Developments in Performance-Based Building Codes and Standards

In the past, most building codes and standards have used prescriptive (or compliance) criteria. In recent years, there has been strong interest worldwide in developing codes and standards that are more performance based.

A prescriptive approach describes an acceptable solution while a performance approach describes the required performance. In order to clarify the difference between these two approaches, it will be helpful to use an example. Consider the goal of fire safety in a building. In order to achieve this goal, a prescriptive code would specify what materials the structural frame of the building should or should not be made of. Whereas a performance-based code might state that the building structure should be able to withstand a fire long enough for the occupants to escape safely, but would not “prescribe” exactly what materials must or must not be used. Therefore, if it can be demonstrated that a given set of materials would achieve the goal of fire safety, those materials would be accepted under a performance-based code.

Prescriptive criteria are straightforward for a builder or designer to follow, easy for a third party to check, and relatively easy for building regulators to enforce. However, there are some fundamental difficulties associated with the use of prescriptive criteria and these problems have increased the interest in the development of performance-based codes and standards.

The most serious problem with the prescriptive approach is that it serves as a barrier to innovation. Improved and/or cheaper products may be developed, yet their use might not be allowed if construction is governed by prescriptive codes and standards. One example of this is the development of base isolation systems that protect buildings from expensive and life-threatening damages during earthquakes. Widespread application and adoption of these systems soon after they were first developed in the 1960s would have saved many lives and reduced economic damages from earthquakes. But prescriptive code requirements hampered and greatly delayed their adoption. With a
performance-based code, these systems would have been allowed for much sooner.

Another problem with the prescriptive approach is that it makes it very difficult to cost-optimize building construction. For example, in the prescriptive approach, a specific set of framing and construction details for houses in a high-wind region would be required. This prescriptive solution would "imply" a certain level of performance, but this is not explicitly or quantitatively stated. Thus, it would take a tremendous amount of work to demonstrate that another solution (e.g., a framing system with fewer members but with innovative configuration and connections) would equal this unspecified performance level. In contrast, a performance-based code would have a clear and quantified description of required performance, ideally in terms of risk. This would allow the use of newer, and possibly less expensive, products or processes that can be shown to meet or exceed the code’s acceptable level of risk. Design tools can then be developed to balance cost and risk (17).

A third problem is related to international trade in building products. If two trading countries each use their own prescriptive criteria, it is often difficult to establish the equivalence between the two sets of criteria and to show that one country’s accepted solution would equal the implied performance level required in the other country. Thus, it is difficult to establish fair trading agreements with the prescriptive approach.

Recognizing that prescriptive codes and standards are major non-tariff trade barriers that inhibit trade, the World Trade Organization (WTO) has stated in Clause 2.8 of the Agreement on Technical Barriers to Trade (25):

"Wherever appropriate, Members shall specify technical regulations based on product requirements in terms of performance rather than design or descriptive characteristics." (italics supplied).

Member economies that are signatories to the WTO General Agreement on Tariffs and Trade (GATT) have therefore committed themselves, knowingly or not, to the use of performance requirements in evaluating a product’s fitness for purpose and in accepting new and/or innovative products in their market, or, in other words, to use the language of performance in trade.

The Performance Approach

Historical Background

The performance approach is, in essence, the practice of thinking and working in terms of ends rather than means (5). The performance approach is concerned with what a building or building product is required to do, rather than prescribing how it is to be constructed. This concept as applied to building and construction is not new; its development has been discussed in an article by Gross (14).

The first known building regulation record has been attributed to King Hammurabi, who reigned in Babylonia from about 1955 to 1913 B.C. It contained a performance statement on structural safety. Upon an obelisk in the Louvre in Paris is inscribed a quote from the Hammurabi Code:

"Article 229: The builder has built a house for a man and his work is not strong and if the house he has built falls in and kills a householder, that builder shall be slain."

This statement does not say anything about the ways and means of buildings, e.g., the type of material, the thickness, dimension, and size of building parts, or the method of construction, but it clearly states the required end result: that the building should not collapse and kill someone.

