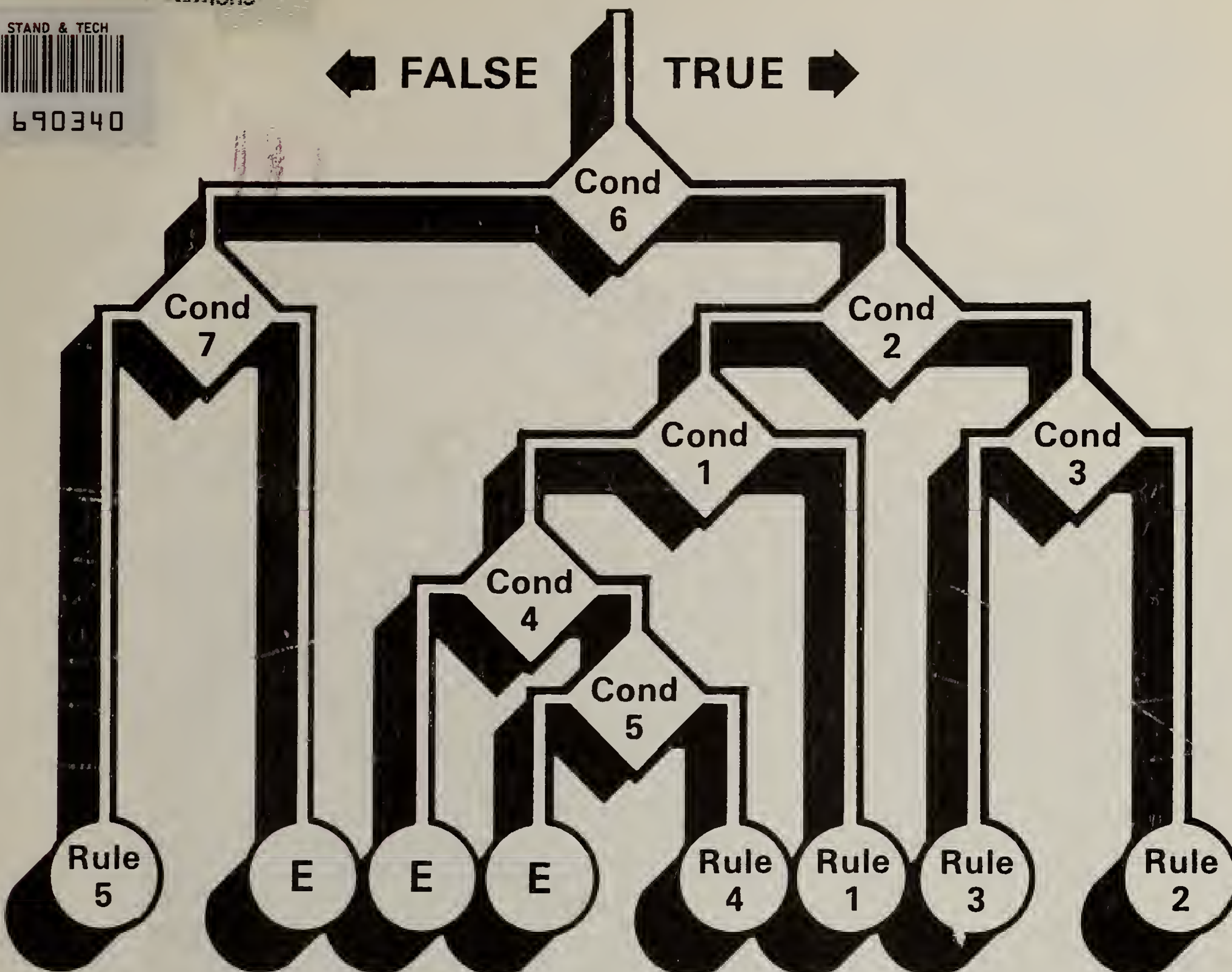

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Modeling of Standards

Technical Aids for Their Formulation, Expression, and Use

Center for Building Technology
National Engineering Laboratory
Washington, DC 20234

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MODELING OF STANDARDS

Technical Aids for Their Formulation, Expression and Use

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ABSTRACT

Standards are the primary communication and control mechanism used to describe building practices and products in communications between the various participants in the building process. Most prior research related to building standards has been concerned with understanding and improving the performance of building products. This work, in contrast, is concerned with improving the organization, expression and interpretation of the information contained in a standard. Techniques are described for objective and rigorous representation of the meaning of a standard. These allow it to be tested for aspects of clarity, completeness, consistency and correctness. Furthermore, the techniques allow alternative organizations and expressions to fit the needs of various users with assurance that meanings remain unchanged and that users will readily find and understand all provisions even in a new or unfamiliar standard.

