147 TOWARDS PREDICTION OF BUILDING SERVICE LIFE: THE STANDARDS IMPERATIVE

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Abstract
Twenty years ago, predicting the service lives of building materials and components was only a distant vision. Today, the possibility of incorporating predictions of service lives of materials and components into the design process for whole buildings is being given serious attention. The change in perspective is due to the sustained efforts of a small group of researchers and to developments in computerized knowledge systems and advances in building materials science. This paper reviews progress and suggests directions for further development. It emphasizes that standardization will be critical to acceptance of service life predictions in the building design process. The authors challenge researchers who want their work to have the greatest practical impact to participate in the standards-development process and help fashion the body of standards needed.
Keywords: Building materials, computer-integrated knowledge systems, design life, performance concept, reliability-based standards, service life prediction, standardization, standards.

1 Introduction

It has long been apparent that standards for service life prediction are needed to support application of the performance approach --"an organized procedure within which it is possible to state the desired attributes of a material, component, or system *in order to satisfy the requirements of the user without regard to the specific means* employed in achieving the results" [1]. Standards, including practices and guidelines, for predicting service life would support the performance approach by facilitating

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evaluation of long-term performance ("durability performance") of both new and traditional materials and components in their intended service environments. Significant progress towards the goal of standardized service life prediction has been made over the last 20 years through our efforts in the United States [2], and those of researchers in other countries, particularly Canada, Finland, Japan, Singapore, Sweden, and the United Kingdom.

This paper presents the authors' views on the role of standards in gaining acceptance of service life prediction as an explicit part of the building design process. We summarize progress and comment on the range of standards needed. Essential points are:

1. While designers have an appreciation of factors affecting service life, they usually lack reliable information on the expected lives, in a building's expected service environment, of candidate materials or components, whether traditional or innovative.
2. Advances in materials science, and computing and other aspects of information technology, are making feasible service life predictions for materials, components, and whole buildings.
3. If service life predictions are to achieve general acceptance by the building community, it is imperative that the service life prediction methodology be standardized, whether as practices or guidelines.
4. While the principles of service life prediction can be presented in a single, generic standard, many related standards will be required to facilitate application of the principles.
5. Because service life predictions should have a sound scientific basis if reliable extrapolations to long lifetimes are to be made from short-term observations, service life prediction standards must be qualitatively different from the typical empirical durability standard -- emphasis on scientific understanding and assessment of reliability makes it essential that the standards should be prepared and applied by, or in consultation with, materials specialists.
6. Advances in experimental approaches to service life prediction and in computer-integrated knowledge systems which can provide ready access to available knowledge will both be needed to make service life predictions cost-effective.
7. Since manufacturers of building products are in the best position to provide service life information on their own products, they should be provided with guidelines on the information needed and its preferred format.

In the United States, an incentive to develop reliable predictions of service lives of uildings is provided by three of the seven recently-established national construction oals [3]. The three are: Goal 2, 50% reduction in operation, maintenance and nergy costs; Goal 5, 50% less waste and pollution; and Goal 6, 50% more durability nd flexibility.

To provide perspective on progress towards the service life prediction goal, a ıronological list of some actions and activities that have helped lay the foundation ›r service life prediction standards is given in Table 1.

Table 1. Some activities contributing to advances in service life prediction of building materials, components, and whole buildings -- a chronology

