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NRCC-40671

A version of this paper is published in / Une version de ce document se trouve dans:
7th Conference on Building Science and Technology: Durability of Buildings Design, Maintenance, Codes and Practice, Toronto, Ont., March 20-21, 1997, pp. 153-167

Towards Integration of Service Life and Asset Management Tools for Building Envelope Systems

M. A. Lacasse[1], D. J. Vanier[1], B. R. Kyle[2]

Abstract

Asset managers are faced with many difficult decisions regarding when and how to repair their building stock. The reasons for the difficulties relate directly to the lack of usable data, information and knowledge related to service life prediction, and the lack of tools to assist the asset manager in making a proper repair choice. The Building Envelope Life Cycle Asset Management (BELCAM) project addresses these two deficiencies: its goal is to develop methods to predict the service life of the building envelope and its elements, and to assist asset managers in maintaining these building components. The project in the initial stages focuses on roofing, and seeks to integrate existing enabling technologies used in this domain, namely: maintenance management, life cycle economics, service life prediction, user requirement modeling, risk analysis, and product modeling. Although there exists degradation models for flat roof systems, as well as a number of roofing maintenance management packages, these have yet to be integrated into a consistent resource that satisfies the asset manager's requirements. Indeed, efforts have been made in the past to provide designers insight into the functional use and related performance requirements of building elements; however, little of this information has been used in the context of maintenance of facilities. This paper describes details on the programmed approach adopted within the BELCAM project to achieve practical solutions for asset managers. Examples are provided to illustrate the concept as applied to the roofing domain.

Keywords: Asset Management, Building Envelope, Durability, Information Technology, Life Cycle Costs, Maintenance Management, Risk Analysis, Service Life Prediction, Product Modeling.

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1 - Associate Research Officer and Senior Research Officer respectively, National Research Council Canada, Institute for Research in Construction

2 - Senior Research Engineer, Public Works and Government Service Canada, Architectural and Engineering Services

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Introduction

Asset managers are faced with many difficult decisions regarding when and how to repair their building stock. The reasons for the difficulties relate directly to the lack of usable data, information and knowledge related to service life prediction, and the lack of tools to assist the asset manager in making a proper maintenance, repair or replacement choices [1,2]. Some of the most difficult decisions relate to the building envelope, which normally incurs the major portion of the initial cost of a building and it is the most significant system in terms of maintenance, repair and replacement [3].

It may be generally acknowledged that building construction expenditures in Canada represents a significant portion of the total value of construction. Indeed, a review of construction statistics [4] has shown that every year, between 1983 and 1993, 52 billion dollars, on average, was spent on building construction, representing about 65 percent of the total value of construction in Canada. Maintenance and repair expenditures are no less significant; a review of the proportion of repair expenditures in relation to total construction expenditures in this same period revealed that yearly, roughly 16 percent, on average, is spent on repairs representing a value of 8.5 billion dollars for repairs to building construction alone. Of this value, maintenance repairs to roofing membranes and systems may account for approximately 30-35 percent of these costs or approximately 2.5-3 billion dollars. In the United States of America the numbers can be conservatively estimated at ten times higher [5]. Therefore, asset managers are responsible for managing a substantial amount of construction and maintenance work. In many instances, the initial design and construction costs are small compared to the asset maintenance costs throughout the building's life: this makes the asset manager a major player in the construction game.

Asset managers are faced with many difficult decisions regarding when and how to maintain and repair their constructed facilities. The reasons behind these difficult decisions are the growing fiscal constraints, an increasing maintenance deficit and a substantial repair backlog. In addition, asset managers resources are being challenged from all sides: they are also being asked to cut cost, to privatize operations, to outsource responsibilities, to reduce maintenance and to increase efficiency. These problems are exacerbated by the lack of usable data, information and knowledge related to maintenance and repair, and the lack of tools to assist the asset manager to make proper inspection, maintenance and repair choices.

Many of these problems would be solved if there was more information exchange in the construction industry regarding service life and asset management. The roofing industry is no different from the rest of the construction sector: money is tight, maintenance backlogs are increasing and information is scarce.

Many organizations have recognized the asset management problems identified in the previous section [5-7]. Unfortunately existing opportunities offer only partial solutions to many of the problems in asset management, and more specifically to the problems in roofing asset management. There is still need for research in this field: (1) what data should be collected, (2) what are the life cycle costs of maintenance, (3) what data are required for service life prediction, (4) what is the essential maintenance and what can be deferred, (5) how to deal with risk and the consequences of asset failure, repair and renewal, and finally, (6) how to integrate all these new data and information.