Keywords: Building standards; classification; decision tables; information networks; modeling; standards; standards-writers; system analysis.

1. INTRODUCTION

We use the term "standard" to include all types of formal documents used to define the qualities of buildings, building products, materials, or building processes. The term includes legal building regulations, standards such as those of the International Standards Organization, or proprietary specifications such as those describing proper installation of a window. Standards are used for communication between buyer and seller and for protection of public health, safety and welfare.

A standard usually is drafted by a small group of experts (hereafter called "experts") who:

- define the scope, including the products or processes to be covered and their required performance attributes,

- determine whether to express the standard as a performance standard (attributes in terms of user needs [1]), procedural standard (attributes in terms of specified, rigorous technical evaluation procedures [2]), or prescriptive standard (attributes given as dimensions or properties completely defining the acceptable configuration or procedures)

- formulate the standard and submit it to the organization responsible for promulgation and maintenance.

The process of promulgation and maintenance may be of long duration. Modifications and interpretations may occur without participation of or consultation with the experts who initially drafted the standard.

It is not surprising that problems arise from the process for the formulation and use of standards. Rapidly changing societal demands for building qualities, such as energy conservation, and rapidly developing technologies, such as air quality measurement and electronic computation, lead to many new subjects for building standardization and frequent changes in the standards. As a result users find it difficult to:

- locate all relevant provisions in a standard, and

- understand and correctly apply the provisions they select.

The process of standards development is expensive in itself because much time and effort are required from leading experts in the subject area and from those whose interests are affected. Most of this time and effort goes to mutually understanding issues and resolving them. Even greater expenses associated with the present process of standards development come from the continued use of obsolescent standards and from failures and waste associated with the use of standards that are technically incorrect or are misunderstood. Computer-aided design practices potentially exacerbate these problems. It is expensive to develop the programs for applying a new or revised standard in computer-aided design.

Errors due to misunderstandings of standards may lead to many errors in application as the programs are used. Furthermore, the great time and expense associated with updating programs to incorporate revisions in standards act as an impediment to the application of improved technologies that can increase the economy, safety, or usefulness of buildings.

Standards often fail to make the intended performance attributes (such as safety, functionality, or durability) or pertinent mechanisms of failure (such as fracture or corrosion) explicit for each provision. This lack of clarity makes it difficult to assess the benefits and costs associated with a standard and therefore difficult to improve it through research.

2. QUALITIES OF A STANDARD

The qualities of the organization and expression required for a standard can be expressed at three levels:

1. Individual provisions need to be: Clear - the provision yields the one and only result in any possible application, Complete - the provision applies explicitly in any possible situation, Correct - the result of applying the provision is consistent with the objective of the standard.

2. Relations between provisions should make them: Connected - explicit cross references show the data required to use each provision and the use stipulated for the data produced by each provision, Acyclic - the data produced by evaluation of a provision need not be known prior to its evaluation (no loops in logic), Consistent - uniform logical and technical bases are provided for comparable provisions.

3. The organization of the standard should be: Complete - explicit scope so a user knows what subjects and qualities are covered by the standard, Clear - the arrangement and display of provisions is such that the user readily finds all provisions pertinent to his query.

The following sections illustrate how the model for standards provides a systematic means for providing these qualities in processes of formulation and expression for a standard.

3. MODELING OF PROVISIONS

A provision is defined here as a statement stipulating that a product or process shall have or be assigned some quality. A number of forms and types of provisions fit this definition:

- a performance requirement, e.g., "the system shall maintain an adequate supply of hot water,"

° a performance criterion, e.g., "hot water temperature shall be controlled between 40°C and 50°C,"

° a prescriptive criterion, e.g., "the hot water tank shall have a capacity of 150 liters,"

° a determination or function, e.g., "the flow q = av."