1974	ASTM E06.22, Durability Performance of Building Constructions, formed
1978	ASTM E-632, Standard Practice for Developing Accelerated Tests to Aid Prediction of Service Life of Building Components and Materials, issued
1978	1st DBMC held in Ottawa, Canada
1981	2nd DBMC held in Gaithersburg, U.S.A.
1982	RILEM 31-PCM, Performance Criteria for Building Materials, formed
1982	CIB W80/RILEM Joint Committee, Service Life Prediction of Building Materials and Components, formed; (W80/71-PSL, 1982-86; W80/100-TSL, 1987-89; W80/140-TSL, 1990-96)
1984	3rd DBMC held in Espoo, Finland
1984	NATO Advanced Research Workshop, Problems in Service Life Prediction, held in Paris, France
1987	4th DBMC held in Singapore
1989	RILEM Technical Recommendation, Systematic Methodology for Service Life Prediction of Building Materials and Components, issued
1990	5th DBMC, Brighton, U.K.
1992	BS 7543:1992, Guide to Durability of Buildings and Building Elements, Products, and Components, issued
1993	AIJ Principal Guide for Service Life Planning of Buildings (English edition) issued
1993	ISO TC59/SC3/WG9, Design Life of Buildings, formed
1993	6th DBMC held in Omiya City, Japan
1994	CSA S478-1994, Guideline on Durability in Buildings, issued
1996	7th DBMC held in Stockholm, Sweden

2 The challenge of developing service life standards

Standard tests of building materials have usually been used as indicators of one or more of product quality, uniformity, initial properties, changes in properties with time under prescribed laboratory conditions, and arbitrary measures of "durability." It is only relatively recently [2] that standard methods for service life prediction have started to be developed within the building community. The main approaches that can be used for service life prediction are individual or collective judgment based on one or more of the following, with recognition that an appropriate margin of safety must be provided:

1. Observed performance of similar materials
2. Deterministic extrapolation from results of short-term laboratory tests
3. Information provided by product manufacturers
4. A reliability-based experimental program
5. Simulated performance ("virtual" performance)

These approaches recognize that the typical standard durability test cannot provide useful service life information because: a) it was developed as a screening test and employs a single arbitrary set of severe conditions intended to cause the same mode of failure as that expected in service, and b) the relationship between the laboratory exposure conditions and the expected service conditions is not known. What is really needed is an approach that yields information about the individual and combined effects on service life of differences in material, processing, design, exposure, and application variables. In contrast to the typical durability test, service life prediction requires definition of one or more failure criteria, characterization of the service conditions, determination of the rates of degradative reactions in many specimens under conditions which can be related to those expected in service, and calculation of the times to failure and their distribution. Because a reliability approach is clearly preferred [4, 5], service life prediction tends to be data-intensive both in the amount of data that should be collected and that which should be available in databases.

A typical standard durability test can usually be performed by a technician with little supervision, whereas service life prediction requires experiments planned, supervised, and analyzed by a materials specialist. As a result, a service life prediction standard is different from a typical durability standard. Whereas an often-quoted rule for standards development is "Keep it simple!", for service life prediction standards, the rule would have to be modified to "Keep it as simple as possible!"

Because the development of standards for service life prediction requires a departure from the "Keep-it-simple" philosophy, it is imperative that those interested in development of service life prediction standards work to broaden the standards culture. The triennial series of International Conferences on Durability of Building Materials and Components (DBMC), which began in 1978 [6], is helping bring about the needed cultural change, as are international prestandardization committees such as the joint CIB W80/RILEM 140-TSL Committee, Service Life Prediction of Building Materials and Components, and the RILEM 130-CSL Committee, Calculation Methods for Service Life Design of Concrete Structures.

The problems of service life prediction tend to increase in difficulty with the number of materials in a building component, largely because of the increased number of interfaces between dissimilar materials; the difficulties increase even more with systems consisting of many components. As we consider the development of standards for predicting service lives of systems of increasing complexity, up to whole buildings, we must continually ask such questions as:

1. What standards are needed?
2. Would the benefits from development of the standards justify the development effort?
3. Can the resources needed to develop the standards and bring them into use be obtained?

