The Use of Predictive Tools and Software
In a Building Regulatory Environment

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ABSTRACT

The ubiquitous nature of computers in modern society has resulted in the widespread development and use of software to automate previously manual procedures. Further, advancements in the technical understanding of even highly complex phenomena such as fire have been embodied in predictive tools and models that can be used in engineering analysis of the performance of materials and systems in their context of use. The ability to predict structural and fire performance has enabled performance-based building regulation now in place or being developed in many countries.

The growing use of these (often proprietary) software products in regulated environments raises a number of issues that need to be addressed to avoid legal challenges and to limit liability of regulators and standards developers. These include mandatory references to proprietary software; validation, documentation, and version control of software used in design; engineering design methods as Standards of Practice; and professional qualifications of software users. The paper also addresses the design of software to identify key assumptions that represent bounding conditions on regulatory approval and to quantify uncertainties and appropriate safety factors to be applied. The purpose of this paper is to identify these issues and to present some suggestions on how they may be addressed to meet the needs of regulators.

INTRODUCTION

In general, a building regulatory system consists of regulations adopted into law that contain prescriptive rules or performance objectives either of which define the minimum acceptable design for a given condition or use. These regulations reference standards that define how these minimums can be satisfied. For example, a U.S. building regulation on the safe installation of electrical distribution equipment requires compliance with the National Electrical Code®[1], which provides the details of acceptable design, installation, maintenance, and use of the electrical distribution system.

Thus, the regulations are laws that reference standards that are not laws even though the reference may give the standard the force of a law. This is an important distinction. In most countries the right to make laws is granted to specific people and the process is highly structured. Most standards development does not follow the so-called *due diligence* process required of laws.

Interpretation of laws is also usually restricted to certain parties. In the U.S., laws can only be made by legislators (generally elected officials) and laws can only be interpreted by the courts. As set out in the U.S. Constitution, these authorities cannot be delegated. The legal system provides administrative details for responsibilities, enforcement and penalties. Similar limitations occur in most countries and legal systems.

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BUILDING REGULATORY SYSTEMS

Regulation of the safety of buildings is part of the more general public safety policy of a country. Building regulations are developed by governmental (or quasi-governmental) bodies and are adopted legislatively or administratively into law. The details of how this is done vary. For example, in Japan the regulations (the Building Standard Law) are developed by a national government ministry and are adopted to apply nationally. In Canada a model regulation (code) is developed by a national government agency and is adopted by the provinces. In Australia the states and territories jointly founded a private code body (Australian Building Codes Board) to develop a model regulation that, like in Canada, is adopted by the states or territories. The U.S. uses model regulations developed by private organizations and adopted by states and local governments. In each of these examples the adopting bodies have the ability to incorporate modifications to the model regulations to account for local conditions or practices, and such modifications are common.

Regardless of the method of development and adoption, most building regulatory systems are applied and enforced at the local level by officials empowered to make a legal determination that the building complies with the regulation. Even in Japan where the regulations are developed and applied nationally, local officials are empowered to judge compliance. Many building regulatory systems also allow the local official the flexibility to determine the acceptability of alternate methods of meeting the intent of the regulation where strict compliance is not met, although some (e.g., Japan) require a higher level determination of equivalency.

The adoption of model regulations into law is generally a structured process involving public notice and comment on the proposed regulation. Notification of the proposed regulation is published in specific places and comments can be submitted that often require a formal response. This process also serves to educate those who will be affected by the regulation on what they must do to comply. This is sometimes referred to as a *due diligence* process and is generally lacking in the development of standards.

STANDARDS REFERENCED IN REGULATIONS

The reason for the preceding discussion is that the same concepts apply to standards, proprietary products, and computer software referenced in regulations so that these references are incorporated in a legally appropriate form.

Standards referenced in building regulations are often there to supply technical procedures for the reliable or safe installation, maintenance and use of critical equipment and systems. Developed by specialists in a given field, they incorporate details with which the regulatory official is not familiar but on which they need to rely. Common examples of such standards referenced in building regulations are electrical, fuel gas, fire alarm, and fire sprinkler standards.

In most countries mandatory references to standards in regulations must be to specific editions of the standards (so-called dated references) to avoid illegal delegation of legislative authority. That is, if a regulation requires that fire sprinkler systems comply with a sprinkler standard the reference needs to be to a specific edition (in the U.S. this might be to NFPA 13-1999, Installation of Sprinkler Systems). If the reference were undated the regulation legally would be accepting any future changes to the referenced standard, illegally delegating the authority to modify the law to the committee that writes the standard. In recent years it has become common for regulations to cite the standard generally in the text and to include a specific chapter on referenced standards that contains all the dated references in one place for ease of updating.