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Developments in the last couple of decades can be found in the proceedings of the series of conferences sponsored jointly by the International Council for Research and Innovation in Building and Construction (CIB), the American Society for Testing and Materials (ASTM), and the International Union of Testing and Research Laboratories for Materials and Structures (RILEM). A conference was held in Philadelphia in 1972 (12), Lisbon in 1982 (18), and Tel Aviv in 1996 (3). The group of sponsoring organizations was joined by the International Organization for Standardization (ISO) in the Tel Aviv conference. Other helpful publications include those from CIB (5-8), the proceedings of a workshop in Tsukuba, Japan, on performance-based structural design standards (4), and the proceedings of the International Conference on Performance-Based Codes and Fire Safety Design Methods (22).

Most recently, the major research and development activities that are still needed to better implement the concept have been identified (2,11). CIB has developed a Proactive Program on Performance-Based Building.

Paradigm Shift: From Parts to Attributes

If a building is viewed as a matrix of parts and attributes, the main difference between the traditional prescriptive approach and the performance approach can be illustrated as shown in Figure 1 (15). In the prescriptive approach, the building parts are described, specified, and procured, resulting in a building with an implicit set of attributes (Fig. 1a). In the performance approach, the building attributes are described and specified, and many combinations of different building parts can be procured for which it can be demonstrated that the specified attributes will be provided (Fig. 1b).

This focus on attributes enlarges the field of building technology to include whole new areas of research. Since human requirements are the defining parameters for the building attributes, their proper definition are required in the development of performance criteria. This process must include research on human response to the built environment, which covers areas of physiology, psychology, sociology, anthropology, ergonomics, and special populations (such as geriatrics and the disabled) (15). Quantifying these criteria requires the application of uncertainty modeling and probabilistic methods (9-11). This is necessary if multiple performance levels are to be developed. The example of a floor system might help to clarify this. The design of a floor system must certainly insure that the floor will support the required loads. But beyond that, floor deflection and vibration must be considered. Research on human response to floor vibrations can help develop various levels of acceptable vibration, e.g., level 1 might be that 75 percent of humans would find this level of vibration acceptable 90 percent of the time; and level 2 might be that 90 percent of humans would be satisfied 90 percent of the time, etc. Building designers and their clients would then have a choice regarding the floor performance level they wished to accept, considering the combination of the clients’ expectations for comfort and their willingness to pay for that level of comfort. In the performance approach, the building clients or users can choose the balance of performance and cost they are willing to accept.

Performance and Prescription Mix

Most design briefs agreed between building owners/clients and designers are a mixture of prescriptive and performance specifications. The more performance-oriented the specification is, the more freedom the designers have to provide alternative solutions or products (Fig. 2 and Table 1). A lower-level specification is more prescriptive and constraining. But the higher the level of specification in terms of performance, the more

FIGURE 1.
A matrix of parts and attributes: (a) Prescriptive; and (b) Performance approach (from ref. (15)).
difficult it is to find a universally acceptable method for the verification of performance (21).

**Verification**

Verification is an important component of the performance-based approach because it will be necessary to demonstrate that a particular material or building solution will meet a given performance criteria. In most regulatory systems, the company responsible for developing and marketing a new product is also responsible for demonstrating that this product meets the performance requirement for its intended use. Verification can be through 1) actual testing; 2) calculation (e.g., use of a computational procedure or mathematical model to show that the required performance will be achieved); or 3) a combination of testing and calculation. Preparation of supporting data from testing and/or calculation can be done in-house or out-sourced by the company to a third-party testing agency or consulting company. Either way, building officials, who make the final decision whether the product is satisfactory or not, typically require another third-party check or certification that the verification method employed by the company or its consultants is an appropriate method of verification.