For purposes of modeling provisions it is necessary to stipulate that a provision should have a single subject and require or assign a single quality.

In the model a datum is considered to be associated with each provision. For requirements or criteria the value of the datum can be either satisfied or violated, for a determination or function the value can be numerical or a term such as "red" for color.

Recent work [3, 4] provides guidance on expressing provisions, such as using the active voice and making explicit the performance attribute to which the provision pertains in order to promote clarity, consistency and correctness.

Often the logic of a provision is too complex to express in a simple declarative sentence. Then a decision table is used to model the provision. Consider the following provision, from an early draft of tentative seismic provisions [5], that assigns a value to a datum Soil Profile Type (SPT):

> Site effects on building response shall be established based on three profile factors defined as follows:
>
> SOIL PROFILE TYPE A is a profile with:
>
> 1. Rock of any characteristic, either shalelike or crystalline in nature. Such material may be characterized by a shear wave velocity greater than 2,500 feet per second, or
>
> 2. Stiff soil conditions where the soil depth is less than 200 feet and the soil types overlying rock are stable deposits of sands, gravels, or stiff clays.
>
> SOIL PROFILE TYPE B is a profile with deep cohesionless or stiff clay conditions including sites where the soil depth exceeds 200 feet and the soil types overlying rock are stable deposits of sands, gravels, or stiff clays.
>
> SOIL PROFILE TYPE C is a profile with soft-to medium-stiff clays and sands, characterized by 30 feet or more of soft- to medium-stiff clay with or without intervening layers of sand or other cohesionless soils.

In locations where the soil type is not known in sufficient detail to determine the soil profile type and where foundations are supported without the use of piles, Soil Profile B or C shall be used whichever produces the larger base shear.

Table 1 shows the decision table representation of the provision. The four parts of the decision table are separated by the rows and columns of asterisks. The condition stub in the upper left gives the logical conditions that pertain to the provision, for instance "1. Soil Type = Rock". The condition entry in the upper right is a set of rules. Each column contains one combination of values for conditions that define a rule, for instance rule 1 pertains when condition 1 is true (T), conditions 2, 4, and 5 are implicitly false (-) because of condition 1, conditions 3 and 6 similarly are implicitly true (+) and condition 7 is immaterial (•).

Table 1. Decision Table for Soil Profile Type (SPT)

Conditions		Rules					
		1	2	3	4	5	E
1. Soil type = Rock	*	T	-	-	-	•	
2. Soil type = Stiff	*	-	T	T	-	•	
3. Soil depth < 200 ft.	*	+	T	F	•	•	
4. Soil type = Soft Clay	*	-	-	-	T	•	
5. Depth of Clay > 30 ft.	*	-	•	•	T	•	
6. Soil type known	*	+	+	+	+	F	
7. Piles support foundation	*	•	•	•	•	F	

****

Action Stub		Action Entry					
1. SPT = A	*	X	X				
2. SPT = B	*			X			
3. SPT = C	*				X		
4. SPT = B or C	*					X	
5. Else Rule	*						X

The action stub in the lower left describes all possible values the provision can take and the action entry in the lower right shows by X which one value pertains to each rule. Note that a rule designated E for else corresponds to all combinations of conditions entries that are not explicitly included in preceding rules.

The clarity and completeness of the provision is analyzed by generating a decision tree corresponding to the decision table, as shown in Figure 1. For clarity we note that no terminal node fits more than one rule. If the latter were to occur there would be either redundancy (two or more rules that match the same set of condition entries and have