3 The scope of the standardization problem for service life prediction

The present authors assume the answers to Questions 2 and 3 in the preceding paragraph are affirmative. In regard to the question about standards needed, topics of obvious importance which should be addressed in the standards are:

1. Determination of mechanical and environmental loads (in laboratory tests and in service, real and simulated) to which materials or components are likely to be subjected,
2. Characterization (macro, micro, and surface) of materials and components,
3. Identification of degradation mechanisms of materials and components,
4. Determination of degradation kinetics of materials and components (in different environments and at different locations in the specimen, taking size effects, surface effects, and effects of flaws into account),
5. Identification and expression of performance requirements and performance criteria for materials and components, and
6. Organization and representation of computerized knowledge of materials and components.

Relationships among the needed standards are discussed in the following sections.

If the standards are to be developed expeditiously, scientists and engineers developing the basic knowledge must take the initiative, because they are most likely to see the possibilities and have the needed perspective. It is apparent that the need for a sound technical basis for standards for service life prediction will require advances to be made in some fundamental aspects of applied science -- for example, development of methods for modelling microstructures and degradation processes of random porous materials such as concrete [7] and organic-matrix composite materials such as paints and coatings [8]. In spite of this, many building materials researchers fail to see the intellectual challenge of standards development and the importance of standards to society.

In general, there is a high level of interdependence among building material standards. As an example, Mathey and Clifton [9] showed that the U.S. Navy Guide Specification for Cast-in-Place Concrete (Minor Construction), NFGS-03302, referenced 31 standards, while the 31, in their turn, referenced over 100 standards. Since a relatively simple standard depended on so many other standards, it might be expected that a standard for service life prediction would depend on at least as many.

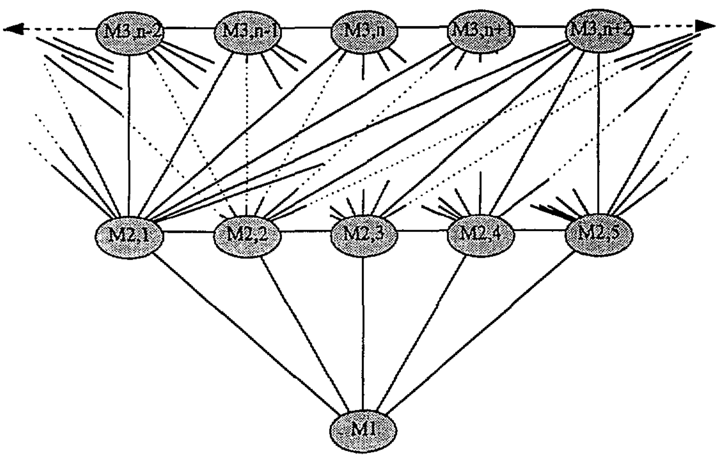
4 Standards for prediction of service lives of materials and components

In 1978, a procedure to be followed in predicting the service life of a building material or component was described in the generic standard, ASTM E-632, Standard Practice for Developing Accelerated Tests to Aid Prediction of Service Life of Building Components and Materials [10]. Similar concepts were subsequently presented in the RILEM Technical Recommendation, Systematic Methodology for Service Life Prediction of Building Materials and Components [11]. These two documents may be considered "Level 1" service life prediction standards -- standards which define the principles with which other standards on the same subject should be logically consistent.

Although not stated explicitly, the Level 1 service life prediction standards imply a need for a hierarchy of at least three levels of standards for prediction of service life. Such an hierarchy, outlined at the 5DBMC [12], is depicted in Figure 1. The figure suggests the complexity of inter-relationships among the needed service life standards. While the present authors know of no existing Level 2 and Level 3 standards for service life prediction, a set of Level 2 standards is being developed in pre-standard form by the joint CIB/RILEM committee, W80/140-TSL. Also, in ASTM Committee G03, Durability of Non-Metallic Materials, Subcommittee G03.08, Service Life Prediction, is developing a Level 3 standard for prediction of the service lives of organic coatings, based on the reliability concepts described by Martin, Saunders, Floyd, and Wineburg [5], and the report, "Design of Durable Concrete Structures" [13], recently published by RILEM Committee 130-CSL, provides the basis for a Level 3 standard for concrete structures. The RILEM 130-CSL report discusses

Fig. 1. Suggested hierarchy of standards for prediction of service life of building materials and components showing interrelationships among levels.