### TABLE 1. Sample specification of a door (from ref. (21)).

<table>
<thead>
<tr>
<th>Level</th>
<th>Performance/Prescriptive Mix</th>
<th>Specification Text</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fully prescriptive</td>
<td>Provide Door Cat. No. 123 from Fantastic Door Company</td>
</tr>
<tr>
<td>2</td>
<td>Prescriptive with some performance criteria</td>
<td>Provide timber rectangular door 1800 x 800 x 40 mm with dead lock capable of resisting a horizontal force of 2 kN.</td>
</tr>
<tr>
<td>3</td>
<td>Performance with some prescriptive criteria</td>
<td>Provide lockable 1800 x 800 door capable of resisting intruder with crow bar</td>
</tr>
<tr>
<td>4</td>
<td>As a sub-system with performance and interface requirements</td>
<td>Provide controlled access to fit 1800 x 800 opening in wall with appropriate security measure.</td>
</tr>
<tr>
<td>5</td>
<td>As a sub-system with performance requirements only</td>
<td>Provide controlled access suitable for average Sumo wrestlers with appropriate security measures.</td>
</tr>
<tr>
<td>6</td>
<td>As part of a total system in risk-based performance terms</td>
<td>Provide controlled access for Ali Baba and the 40 thieves that 90% of the occupants will be happy with.</td>
</tr>
</tbody>
</table>

**FIGURE 2.**

Levels of specification with different performance-prescriptive mixes (from ref. (21)).
General Applications

The performance-based approach is applicable to:

• building production (from project initiation to occupancy; see “Process” in Fig. 3);
• building quality control (regulation; see “Product” in Fig. 3).

In the case of building production, the freedom encouraged in preparing the design brief and in the actual design and construction leads to more innovative, economical, and better-performing buildings. In the case of regulation, the performance concept allows innovative and cost-optimized construction while at the same time protecting the safety, health, and general welfare of building inhabitants (14).

Critical to the development, support, and implementation of the performance concept in both building production and building regulation is the availability of building performance models that can be used to 1) develop quantified performance criteria for building codes and standards; 2) design a building or its parts to a target performance; and 3) evaluate or verify the performance of specific buildings (or products) in service. For example, a structural analysis model for a floor system could be used to 1) develop quantified performance criteria regarding acceptable floor deflection and vibration, in conjunction with human response studies; 2) design a new floor system to meet the stated performance criteria; and 3) evaluate the performance of an existing floor system as part of a performance review or audit.

Regulations vs. Standards

To facilitate world trade, internationalization of performance-based standards is needed. This is possible only if a distinction is made between “standards” and “regulations,” and if their relationship is clarified. The importance of this is often overlooked or taken for granted. Some countries have a building regulatory structure that makes it difficult to separate the two, but in most countries a distinction between them can be made.

In this article, a building code or regulation is defined as a document used by a local, state, or national government body to control building practice through a set of statements of “acceptable” minimum requirements. This is typically a legal document. Since the acceptable requirements are usually established based on socio-political and/or community considerations, they naturally differ from country to country or from locality to locality. Building standards, on the other hand, are essentially technical documents that standardize, generally in terms of quality or performance, but sometimes in terms of size or procedure, some activity in relation to building construction (24). They serve as some kind of benchmark. There are different levels and types of building standards (e.g., product, design, workmanship, etc.)
When building regulations cover technical aspects of performance, they typically incorporate or refer to relevant standards. Thus, building regulations are a user of standards. But this is not the sole purpose of standards; they have other uses. For example, in countries that have low levels of regulation, those who contract with a builder for construction of a building might ask the builder to use relevant standards as assurance that the building will perform as needed. The insurance industry is also now beginning to use standards in rating buildings in countries like this for catastrophe insurance (24).

### Basic Regulatry Framework and Contents

Most performance-based regulatory frameworks are variations of what is known as the Nordic Five Level System (8) (Table 2). In this system, Level 1 (GOAL) addresses the essential interests of the community at large with respect to the built environment, and/or the needs of the user-consumer. Level 2 (FUNCTIONAL REQUIREMENT) addresses one specific aspect or required performance of the building to achieve the stated goal (note that other functional requirements may contribute to achieving the same goal).