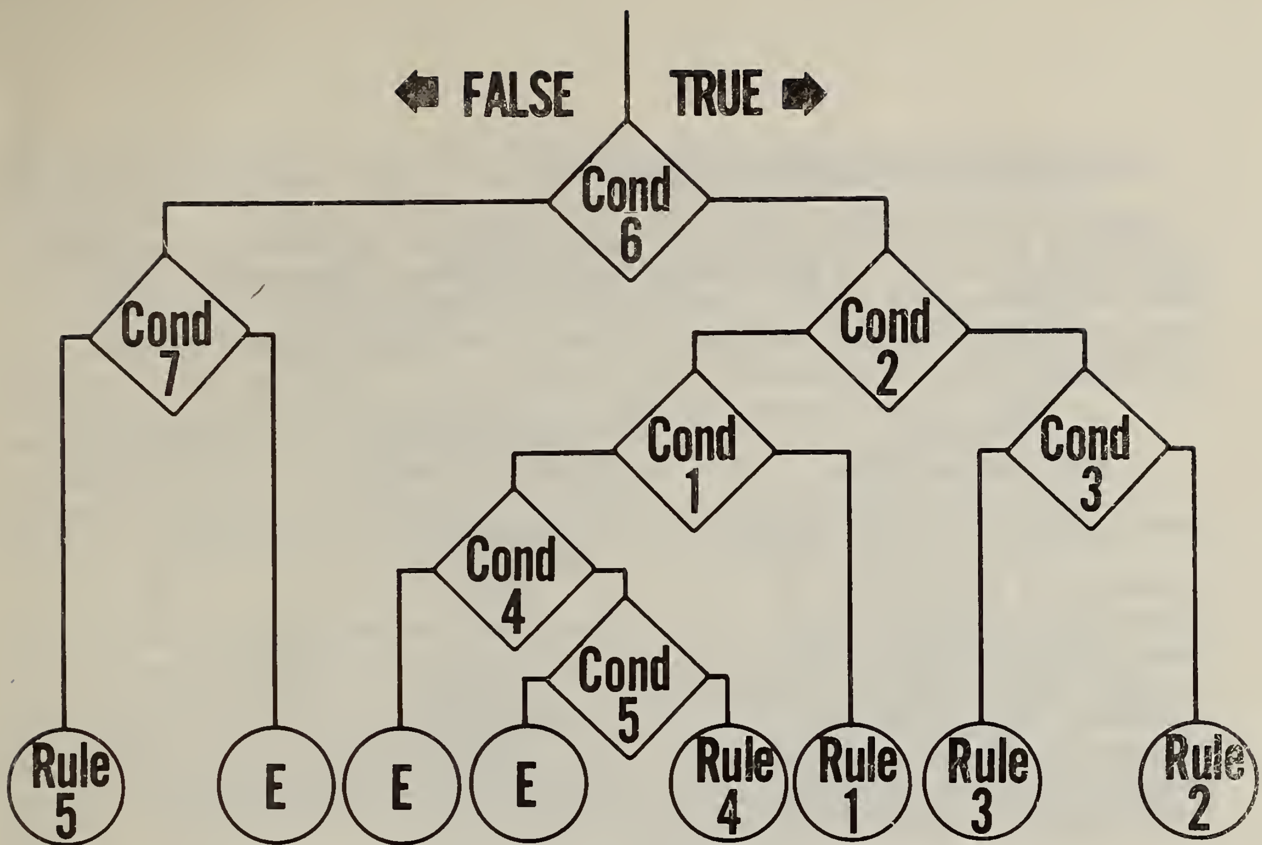

Figure 1. Decision Table for Soil Profile Type (SPT)

the same action value) or contradiction (two or more rules that match the same set of condition entries but have different action values). For completeness we trace each set of condition entries leading to an E (else) node in the terminal row to see that no possible set of conditions lacks an explicit action value. Here we see problems in the example provision:

- What soil profile type applies when condition 6 is false (F) and 7 is true?

- What soil profile type applies when condition 6 is true and conditions 1, 2, and 4 are false?

- What soil profile type applies when conditions 6 and 4 are true and conditions 1, 2, and 5 are false?

These problems were noted for the drafters of the provisions, and they responded by accounting for them [5].

Principles for forming decision tables and trees are given in texts such as [6], the techniques used by the writers are described in [7] and a result for the revised example provision is given in [8].

Correctness must be judged by the technical experts developing the standard. We have found, and this example illustrates, that the model of the provision with its clear presentation of the logic helps experts in expressing correctly their intent.