M1 is a generic standard describing a methodology for predicting the service life of a building material or component (Level 1)
M2,x are a small number of generic standards consistent with M1 and which provide guidance on specific aspects of M1 (Level 2)
M3,n is an open-ended, group of material- and component-specific standards, each consistent with the M2 standards (Level 3).



three approaches to prediction of service life of concrete -- deterministic, stochastic, and lifetime safety factor. The stochastic and lifetime safety factor approaches, both of which emphasise reliability, are preferred.

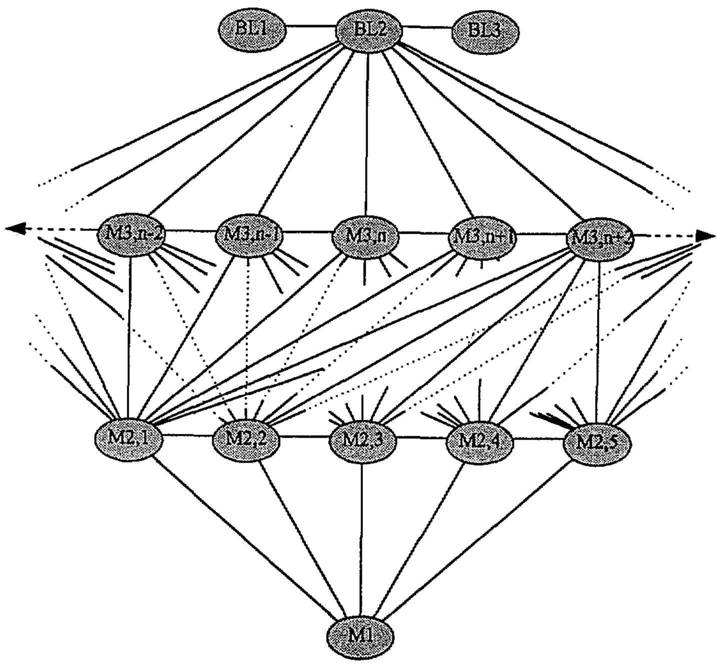
In some cases, it should be possible to simulate a material and an environment to determine the time-to-failure of the simulated material in the simulated environment. This might be described as determination of the virtual performance of a virtual material in a virtual environment. Its achievement would provide a tool for selecting or designing materials for specific applications. The concept of virtual cement and concrete was put forward in a recent paper [14]. It probably represents a type of approach that a designer could adopt in the future when designing for durability, or a building owner could use in confirming that the design life of a building is realistic.

5 Standards for prediction of service lives of buildings

Just as the service life of a building material or component can, at least in principle, be predicted if enough information is available, so, with enough information, it should be possible to predict the life of a complete building. from the predicted service lives of the materials and components within it. This is indicated in Figure 2 which shows

Fig. 2. Suggested hierarchy of standards for prediction of the service life of a building

M1, M2,x and M3,n are as in Fig. 1; the BL are a small group of standards to provide guidance on how the M standards in Level 3 should be used in predicting the service life of a building.



how the prediction of the service life of a building should be able tó be predicted from the Level 3 service life prediction standards for materials and components. Guidelines for putting evaluation of the service life of a building on an explicit scientific footing are being drafted by an ISO working group, ISO TC59/SC3/WG9, Design Life of Buildings. The objective of the ISO working group is:

> To develop standards for assuring that the designed life of a building under anticipated environmental actions will be achieved and to provide a basis for maintenance management.