While the mandatory reference to a standard in a regulation gives the standard the force of law it does not make the standard a law because the determination of whether the installation in fact complies with the standard is made by the regulatory official. The standard provides guidance to the official in making that determination but the official can request special arrangements because

of unique circumstances. As long as the decision rests with the official and the standard provides guidance it is not a law and does not require due diligence in its development.

References to Proprietary Products
Building regulations sometimes require the use of products to fulfill an objective; for example electric outlets in kitchens, bathrooms, and other wet locations are required to be of the ground fault circuit interrupting (gfci) type. Product standards are in place to define the performance of such devices as evidenced by third party listings of commercial products. This situation would only represent a problem if the product required in the regulation were proprietary – only available from a single source such as where the product technology is protected by a patent that is not licensed. This is because it is considered inappropriate to require the use of a specific product or service only available from a single source.

Such requirements for use of proprietary products only available from a single source are generally forbidden in standards and regulations. In the U.S., the American National Standards Institute (ANSI) has a formal policy[2] that requires that for patented inventions either:

1. a license will be made available without compensation to applicants desiring to utilize the license for the purpose of implementing the standard, *or*
2. a license will be made available to applicants under reasonable terms and conditions that are demonstrably free of any unfair discrimination.

A similar policy has been adopted by CEN/CENELEC for European standards[3].

PERFORMANCE BASED REGULATORY SYSTEMS

As many countries are adopting performance-based regulatory systems there are some important issues arising. Traditional (prescriptive) systems specify characteristics and arrangements of building components as minimum requirements of acceptability. Performance systems specify outcomes that can be achieved in many ways.

Performance regulations generally employ a hierarchical structure often referred to as the NKB model. As shown in figure 1, at the top level are qualitative (societal) objectives that

Figure 1 The Performance-based regulation hierarchy

are broken down into functional statements for functions that need to be addressed in order to reach the objective. Next are performance requirements that provide metrics to tell if the functional requirements have been met. At the base are verification methods or acceptable solutions that have been found to (or are deemed to) satisfy the objective.
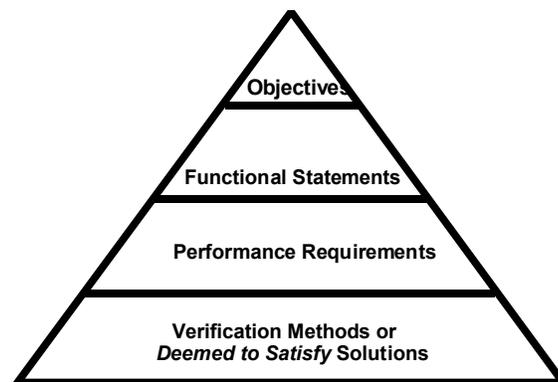
Performance systems link to prescriptive at the level of "acceptable methods," some of which may be "deemed to satisfy" the performance requirements. Since prescriptive regulations list what must be done and reference standards as providing necessary details, they do not deem anything to satisfy the prescribed approach.

If a standard is referenced in a performance regulation in such a way that systems conforming to the standard are "deemed to satisfy" the requirement and thus must be accepted by the

regulatory official, the standard has been given the force of law and has itself become law. This is not an illegal delegation of legislative authority (as long as the reference is to a specific edition of the standard) because the designation of the standard as law is made through the adoption of the referencing regulation. But where standards have the force of law it can be argued that they need to follow the due diligence process that is applied to the development of model regulations.

ENGINEERING DESIGN METHODS

Various engineering design methods are recognized in building regulations. For example the U.S. codes cite ASCE 7[4] as the methodology to use for structural design. This standard establishes the design loads, safety factors, and calculation methods to follow in carrying out the design. The responsible engineer is generally required to be (State) licensed, through which competency and legal responsibility is established. The certification by a licensed engineer is proof to the enforcement official that the analysis was done properly, although the official can review the calculations or request a third party reviewer if deemed necessary.

This is a typical practice around the world. Professional societies establish the Standards of Practice to be followed and licensing (certification or chartering) establishes qualifications and legal responsibilities. Licensing frequently includes ethics provisions that self-limit scope of practice and advocacy for clients at the expense of public safety. Historically these professional practices have been open and transparent, taught in engineering education and vetted in the literature to the point of common acceptance and regulatory comfort. While mistakes are still possible they would be generally in the application of the methods rather then errors in the methods themselves so legal responsibility would rest with the professional.