4. MODELING RELATIONS BETWEEN PROVISIONS

A standard consists of a system of interrelated provisions. An information network is used to model these interrelations. Each node of the network represents a datum. Consider the following excerpt of a provision, from Ref [5], that assigns a value to the Response Modification Coefficient (R).

Type of Structural System	Vertical Seismic Resisting System	Coefficient R
Moment Resisting Frame System:	Special Moment Frames	
A structural system with an essentially complete Space Frame providing support for vertical loads. Seismic force resistance is provided by Ordinary or Special Moment Frames capable of resisting the total prescribed forces.	Steel	8
	Reinforced Concrete	7
	Ordinary Moment Frames	
	Steel	4 1/2
	Reinforced Concrete	2

To evaluate the response modification coefficient (the datum R) one must first know the ingredient datums: the type of structural system (GFC), vertical seismic resisting system (SRS), ordinary or special moment frame (FRT), frame material (FM) and ordinary or special moment frames capable of resisting total prescribed forces (FRTF). These datums are shown as nodes of the information network in Figure 2. The arrows on the branches connecting the ingredient nodes with their dependents (R for GFC, SRS, FRT, FM and FRTF) show the precedence relations between these datums.

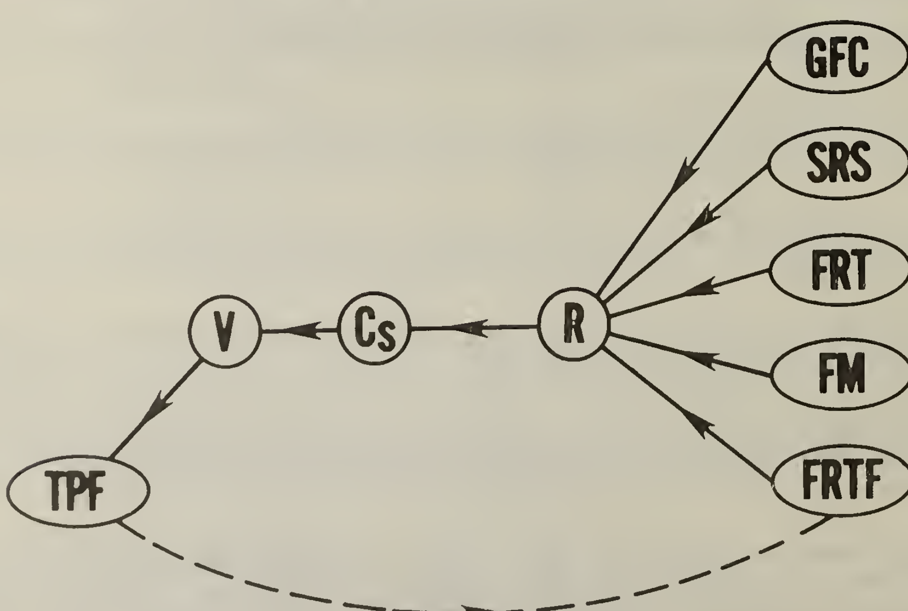

Figure 2. Partial Information Network

The information network is extended as further relations between provisions are considered. Thus R is an ingredient to the seismic design coefficient (C_s) which is ingredient to the seismic shear force (V) that in turn is ingredient to the total prescribed force (TPF). This extention of the network has been simplified for clarity.

Here we see a problem revealed by the information network. Because the wording of the provision for R contains the requirement "Seismic force resistance is provided by ordinary or special moment frames capable resisting the total prescribed force," TPF may be interpreted as an ingredient to R. With this interpretation a loop exists because R is in its own ingredient subnetwork. In this instance the loop seems easy to break by removing the requirement from the provision for R. It still can be applied in the standard but need not be an ingredient of R.

The information network defines explicitly all cross references in a standard so that the user readily can identify the flow of information. The information network is useful to determine whether appropriate cross references are provided or if some provisions seem to be unused - unconnected with the main element. The information network will help to test for consistency. It shows where the various datums are used, those uses can be compared for appropriate uniformity in technical and logical bases.

The information network provides information useful in ordering the text of a standard. Text must express the logic of the multiply connected network in a linear format that is easy and convenient to use. Different types of use are facilitated by different forms of expression. These can be related systematically to the information network and decision tables as described in Ref [2].