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<td>2</td>
<td>FUNCTIONAL REQUIREMENT</td>
<td>Building or building element specific requirements. A functional requirement addresses one specific aspect or required performance of the building to achieve the stated goal (note that other functional requirements may contribute to achieving the same goal).</td>
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<td>3</td>
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<td>Actual requirement, in terms of performance criteria or expanded functional description. This is also some times referred to as PERFORMANCE REQUIREMENT.</td>
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<td>4</td>
<td>VERIFICATION</td>
<td>Instructions or guidelines for verification of performance.</td>
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<td>EXAMPLES OF ACCEPTABLE SOLUTIONS</td>
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**TABLE 2. The Nordic Five Level System.**

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**FIGURE 4.**

General four-level regulatory framework (from ref. (11)).

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Performance Matrix and Criteria

A building can be described as a Performance Matrix of parts and attributes; an example is shown in Figure 5. Not shown in the matrix is a third dimension, which is the type or class of building (e.g., residential, commercial, industrial, etc.). Ideally, functional and performance statements, and performance criteria for each cell or group of cells in the Performance Matrix would already be available for all classes of buildings and could be included in the matrix. But current performance-based building codes that are in use in some countries do not contain a complete set of functional and performance requirements. For example, the level of understanding of the "durability" of structural materials in a building is not yet as developed as it is for "structural and fire safety" performance. We should also remember that currently most performance statements are a combination of performance and prescription (e.g., Fig. 2). Thus, the matrix may serve as a guide on what performance statements and criteria still need to be developed to support a more complete performance-based code.

Performance Criteria means a statement of the operative or performance requirement. As stated in an earlier example, the performance criteria for a floor system will include the following: 1) it will have sufficient strength to support the anticipated load in the lifetime of the structure (i.e., structural safety, marked X in Fig. 5); 2) it will not sag or vibrate so much that it annoys or brings discomfort to occupants (i.e., structural serviceability, marked Y in Fig. 5); and 3) other performance statements related to fire safety, acoustics, thermal comfort, etc. The performance statements on structural safety and serviceability are further given in quantified terms in the form of a set of equations. For safety, the bending and shear strength of the floor joists should be larger than the anticipated load, and for serviceability, there could be limits set on the deflection of individual joists or the whole floor system, and on the acceptable vibration of the floor system.

**FIGURE 5.**
An example of a building performance matrix (from ref. (11)).
In the Inter-jurisdictional Regulatory Collaboration Committee (IRCC) Guidelines for the Introduction of Performance-Based Building Regulations (Discussion Paper) (16), two types of performance criteria are identified: technology-based performance criteria and risk-based performance criteria.

Technology-based performance criteria are primarily concerned with the characteristics of a product under well-defined conditions, such as in tests or in design specifications where performance is measured or evaluated in terms of physical parameters. Risk-based criteria, on the other hand, are primarily concerned with the behavior of a product in use, where performance is measured in terms of the reliability of the product to perform as expected. Using the floor system example to illustrate, setting a maximum allowable deflection for a floor system under 1 kN load at the center of the floor or a minimum system frequency for the floor system is a technology-based performance criterion; whereas setting the percentage of people who are satisfied with a particular level of floor vibration is a risk-based performance criterion. Ideally, technology-based criteria should be derived from target risk-based criteria. But this is currently not the case; in housing, all available performance criteria are currently technology-based (21). Much further work is needed to develop the background risk-based criteria needed to underpin technology-based criteria.

**Current Codes and Standards**

In 1994, the model building code organizations in the United States formed a new national organization called the International Code Council (ICC) to develop a single building code for the United States. The ICC Performance Code for Buildings and Facilities is scheduled for publication later this year and will be available for Internet download at www.intlcode.org. A similar effort is underway in Canada, where it is called an objective-based building code; this is scheduled for publication in 2003. The European Commission (EC) has developed the ECE Compendium of Model Provisions for Building Regulations (23) to provide guidance to EC countries that would like to develop performance-based codes.

