Defining Reference Service Life: An Open Innovation Approach

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ABSTRACT

The endeavour to obtain estimates of durability of components for use in lifecycle assessment or costing and infrastructure and maintenance planning systems is large. The factor method and the reference service life concept provide a very valuable structure, but do not resolve the central dilemma of the need to derive an extensive database of service life. Traditional methods of estimating service life, such as dose functions or degradation models, can play a role in developing this database, however the scale of the problem clearly indicates that individual dose functions cannot be derived for each component in each different local and geographic setting. Thus, a wider range of techniques is required in order to devise reference service life. This paper outlines the approaches being taken in the Cooperative Research Centre for Construction Innovation project to predict reference service life. Approaches include the development of fundamental degradation and microclimate models, the development of a situation-based reasoning 'engine' to vary the 'estimator' of service life, and the development of a database on expert performance (Delphi study). These methods should be viewed as complementary rather than as discrete alternatives. As discussed in the paper, the situation-based reasoning approach in fact has the possibility of encompassing all other methods.

KEYWORDS

corrosion prediction, service life, case-based reasoning, durability, holistic model

1 INTRODUCTION

Service life planning is a design process that seeks to ensure that the service life of a building will equal or exceed its design life. Accurate estimates of the service life of a building are required to address and possibly optimise the lifecycle costs. It may also provide a means of comparing different building options.

ISO 15686 [2000] provides a methodology for forecasting the service life and estimating the timing of necessary maintenance and replacement of components. A forecast of service life should seek to use available data of known quality, account for variability and reduce uncertainty. Relevant data for forecasting includes:

- Data recorded over time.
- Comparison between exposure data and other evidence.
- Experience, feedback from practice and estimates of experts.

2 REFERENCE SERVICE LIFE

ISO 15686 (Clause 9) suggested the factor method as a means of estimating the service life of a particular component or assembly in a specific set of conditions. The factor method is based on a reference service life (RSL), which is defined as the expected service life of a component or assembly situated in a well-defined set of conditions. The factor method also incorporates a series of modifying factors that relate to the specific conditions of the case.

However, the quantity of data required in defining the RSL of dwellings in any given country is extremely large. The possible number of metal components in a simple detached Australian domestic dwelling indicates the extent of this problem. In such a dwelling, there are over 300 metal components, however each component may be commonly fabricated from 2 or 3 materials and coated with 2–3 different coatings, and thus RSL values would be required for in excess of 2000 distinguishable components. Further, these components may be placed in environments which may differ significantly, firstly due to local conditions or arrangements in the dwelling, and secondly due to the external environment.

Traditional methods of estimating service life, such as dose functions or degradation models, can play a role in developing this database, however the scale of the problem clearly indicates that individual dose functions cannot be derived for each component in each different local and geographic setting. Thus, new methods need to be derived to estimate service life and then these methods need to be combined in a rigorous manner.

3 OPEN INNOVATION APPROACH

The question is: how can one build a system that implements the factor method, while taking into account various sources of information such as measured data (both field and laboratory), results of mathematical models, anecdotal evidence from practice and estimates of experts and practitioners? The required system must be able to store, manipulate and compare numerous use–case scenarios.

In this paper, a business model for an R&D organisation proposed by Henry Chesbrough [2004] is adapted. In essence, the model proposes that rather than relying entirely on internal ideas to address an issue, an 'open' approach to innovation leverages internal and external sources of ideas. Note that the Chesbrough model is more than that, but for the purpose of this paper, the above concept should suffice.

How does one go about applying the open innovation approach? The guiding principle is to look at the current problem and try to identify solutions for each component of the problem. These solutions are normally mature or tested technologies and hence no longer considered an innovation.

For instance, the problem of defining reference service life and estimating the service life of a building component is about:

- Operating on use–cases or scenarios.
- Integrating data from different sources.
- Spatial references and operations.
- Rules and representations of expert knowledge and anecdotal evidence.

It is evident from the above list that several mature technologies can be used and integrated to address the issues of defining an RSL and service life estimates. These technologies include:

- Situated case-based reasoning [Liew & Maher 2004].
- Heterogenous databases [Widom 1996].
- Geographic information systems [Cole *et al.*, in press].
- Logic programming [Sterling & Shapiro 1994].

4 SITUATED CASE-BASED REASONING

The principles of case-based reasoning in building design have been developed [Maher 1998]. For example the work of Maher *et al.*]1995] and others provides a model for design reasoning based on the use of a set of previous design experiences represented as design cases. These cases are indexed and retrieved using information about a current design problem and then, through analogical reasoning, a selected case (or set of cases) is adapted until it satisfies the current design specifications and constraints. One aspect of design reasoning that is not addressed by traditional models for case-based reasoning is that design problems are situated. To accommodate the notion of 'situatedness' in design, the basic idea of case-based reasoning is extended to create a model of situated case-based reasoning (situated CBR) as shown in Fig. 1.