PREDICTIVE METHODS AND SOFTWARE

Validation and Verification

With the increase in use of computers has come the automation of engineering design methods. In some cases this automation is straightforward and it is possible to verify the software by performing the same analyses manually and using the software, and compare the results. This can develop confidence in the software, although it must be remembered that just because it gets some answers right does not mean it will get all the answers right. Where possible, the traditional engineering approach of performing an analysis by two, independent methods that both yield the same answer can provide real validation.

In many cases, however, predictive models solve problems that are insoluble by hand and for which there is no "right" answer. Predictive fire models now being used in building fire safety analysis are a case in point. There has been a long running discussion on how to validate fire models or to even judge how close is close enough. The author has proposed a criterion that has been positively received by some regulators. This is, regulators have long accepted full-scale fire tests as demonstration of the acceptability of a new material or method. In such cases, if a model is run on a scenario that is then tested in full scale and, if the model agrees with the experimental data to within the measurement uncertainty, then the model can predict as closely as we can measure and it should be "close enough." Validation studies and test cases should be included in the documentation or published separately, either by the developer or by independent third parties or users not affiliated with the developers[5].

Documentation

Predictive tools and software used in a regulatory environment must be thoroughly and openly documented. The technical basis for the calculations must be shown and referenced to appropriate technical literature. Further, the computer coding of the equations must be documented since the implementation can affect the solution. This documentation must be freely available for review by the technical community at large and by the regulators and their technical

experts or peer reviewers. Standards for computer model documentation have been published in the U.S. by ASTM[6] and are under development by ISO TC92.

Version Control

Regulatory references to software without version numbers and dates would constitute an illegal delegation for the same reasons as undated references to standards. This also means that the software developer must follow accepted practice for version control and documentation, such as by using Computer Aided Software Engineering (CASE) tools. Even better would be the provision to regulators of verification tools such as a checksum value for executables that can verify that a certain (specified) version was used.

Professional Qualifications of Users

In a regulatory environment professional qualifications are usually addressed through licensing requirements. Licensing generally incorporates professional considerations where the person is ethically bound to refrain from practice in areas where they are not qualified. If challenged, the state licensing board can revoke the license if they are found to be practicing outside their qualifications.

This process has generally worked well in most disciplines. Structural design calculations are referred to qualified structural engineers; seismic issues are also addressed by engineers with specialized knowledge and experience. However, there have been some problems in fire engineering because of the relatively recent emergence of fire science as a specialty. Many fire engineers have practiced in the environment where expert judgment in the application of prescriptive rules was the norm and are not qualified to apply this science to analyze building performance in fire.

Historically, architects have specified fire protection features from prescriptive code requirements and structural engineers are used to integrating structural performance for load combinations specified for specific performance attributes. Modern fire engineering has reached a level of sophistication that requires specialists in fire dynamics, fire hazard and risk analysis, human behavior in fire, and related topics, to conduct reliably the types of performance analyses needed. This has led some to develop minimum qualifications for fire engineers (e.g., Australia, New Zealand, England and Wales) and/or for users of fire models (e.g., ICC Performance Code for Buildings and Facilities[7] addresses this in an informative annex).

SOFTWARE IN THE DESIGN PROCESS

In the traditional system of architects specifying fire protection features based on prescriptive code requirements, fire engineers often were not involved or only became involved when a constrained design could not meet the prescriptive solution. Thus architects and building owners are used to paying relatively small fees for fire engineering and are not used to having fire engineers monitoring construction. The much more complex process of fire engineering for performance-based designs demands that this change. Additionally, fire engineers need to refuse to do a less than adequate job on the grounds of professional ethics and standards of practice.

In structural engineering there are agreed design loads and load combinations that represent a consensus of the design and regulatory community. For natural hazards such as earthquake and wind these loads reflect a public policy decision on the performance of buildings that strikes a balance between the likelihood of an event exceeding the design level (the so-called extreme event) and the societal costs of designing buildings to a higher performance level. Agreed safety factors are also specified that account for uncertainty in both loads and material properties within the so-called limit state design process which has become the standard of practice for structural engineers.

Modern fire and structural engineering are both increasingly incorporating software-based analysis into design, especially for performance-based design. Where a standard of practice exists this software should be designed to comply with that standard – for example, in the application of loads and load combinations, or safety factors. But this software can and should go further by facilitating the conduct of engineering analyses appropriate to the regulatory environment in which it is used.