The NRCC and PWGSC are addressing these questions with the BELCAM Project. The BELCAM project will attempt to build on the existing service life and asset management information discussed above, will endeavour to provide a clearinghouse for service life and asset management research for roofing systems, and will provide tools and techniques for building practitioners.

BELCAM Approach to Roofing Asset Management

The overall goals of this initiative are:

1. To develop models and tools to facilitate predicting the service life of building components.
2. Assist asset managers to maximize the effectiveness of their maintenance dollars.

The objective of this initiative is to develop models, methods and tools to achieve these goals. This joint NRCC/PWGSC initiative should be considered as the large picture on service life and asset management research; however, to meet the goals and objectives there is need for focused research and development in specific construction sectors. NRCC and PWGSC have agreed to participate in a pilot project dealing with near-flat roofing systems.

Service Life / Asset Management Enabling Technologies

The BELCAM project [1,2] has identified the six enabling technologies, illustrated in Figure 1, that can help asset managers predict the service life of building envelope components:

- Maintenance Management to record and monitor the current condition of building elements and systems;
- Life Cycle Economics to model the construction as well as operation and maintenance costs from cradle to grave;
- Service Life Prediction to collect the necessary laboratory and field data for the development of building component performance curves;
- User Requirement Models to quantify the desired building performance levels and to establish criteria for;
- Risk Analysis to determine the probability and consequences of repair and rehabilitation decisions;
- Product Modeling to manage and integrate data and information related to service life prediction and asset management.

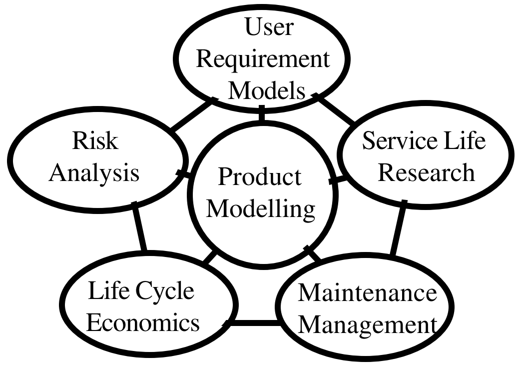

Figure 1: BELCAM Integrated Models

In essence, the six enabling technologies address many of the problems identified in the previous sections, as well as, many of the objectives for sustainable roofing. That is, the integrated model shown in Figure 1 identifies the need for close ties between maintenance management, life cycle economics, and user requirement models; these are all components of a sustainable roof system. Product modeling is seen as the integrator for these well-established research areas.

Enabling Technologies: a synopsis of the current State-of-the-Art

User Requirement Models

User requirements and their relationship to functional requirements for building elements have been derived from work on the performance concept in building technology. Although a proposed structure for the performance concept has been available for more than two decades [8], there has since been considerable research in this field, much of which has evolved within the CIB Working Commission on the Performance Concept in Building [9,10]. The definition of the performance concept "takes as a starting point a recognition of the needs expressed in terms of human and user's requirements". This CIB Working Commission also supplements the earlier work in the field with clear definitions for terms such as "stress", "functional performance requirement", and "performance assessment". CIB W60 has worked to provide more depth to the vocabulary and structure and has promoted the development of performance standards. Indeed, the building industry now has concise descriptions of the performance concept included in ISO documents that provide clear and concise examples and classifications for components of the performance models. A number of formats and templates for the development of performance standards [11-13] are available and this work has been applied in a number of domains [13].

Within the roofing industry, attempts are being made to establish a consistent set of performance standards related to building functional requirements: work has been undertaken to describe and relate the functions and components [14] and to outline the performance requirements in terms of specific test standards and specifications [15]. Although there appears to be a certain degree of skepticism in regards to the use of the performance approach to meet industry needs [16,17] there nonetheless is a recognition that new methods are needed to interrelate functional requirements to performance requirements, and specifications [18].

