explicit computer-interpretable representation of the regulation. That representation of a regulation should not require its users to be familiar with all the detailed object classes used to determine the applicability of various requirements in that regulation. In other words, the nonstandard and more detailed classifications of building components (e.g., beyond walls, windows, and doors) referred to within the regulation should be explicitly and formally defined so that the various

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components and systems in the building-information model can be automatically (or at least semiautomatically) determined for a given instance of a building information model. This will make it possible to use a wide variety of specific and appropriate object classes when modeling regulations, and enable all specific classes to be mapped to a much more general building-information model schema. Without such definitions of concepts, these classes would have to be defined within the schema of the building-information model, and this is simply unworkable for all of the different regulations that must be addressed for a given building.

5. A computer-interpretable representation of regulations must be able to represent different kinds of logic and information present in a regulation, not just the simpler first-order logic. For those parts of the regulations that cannot be modeled and evaluated automatically using the existing computable representation, it must be possible to at least identify those provisions as "not represented in this model." Many representations that are based solely on first-order logical representations, such as rules and predicate logic, will be able to represent most of the provisions in a regulation, but not all of them. Knowing what is represented and what is not represented in computer-interpretable representations of building regulations is not easy to determine. This requires that the second and third principles are diligently followed.

Establishing the Infrastructure for Digital Building Regulations

The most important commitment we can make as a community is to leverage the lessons from early research and the current initiatives and to broaden the cooperation on delivering standardized, formalized, model-checker independent representations of building regulations. The Fiatech Consortium and its Regulatory Streamlining Committee have demonstrated the applicability of these concepts and collaborated with the International Code Council (ICC) on the application of model-checking technology to accessibility and egress reviews. The U.S. Army Corps of Engineers has provided leadership in advancing these principles with a number of initiatives, and in adding emphasis on validation and implementability assessment. We need to establish a coordinated industry strategy that leverages the insights from earlier research and prototyping, and establishes effective methods and tools for the industry deployment of formal computable representations of building regulations. This must be accomplished in the near future before large numbers of building regulations start to be represented in individual efforts on the basis of one or more different proprietary approaches that only address some of these recommendations. We need to be deliberate and bring as many of these recommendations as possible to bear on the creation of computer-interpretable representations of building regulations. We need to commit to a plan whereby we are able to have early victories and represent some of the simpler regulations using simpler representational approaches, such as rules. We also need to commit to get a variety of regulation developers and model-checker providers involved in this process. The early victories may come because a proprietary approach is used, but we should be careful not to allow for a proprietary representation to become a defacto representation, disconnected from the originating building-regulation organization or industry-standards organization. We need to work with the industry-standards organizations that have recognized the opportunities and challenges of transitioning to the digitization of building regulations, and are investigating alternative delivery, deployment, and industry adoption models. We need to strive to create a rich and intellectually-active research and deployment forum and a marketplace for a diversity of tools that help to create, verify, and use such representations of building regulations. Unless we commit to the aforementioned, the creation, verification, deployment, and maintenance of computer-interpretable representations of building regulations will continue to struggle to get broad support and could become a Pandora's box, where many inoperable, nonstandard, unverified, and unmaintained representations of building regulations get released and used by the AEC community, but the compliance-assessment process remains locally unique, slow, and difficult. A number of U.S. organizations have made investments in this area, including AGC, AISC, ASHRAE, Fiatech, ICC, NIBS, and the U.S. Army Corps of Engineering. Greater communications and collaboration on common methods, tools, prototyping, and deployment is needed. One of these organizations could convene meetings to advance these capabilities or step forward to lead such efforts and establish an industry roadmap for achieving the transition to automated regulations compliance assessment processes.

Professional societies that are stewards for regulations, engineering standards, and industry vocabularies are starting to recognize the importance of migrating these knowledge resources into computational formats using formalized logic and semantics. We need these professional societies that steward the text-based versions of their regulations also to engage strongly in this effort, and be prepared to be the stewards of their computer-interpretable versions (not just the digitized text, but the representations of the logic and vocabulary used in the regulation). To do so, they need a standard for the computer-interpretable representation of regulations and a set of tools to help create, analyze, and evaluate these representations of specific regulations using a wide variety of model-checking environments.

We recognize that there may be differences of opinion on this topic. We welcome others to contribute editorials on this topic that present alternative opinions.

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