The working group's task will be simplified because of three existing national standards -- British Standard, BS7543:1992, Guide to Durability of Buildings and Building Elements, Products and Components [15]; Architecture Institute of Japan (AIJ) Principal Guide for Service Life Planning of Buildings [16]; and Canadian Standard, S478-1994, Guideline on Durability in Buildings [17]. A critical analysis of the documents is helping to identify features of their different approaches to "design for service life" that should be considered for adoption in the ISO standard.

6 Standardization of knowledge needed for prediction of the service lives of materials, components, and whole buildings

As mentioned previously, prediction of the service life of any material in a building will be information-intensive. At present, it is difficult, if not impossible, to glean the needed information from the scattered sources which are of uncertain quality. A list of possible ways of obtaining the information was given in Section 2, but only the first three have been used until now. The others should grow in importance and practicality as standard, reliability-based approaches to life prediction come into use in building technology. There will then be an incentive to build the extensive base of reliable information needed to make confident predictions of service life.

At this point, it will be useful to consider standards relating to the organization of knowledge needed to facilitate predictions of the service lives of buildings. Numerical data are only one of several types of knowledge that will be needed. Others are knowledge contained in simulation models and knowledge-based expert systems. If designers and regulatory officials are to have confidence in service life predictions, it is to be expected that predictions will have to be made using standardized knowledge in standardized ways. Therefore, the authors foresee that, among the needed standards, those for computerization of knowledge will be of comparable importance to that of the knowledge itself. The standards that can be foreseen will be used to integrate the fragmented knowledge already available and new knowledge as it is generated. An impression of the current state of knowledge of building materials and components in relation to the building cycle is sketched in Figure 3, and a vision of the state of knowledge as it might be in, say, the Year 2010 is sketched in Figure 4. Radial arrows represent flows of knowledge, with an outward-pointing arrow representing knowledge being drawn on to support decisions in the indicated stage of the building cycle. Today, we rely on separate forms of knowledge that can only be integrated with difficulty while, in the future, a computer-integrated knowledge system will provide rapid access to many forms of knowledge. New types of standards will be needed to facilitate development of computer-integrated knowledge systems such as have been conceived of for concrete [18], and construction in general [19]. Examples of the needs are standards for:

1. Data dictionaries
2. Classification of building products and components
3. Formats for computerization of data and other forms of knowledge
4. Data quality information
5. Product service life data
6. Maintenance information
7. Life-cycle costing calculations
8. Computer-integrated knowledge systems

While the principles to be applied in predicting the service life of any material or component in any environment are known in general terms, the data are seldom available in a useful form. Similarly, few of the models needed for simulating environments and materials, and simulating interactions between environments and materials are available. The needed databases and models are beginning to be

Fig. 3. The building cycle and the current state of knowledge of performance of building materials and components -- forms of knowledge not integrated.