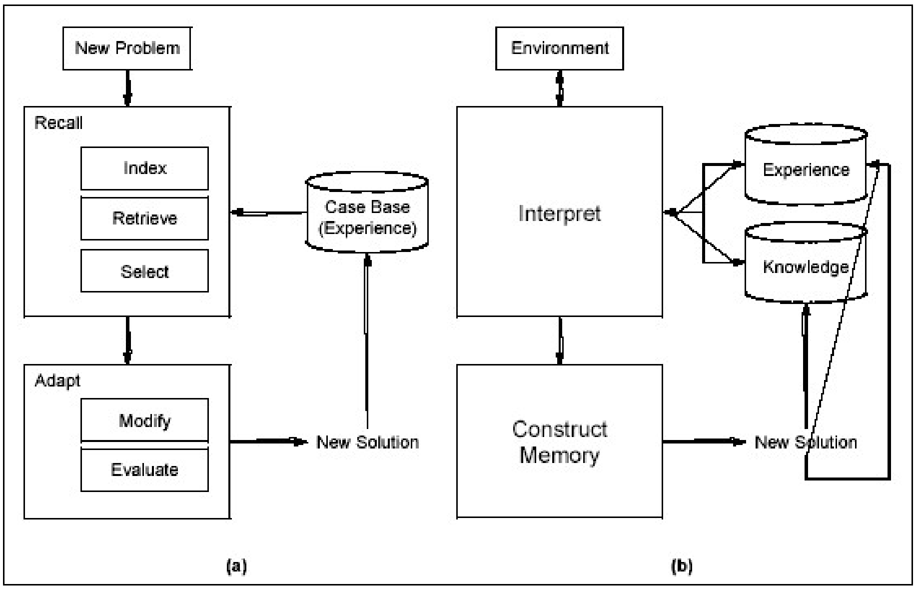

Figure 1. A conventional case-based reasoning (a), and a situated CBR model (b).

In the situated CBR model, instead of focussing on just the design problem and finding a solution to it, emphasis is also given to the environment within which the problem is framed. The model interprets the environment according to the current situation and the problem is framed accordingly. This interpretation is dependent on the current environment, the internal state of the situated CBR system and the interactions between the system and the environment. The internal state of a situated CBR system is defined by its content. This content is made up of individual entities that are classified either as experience or knowledge. Interactions between the system and the environment define different interpretations of the environment according to different interpretations of the selected entities used for memory construction.

A distinctive characteristic of situated CBR is the way its knowledge and experience are understood and used. In CBR, retrieved cases provide a solution or a starting point for case adaptation. In situated CBR, the memory of an experience and/or knowledge (entities) is constructed according to an interpretation of the environment and an interpretation of the selected entities relevant to the problem at hand. Rather than adapt a selected case to new design specifications, the selected entities are interpreted according to the interactions between the system and the environment. These interactions provide a specific view (interpretation) of the relationship between the design specifications and the environment. This view dictates another interpretation of the environment that can introduce new specifications. This 'feedback' loop causes the interpretations of the environment and the selection of experiences and knowledge to occur recursively until a common interpretation is reached. The recursive interpretations of the environment and the selected entities result in new memories as well as new indices to the selected experiences and knowledge to be created. Memories are constructed by:

- Instantiating the parameter values of the selected entities according to the current situation.
- Mapping existing parameters in the selected entities to new ones through an analogical process.
- Restructuring the selected entities according to the current situation.

5 HETEROGENEOUS DATABASE

The required database for the proposed system is actually a federation of three heterogenous databases, as shown in Fig. 2. The first component database is spatially referenced historical data on corrosion derived from CSIRO GIS data on atmospheric corrosion [Trinidad & Cole 2002]. The second component database consists of the synthesised results of a Delphi-based survey study on service life and maintenance of metal components in building assemblies (the Delphi study will be discussed in the next section). The third and final component consists of the database realisation of the 'holistic' corrosion model [Cole *et al.* 2004].