The BELCAM project is developing a user requirement model for the roofing domain called FRAME (Functional Requirement Analysis and Modeling Environment) [19]. It is expected that the user requirement model will be applied in two modes: the functional programming stage of the design process, and, in performance assessment. In the functional programming stage FRAME will find solutions in a multi-variant decision process. The assessment service includes, in the first instance, the commissioning phase of the construction process, where the completed structure is evaluated for compliance to functional building requirements. The assessment service would also include post-occupancy data collection and performance evaluation for the maintenance, repair and rehabilitation phases. Basically, for the applications identified above FRAME can be used to: (1) select the Occupancy (Use); (2) select the appropriate Functional Requirements, taking into account the Occupancy (Use); (3) select suitable Functional Elements to address the Functional Requirements, taking into consideration the applicable Agent (Stress); (4) select the desired Performance Requirements, taking into account the Occupancy (Use); (5) select the appropriate Performance Indicators, taking into account existing standards and testing procedures; (6) establish the Performance Indicators, as well as the Nature and Criteria for assessment, and (7) evaluate the performance. These technical terms are illustrated in Figure 2, below.

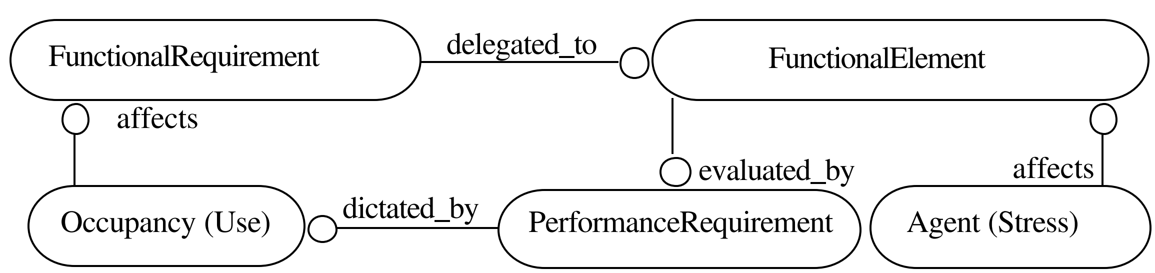

Figure 2 FRAME Product Model [19]

Service Life Prediction

The body of knowledge encompassing the durability of building materials is evidently quite large and this is also true for the roofing domain [2]. Numerous studies have been undertaken to report on the durability of specific roof types, components, or materials in particular those elements of the roofing system identified as having failed prematurely [20]. Studies have, hence, been conducted on understanding premature failure phenomena, causes and prevention. For example, a more recent focus has been on the performance of roofing membranes, in particular single-ply EPDM membranes and those made of un-reinforced PVC. More specifically, in the case of EPDM membranes [21], the effects of shrinkage were found to be the primary factor in the premature failure of these systems, whereas, in the case of PVC membranes [22], considerable research has been undertaken to determine the causes of shattering on these roofing components.

Statistical methods have been used to evaluate the long-term performance of roofing systems[23]; however, few comprehensive methods combining field studies, laboratory accelerated test methods and modeling have been developed. In this area, Baskaran and Paroli [24, 25] are providing insight towards developing a comprehensive evaluation program for roofing membranes. This approach is based on an understanding of the most significant factors causing degradation of low-slope roofing systems and encompasses the use of a dynamic wind test facility together with modeling expertise. In is anticipated that the research results from this work will be incorporated in the BELCAM service life model.

Roofing literature related specifically to predicting the service life of roofing systems is limited not only in terms of scope but also in terms of relating results to in-service conditions. Within the service life area, an attempt will be made to determine what literature is relevant to the domain, to highlight the most significant studies in the area, to review the techniques used and to develop a common vocabulary related to roofing service life. Research undertaken by others in this domain will be incorporated into the service life model.

Risk Analysis and Reliability Assessment

The reliability-based approach is often utilized in assessing the long-term performance of various types of structures or materials [26,27]. It is based on two concepts, the first of which is related to the loss in performance with time (P_t) of a product, or built system, when subjected to a series of loads (including environmental as well as structural) causing deterioration (S_t). The second concept defines failure which arises when the level of performance of the system can no longer sustain the loads to which it is subjected. In other words, failure occurs when $S_t \geq P_t$. The margin of safety of a given system is simply the difference between P_t and S_t at any time, t, and, as a system degrades in time, its margin of safety is reduced. Risk and reliability are two related terms in which risk represents the probability of failure of a given system in a given period of time, and, reliability is the probability that this same system will survive (*i.e.*, not fail). What is important in systems that are to perform in difficult environmental conditions over extended periods of time is maintaining the reliability of these systems, not their condition. Thus, data collected in a condition survey should reflect the change in the reliability of the system as a whole. This implies that the state of condition of a system being inspected should then be linked to the change in reliability of the system or its components. In this way, programmed maintenance and repair for a given system can be based on updated reliability estimates. These techniques represent a valuable tool for maintenance managers to minimize their maintenance costs and maximize the value of their assets.