The precedence relations recorded by the information network are essential for programming for computer use in design calculations. Logical methods based on the information network [9] avoid use of incorrect data and minimize computational efforts for new data as design variables are changed.

5. ORGANIZATION OF A STANDARD

In concept organization includes both the scope and arrangement of a standard [4]. Scope is defined as the products or processes and the set of their required qualities to which the standard pertains. A clear statement of scope tells a user what he can expect to find in the standard.

Arrangement deals with the means of access to locate pertinent provisions. Potential means of access are:

1. The table of contents
2. The index
3. Headings within the text

4. Proximity of related provisions in the text
5. Cross references expressed in the text.

The model for organization of a standard given here deals explicitly with techniques of arrangement for means of access 1-4. The model of relations between provisions, the information network, gives techniques useful for means of access 1, 4 and 5.

The arrangement of a standard is expressed most visibly by the headings in the table of contents, their ordering, and their hierarchy of chapters, sections, subsections, etc. Objectives for the relations of the headings to one another and to the provisions are expressed as follows [4]:

1. Relevant: each heading must be significantly related to its provisions; it must concisely express their scope.

2. Meaningful: the intended user must perceive the heading as relevant.

3. Unique: the headings must be distinct from one another to allow readers to access provisions unambiguously.

4. Complete: the total set of headings must cover the whole scope of the standard and nothing more.

5. Graded: the headings must show progressively narrower scope from chapter to section to subsection, etc.

6. Progressive: the headings at any level, such as chapter titles, should be ordered in a pattern meaningful to the user.

7. Intelligible: the depth (number of levels of subdivision) and breadth (number of headings at one level) should not exceed the average span of immediate memory for the ordinary reader (about seven) [10].

8. Minimal: the headings should be permuted so that the total number of headings is minimized.

9. Even: the depth and breadth should not vary greatly from one part of the standard to another.

The first five objectives must be satisfied to provide the qualities stated in section 2.

For an example of a heading that does not meet these objectives consider the following provision headed "1.4.2 SEISMIC HAZARD EXPOSURE GROUPS" [5].

All buildings shall be assigned to one of the following Seismic Hazard Exposure Groups for the purposes of these provisions:

(A) Group III. Seismic Hazard Exposure Group III shall be buildings having essential facilities which are necessary for post-earthquake recovery. Essential facilities, and designated systems contained therein shall have the capacity to function during and immediately after an earthquake. Essential facilities are those which have been so designated by the Cognizant Jurisdiction."

The sentence underlined (our emphasis) is a fundamental performance requirement for essential facilities. It is easy to overlook beneath a heading that is not relevant to the requirement.

The model for organization of a standard can be illustrated briefly as it is applied for performance requirements. The initial definition of scope is accomplished by establishing a classification for the the subjects and predicates of the requirements. For the structural part of a performance standard for residential buildings [11] the trees of classifiers are shown in Figure 3.