In some cases inputs are not single valued, and software should support the specification of ranges or distributions of input values in any case where a "worst case" value is insufficient. Examples abound in the human factors aspects of egress analysis in fires and other emergencies. An available simulation model[8] for the evacuation of commercial aircraft recognizes the issue that random variations in seating assignments of passengers have a significant effect on evacuation times because of the single-file exit access in the narrow aisles. Thus the model incorporates a feature to randomly re-seat the same passenger population and re-run the timed egress analysis multiple times to obtain a range of results for that population and aircraft configuration. The same software incorporates standards of practice by automatically generating passenger loads with the demographic distribution mandated in US federal regulations for certification of commercial aircraft evacuation.

An issue with fire generally is that the most severe consequences are not necessarily associated with the largest fire. It may be necessary to examine a series of fire scenarios (consisting of differing fire sizes and locations within the building, building conditions, and occupants numbers and characteristics) to identify the most risk-significant for further analysis at a higher level of detail. Subsequently it may be necessary to perform a sensitivity analysis on some of the key variables to quantify the uncertainty in the results, based on assumptions that bound the possibilities examined.

This type of analysis is not currently performed because of the engineering time needed and associated costs. These can be minimized if the software were designed to allow different types of models to be used from a common input data routine. Such systems have been proposed by researchers in Canada (Fierra by NRC/IRC) and UK (Josephine by FRS/BRE) and are currently under development. In these modeling tools the user will be able to describe the scenarios in a single set of descriptors and then call on any of a number of models to predict the outcome.

For example, BFRL's CFAST model could be used to identify risk significant scenarios for more detailed analysis with (the European cfd model) Sophie followed by sensitivity analysis with CFAST and timed egress analysis with Crisp2. Fire environments predicted by any of the fire models could serve as input to finite element models to examine structural performance of beams or columns.

In the late 1980's, NIST developed a fire risk assessment tool[9] (FRAMEworks) that accepted lists of buildings, fires, and occupant sets and automatically ran all the combinations, producing aggregate incident statistics in the same form as the US fire incident data system, NFIRS. Later, Notarianni[10] used a similar approach but adapted to the specification of distributions of input variables to assess the propagation of uncertainties in risk analysis.

Concluding Remarks

At the current state of the technology models used to address regulatory issues serve as guidance to underpin expert judgment of licensed engineers and designers. It is the responsibility of these professionals to recognize the limits of the models, uncertainties in the data, and exacerbating conditions that could result in failure to meet regulatory objectives. This is exactly the situation that concerns these professionals and their liability carriers. When the first major failures due to unforeseen conditions or cascading failure occur it will have a sobering effect on performance design, worldwide.

The first example has recently occurred in New Zealand where an innovative exterior cladding system deemed to comply with the building code allowed water penetration leading to mold and rot. The Building Industry Authority, the quasi-governmental company that develops and administers the building regulations, was successfully sued and has been re-nationalized to make it "more responsive" to the public welfare.

Similarly the events of September 11, 2001 in the US have caused regulators around the globe to ask how buildings will perform in *extreme events* – conditions that exceed the design limits imposed by the designer or regulation. These extreme events will involve combinations of conditions that result in some catastrophic outcome. Thus designers are being asked to assess potential losses under conditions never before considered.

It can be argued that modeling tools and software used in a regulatory environment must meet a higher standard of care and the *due diligence* requirements of the regulations themselves. Similar standards have evolved with respect to expert testimony in civil and criminal litigation. Organizations developing such models and software have an ethical obligation to design their tools to facilitate their appropriate use in these applications. Engineers and designers are obligated to use only appropriate methods and to ensure that the building is constructed in accordance with their designs.

Further, care must be exercised in the way in which models, and more generally software are referenced within performance-based regulations. Proprietary software can be cited as a verification method but could not be an acceptable (deemed to comply) solution because that would represent an illegal delegation of legislative authority. That is, proprietary software might be changed by the developer without the possibility of the thorough public review required of regulations. Openly documented software referenced by specific version could be an acceptable solution if it provides a complete solution for the purpose. For example, hydraulic calculation software results in all of the design parameters for a fire sprinkler system and thus provides a complete solution. Fire models require assumptions and judgment that can affect the outcome and these must be reviewed and approved by the regulatory authority for appropriateness. Thus, fire models would not qualify as acceptable solutions but can be used as verification methods.

As countries adopt Performance-based Regulatory Systems (PBRS) many of the prescriptive standards currently in place will continue to be of value as verification methods or acceptable solutions, but others will become obsolete. There will be a crucial need for standards that address performance metrics for materials, products, and systems that are associated with predictive methods that can assess performance in context. And the standards development process itself will need to change where standards have the status of regulations. If the traditional standards development bodies do not adapt, others will spring up to fulfill these needs. The national and global benefits or PBRS are too great for any other outcome.

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