This method is gaining acceptance in areas such as concrete bridge maintenance and repair strategies, and has been successfully applied to assessing the long-term performance of parking garage structures and to determine the probability and consequences of repair and rehabilitation decisions [28,29].

In the area of roofing, the reliability-based approach was first suggested by Masters [30]. Thereafter, Martin et al. [31] applied these methods of analysis to determining the service life of adhesively bonded seams of single-ply, EPDM, roofing membranes. More recently, Kyle [32] together with Marcellus and Kalinger [33] have shown that a similar approach, based on a statistical analysis of roofing defects over time, can be adapted to resolving maintenance and repair issues related to low slope roofs. The proposed reliability based system being developed by PWGSC will help make maintenance management decisions based on structured data.

Within BELCAM, the risk analysis and reliability assessment model will be used a basis for formulating different inspection, repair and rehabilitation strategies and the development of cost minimization functions.

Life Cycle Economics

In the engineering domain, life cycle costing has been typically used to assess the economic feasibility and benefits of different design or retrofit options. The methods are well documented in a number of [34] and are increasingly being used in the roofing area to assess when to repair or retrofit, or in the selection of new roofing systems [35]. Fundamental components of an analysis include: unit costs to replace, repair, inspect and maintain the roof, as well as design service life and anticipated frequency of inspection and routine maintenance.

The importance of roof inspection and maintenance costs should not be overlooked; studies undertaken by the maintenance division of the department of the US Air Force have shown that aggressive maintenance can provide savings ranging between $1.50 and $2.45 per square metre ($0.10 and $0.15 US per square foot) over moderate inspection. Aggressive maintenance means a semi-annual inspection that includes an annual moisture survey whereas conventional implies a walk-around annual inspection [36]. Level of investment (LOI) studies [5,6] have indicated that maintenance expenditures should be between two and four percent of the capital replacement value (CRV) of a facility. Although CRV has yet to be rigorously investigated for different types of facilities, it nonetheless provides a good basis from which cost estimates can be made. A number of ways have been proposed to determine the CRV; it may be based on: the purchase price plus an appreciation factor, a current cost to replace the asset, or, the cost to replace the functional portion of the asset with current construction technology. However, there are other elements that must also be considered when planning over the life of the facility, including renewal of the roof at the end of its service life.

In this regards, The National Association of College and University Business Officers [6] has proposed a detailed process consisting of identifying work that is capital renewal from that which is deferred maintenance. In this process, the asset manager first identifies maintenance that has been postponed, phased or deferred, and then attempts to provide an estimate of the cost for that deferred maintenance. The second portion of the process is capital renewal (CR) analysis in which the replacements that will be required at the end of the service life of various parts, components or systems are likewise identified. The CR process also includes estimating the renewal costs in five year lumps, and spreads these costs equally over each year. In this way, costs for CR for each system type can be calculated well into the future, and can be brought forward to a present value or calculated as an annuity expense. This process can readily be applied to the roofing industry.

Maintenance Management

In North America, the importance of roof management programs is well understood in both the private [37,38] and public sectors [39]. Both sectors have made a point of providing the necessary guidelines for inspection and maintenance of roof systems [40-41]. Hence, there is considerable literature available in this area from which a standard and systematic approach to roofing maintenance management can readily be developed. Moreover, there now exists a number of computerized maintenance management systems (CMMS), however, their usefulness with respect to life cycle economics and maintenance management is less well known. Many of these are relational database applications that have been developed to meet the data handling needs of asset managers. For example, any number of database applications can manage work orders, trouble calls, equipment cribs, stores inventory, and preventive maintenance schedules, and many include features such as time recording, inventory control and invoicing.

The Construction Engineering Research Laboratory (CERL) has pioneered the use of engineered management systems in many construction sectors including roofing, paving and rail networks [42-45]. Engineered management systems (EMS) attempt to establish a condition index (CI) of an asset based on a number of factors including the number of defects, physical condition and quality of materials or workmanship. Research studies have estimated the potential degradation of the CI based on loads on the system or external agents acting on materials. With all these data in hand, it is therefore possible to estimate the CI well into the future, given degradation curves and the effect of remedial action.