Several countries have already put in place performance-based building codes, and some are in the process of developing them. Representatives from some of these countries formed the IRCC to 1) discuss practical issues related to performance-based code development, support, and implementation (including the required social, political, and legal issues); and 2) promote international understanding of each other’s regulatory framework and practices. Some of these issues have been discussed and published in two important documents:

- CIB Publication 206: Final Report of CIB Task Group 11 Performance-Based Building Codes (8);

Although ISO does not deal with building codes and regulations but only with technical standards, it is worth mentioning here that there are various ISO standards that deal with the performance of building systems and components. The ISO Technical Sub-Committee TC 59/SC 15 is currently actively developing a set of performance criteria for single-family attached and detached dwellings.

**International Developments**

The three most active professional areas in the development and implementation of performance-based building codes and standards are 1) structural engineering; 2) fire safety engineering; and 3) the building project initiation and construction process.

In structural engineering, the push towards performance-based design is strongly motivated, not by trade, but primarily by the desire of the engineering profession to: 1) couple the performance, expectations, and design requirements more closely than is possible in a prescriptive code; and 2) ensure that natural hazard loads (from wind and earthquake events) are treated consistently and that design conservatism is appropriate to required function (9). The former is driven by expectations by building clients and their insurers that designers can design for different levels of performance based on different levels of damage in the event of a natural disaster. Both clients and their insurers do not want a repeat of the extent and cost of damage caused by the 1994...
Northridge Earthquake in Southern California and other recent natural disasters. It would be helpful to be able to alert the building owners that a certain level of damage might be sustained with a particular design, and then the owners could choose to build to that level, or to a higher level (at increased cost) to sustain less damage. The important thing is that building clients have a choice regarding the balance of performance and cost they are willing to accept.

IRCC, ISO, and CIB are very active in building regulatory issues, development and drafting of technical standards, and technology development, respectively. The CIB Proactive Program on Performance-Based Building covers all aspects of the construction process, from project initiation and construction through the entire life cycle of the building. CSIRO has developed a website supplement to the information regarding the Proactive Program already given in the CIB website (www.cibworld.nl/pages/begin/Pro3.html). The CSIRO website supplement can be found at www.cibprogram.dbce.csiro.au.

Together, the interlinked CIB and CSIRO websites provide all the important information regarding the CIB Proactive Program. The CSIRO website provides detailed information about the three priority tasks that have been selected by the CIB Program Committee:

- Task 1: Development of a compendium of building performance models;
- Task 2: Preparation of a report on economic benefits;
- Task 3: Development of pre-standardization documents.

Task 1 is the number one priority. The final product will be a hardcopy publication and/or CD-Rom for general distribution in early 2002. The compendium outline is shown on the website and a compendium survey form is available for downloading as an MSWord file. An on-line survey form is also available.

In addition to the website, there is also an FTP site (ftp.mel.dbce.csiro.au) and an e-mail discussion list (perf-based-stds@its.csiro.au) dedicated to the CIB Proactive Program.

### Issues and Challenges

The future of building codes and standards points toward a performance-based approach, which frees the building regulatory system from the limitations of the current prescriptive approach. Performance-based codes and standards are useful for:

- promoting innovation;
- cost-optimizing construction;
- facilitating international trade.

The performance approach provides a communications interface between building professionals and the public (10). The building clients or owners have the option to choose the balance of performance and cost they are willing to accept. Because meeting user needs and requirements are paramount in the performance approach, this will result in more satisfied building occupants and owners.

Practical developments on this topic will likely drive process, product, and marketing changes in parts of the forest products industry that have a stake in the building and construction industry. This was repeatedly mentioned in a 1998 research needs workshop on wood engineering in the 21st century (13).

Various countries currently have different stages of development, and different degrees of adoption and implementation of the performance concept in building procurement, design, construction, and evaluation. Countries or localities that have been using performance-based codes cite many benefits derived from their use. But before different stakeholders in the industry can enjoy the full benefits of the performance approach in building design and construction, much research and development work still needs to be done (2,11,16).

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**Literature Cited**