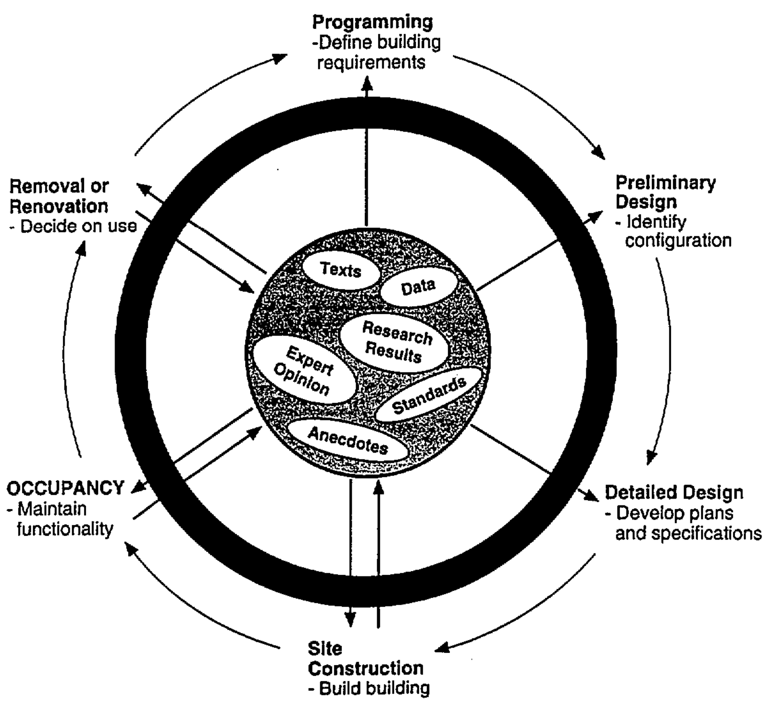
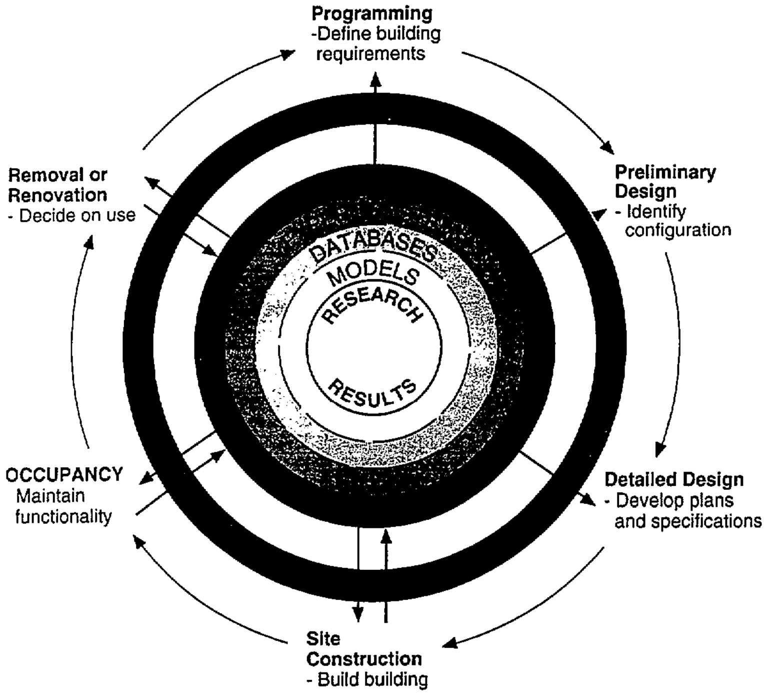


Fig. 4. The building cycle and computer-integrated knowledge of performance of building materials and components as it may be early in the 21st century.



developed and the rate of development should increase as the standards structure is put into place. At the same time, it is likely that easy-to-use knowledge-based expert systems will be developed to aid the making of decisions. The potential of expert systems as decision aids is apparent from the interest in HWYCON [20], an expert system developed for use in diagnosing causes of, and remedying, distress in HighWaY CONcrete. As the number and depth of the databases and models grows, so too will computer-integrated knowledge systems consisting of linked databases, models, expert systems, and other computerized tools. These developments will make possible reliability-based service life predictions of materials and whole buildings as the quality of the predictions increases.

Standards of types listed earlier in this section will be needed to support the integrated knowledge systems that may be expected to develop. For the most part, these will be standards of new types.

7 Summary and conclusions

In this paper, the challenge of developing standards for predicting the service lives of building materials, components, and whole buildings has been described and progress in developing the needed standards has been reviewed. The need for many interrelated standards forming a logically-consistent, coherent framework for service life predictions is pointed out. While, at present, service life predictions require a large measure of expert judgment or opinion, dependence on expert judgment should decrease as computer-integrated knowledge systems become available. Because service life predictions are unlikely to be accepted by designers as a tool for routine use until standards and a computer-integrated knowledge system are in place, and because of the complexity of the system of standards that is likely to be needed, active participation in the standards-development process of material researchers dedicated to making service life prediction a reality is critical.

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