A number of commercial packages exist in the roofing domain of which MicroROOFER, developed by CERL, deals with three CI including the Flashing Condition Index, Insulation Condition Index, and Membrane Condition Index.

Product Modeling

As stated earlier, it is envisaged that product modeling will be used to manage and integrate data and information related to service life prediction and asset management [46]. Product modeling is a means of expressing notional concepts describing different 'products' and their interrelationships in a 'computer-interpretable' format. ISO 10303 is the international standard for the "computer-interpretable representation and exchange of product data" [47]. EXPRESS is its specifications language that provides the necessary language elements for an unambiguous definition of concepts. Text-based representations such as EXPRESS are easily understood by computers, but are difficult for humans. Graphical notations, such as EXPRESS-G, have been successfully developed to represent the complex relations typical of construction components and materials [48]. Based on the general acceptance of EXPRESS-G by the construction product modelers, it was selected to model the BELCAM user requirements. Hence, this tool will be used to derive a product model specific to the roofing domain that will encompass all of the pertinent enabling technologies briefly described above.

Summary and Future Work

In summary, asset managers face many difficult tasks to maintain their building stock in the existing economic times, but fortunately, there are many opportunities to assist them with their problems. However, to take advantage of these opportunities requires a concerted effort from the following three construction communities: research, standards and practice. In essence, without standards there is marginal service life information exchange to practitioners and without research there is limited information and data for development of useful standards.

The technological solutions to the problems of deferred maintenance and expensive capital renewal are neither imminent nor obvious. However, the problem is not intractable provided asset managers have a comprehensive suite of tools to help them manage their facilities. The BELCAM project attempts to address such problems in roofing asset management. The enabling technologies briefly described in this paper provide the research framework for developing tools to collect, classify and analyse service life and asset management data. Provided below are brief descriptions of the types of products the project will deliver in the coming three years.

The deliverables of the three-year BELCAM Project are as follows ('W3' indicates that the deliverable will be available on the World Wide Web):

1. Planned Deliverables (Year One)

   - Roofing 'Standards' Database: A database of Canadian standards on roofing including references to Canadian Construction Codes, Canadian Government Specifications Board (CGSB), and Canadian Standards Association (CSA), including CSA S478 "Guideline on Durability in Buildings" (W3).
   - Roofing Checklists: Inspection sheets based on best-practices, guidelines, or manufacturer's instructions available electronically (W3).
   - Roofing Software Evaluation and Analysis Report: An up-to-date evaluation of software for the roofing industry, including an analysis of ROOFER (W3).
   - Roofing Resources: Technical and practitioner publications (W3).
   - Roofing on the Internet: An analysis of existing Internet web sites dealing with roofing issues (W3)

2. Planned Deliverables (Year Two)

   - Roofing Inspection Manual: A manual of when and how to inspect a roof (W3).
   - Preventive Maintenance Checklists: Inspection reports made available through the Internet to maintain roofing inspection data (W3).
   - Regional Roofing Survey: A comprehensive survey of roofing in the Ottawa region to establish data for service life research.
   - Roofing 'Standards' Expert System: An expert system to indicate which standards are applicable for a specific roofing design.
   - Roofing Costing Data: Information on repair costs that are based on the Regional Roofing Survey and other costing sources of repair data (W3).
   - Roofing CAD Details: Standard CAD details for recommended repairs (W3).

- Roofing Defects Database: A database of defect, including graphics, and remedial action (W3).

3. Planned Deliverables (Year Three)

- Roofing Risk Index: A method for assessing the risks and potential costs of repair, based on age of roof, maintenance profile, defects and roof condition.
- Roofing Condition Expert System: An expert system to predict the service life of roofing systems, based on inspection, maintenance profile and defects (W3).
- Roofing BELCAM Database: An object-oriented database management system for inspection, maintenance, repair and renewal of roofing systems (W3)
- Roofing Maintenance Software: A software package (such as ROOFER), developed or modified to suit BELCAM user requirements, for roofing maintenance (W3).
- Guideline on Roofing Service Life and Asset Management: An objective-based guideline for ensuring that roofing system are "designed for service life".

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