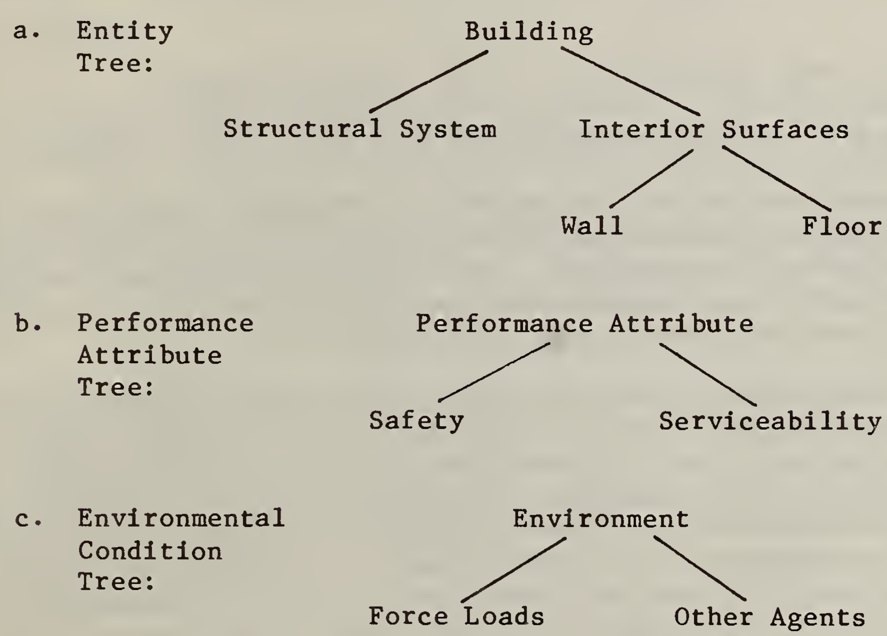

Figure 3. Trees of Classifiers

The trees follow the logical criteria for classification of being exhaustive (over the desired scope) and mutually exclusive.

An outline is developed by systematically combining [4] the trees of classifiers as shown in Figure 4.

```
Building                              Building
   Structural System                     Structural System
      Safety                                Safety
        Force Loads     R1                    Force Loads   R1
        Other Agents   R2                    Other Agents  R2
      Serviceability                        Serviceability
        Force Loads    R3                    Force Loads   R3
        Other Agents   R4                    Other Agents  R4
   Interior Surfaces                     Interior Surfaces
      Safety                                Walls         R5
        Force Loads                         Floors        R6
            Wall
            Floor
        Other Agents
            Wall
            Floor
      Serviceability
        Force Loads
            Wall       R5
            Floor      R6
        Other Agents
            Wall
            Floor

(a)  Full Permutation               (b)  Selected Outline
```

Figure 4. Example Organization of a Performance Standard

The standard writers decided to establish performance requirements only for the headings labeled with an "R" in figure 4(a) so the outline is condensed as shown in figure 4(b). This example illustrates "top down" organization useful when standards writers are beginning ab initio to define the scope and provisions of a standard.

The model for organization also can be applied to the reorganization of existing provisions, a "bottom up" approach. Again trees of classifiers are developed as in figure 3. Each provision is then assigned the uniquely most pertinent classifier from each tree that is relevant and is used for the organization. The classifiers assigned to a provision are called its arguments. The outline again is generated by systematically combining the trees of classifiers in an order meaningful for the intended user. A provision is entered when its arguments and no other, irrelevent classifiers are in the chain of headings.

The index is one other important means of access. It is developed by listing all classifiers in alphabetical order and listing for each classifier all provisions that use it as an argument. An extensive study of the model for organization is nearing completion [12].

6. USES OF THE MODEL FOR STANDARDS

The model for standards provides a rational and systematic approach to achieving standards that are clear, complete and consistent. The model deals with individual provisions, precedence relations between provisions, and their organization for ease in use. The substance of the standard is described in a manner independent of arrangement so alternative arrangements can be used for different purposes without any change in meaning.

The model for standards defines the meaning of a provision in an unequivocal manner, as with table 1, but it does not verify the correctness of the meaning. That is the role of the standards writers, the experts.

As described in Ref [8], analysis and synthesis ideally are conducted in team activities of analysts and standards writers. We anticipate that standards writers soon will become skilled in using the models and specialized analysts will not be needed.

Computer aids implementing the model for standards have been used in studies for References [7, 8]. Work is underway to develop an improved computational resource [13, 14].

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The writers had the opportunity to test the model for standards [8] in a major study conducted in parallel with the formulation of tentative seismic provisions [5]. It has been convenient here to illustrate several points with examples from it. This is not intended to suggest that it has an unusually large number of defects in its qualities of organization and expression. On the contrary, we believe it to be unusually well done.

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☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

Standards are the primary communication and control mechanism used to describe building practices and products in communications between the various participants in the building process. Most prior research related to building standards has been concerned with understanding and improving the performance of building products. This work, in contrast, is concerned with improving the organization, expression and interpretation of the information contained in a standard. Techniques are described for objective and rigorous representation of the meaning of a standard. These allow it to be tested for aspects of clarity, completeness, consistency and correctness. Furthermore, the techniques allow alternative organizations and expressions to fit the needs of various users with assurance that meanings remain unchanged and that users will readily find and understand all provisions even in a new or unfamiliar standard.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Building standards; classification; decision tables; information networks; modeling; standards; standards-writers; systems analysis

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