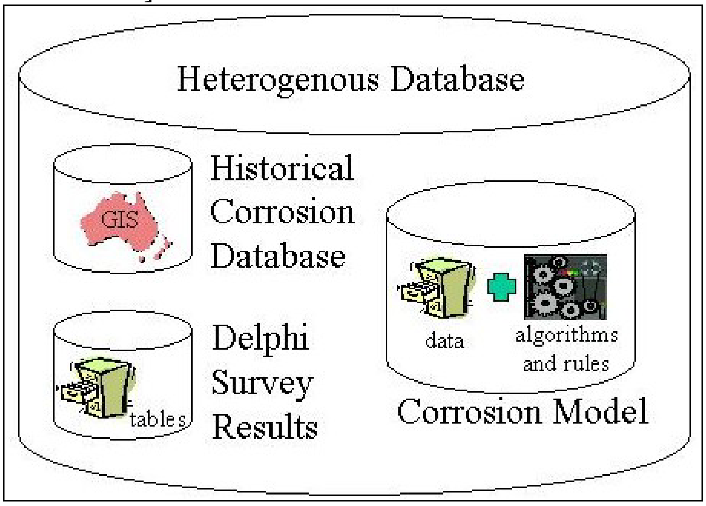

Figure 2. A federation of heterogenous databases; GIS, survey data and model base.

6 DELPHI STUDY

A Delphi survey has been conducted to provide expert opinion on the life of components in buildings. Thirty different components were surveyed, with a range of materials, coatings, environments and failure modes considered. These components were chosen to be representative of a wider range of components in the same building microclimate. The survey included both service life (with and without maintenance) and aesthetic life, and time to first maintenance. It included marine, industrial and benign environments, and covered both commercial and residential buildings. In order to obtain answers to this wide range of question, but still have a survey that could be completed in a reasonable time, the survey was broken into five sections:

- External metal components—residential buildings.
- Internal metal components—residential buildings.
- External metal components—commercial buildings.
- Internal metal components—commercial buildings.
- Metal connectors in buildings.

The survey was conducted in two stages. In the first stage, there were a total of 66 responses, with the number of the responses to each of the survey parts ranging from 9 to 18. The questions were placed in four classes depending on the degree of consensus in responses to the particular question. After the first stage, approximately 80% of questions had a consistent answer from the survey group. In Stage 2, 10% of questions were further investigated, with 75% of these remaining questions then having a consistent answer. The responses to each question were analysed to give a mode (most frequent interval), a mean value and a standard deviation of the mean.

The final database was examined in three ways to determine its accuracy and reliability. These were analyses for internal consistency of the data, for consistency with expected trends based on knowledge of materials performance and environmental severity, and for correlation with existing databases on component performance. In all cases, the Delphi survey data appears reliable.

The possible extensions of the approach are discussed in line with the technical ‘success’ of the method. However, the study was difficult to carry out owing to difficulties in obtaining answers from possible respondents. Thus, if a larger survey is to be undertaken including all building components, it is recommended that committed respondents be obtained before devising a survey.

7 CBR SYSTEM ARCHITECTURE

The system architecture of the situated CBR for service life prediction is shown in Fig. 3.

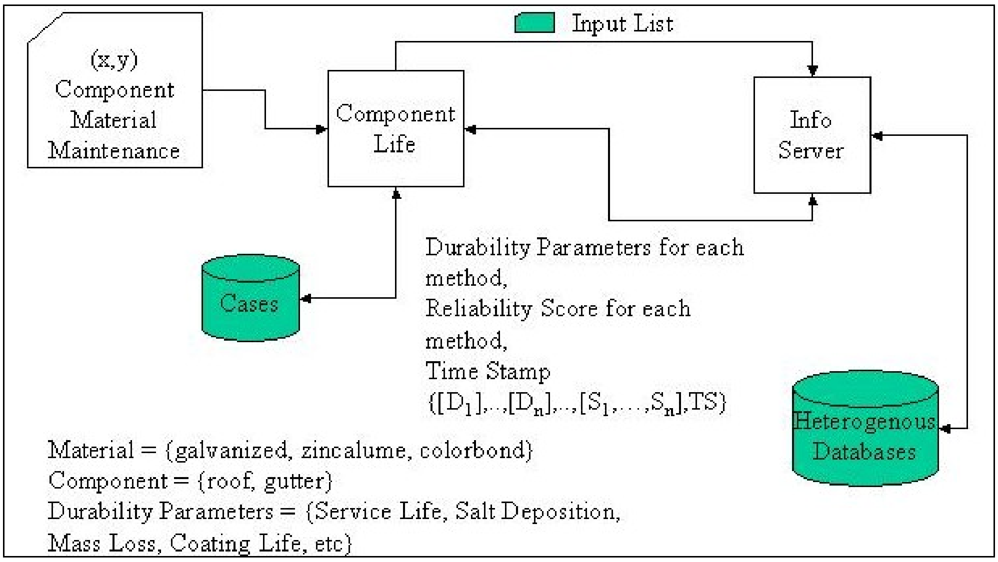

Figure 3. System architecture for a situated CBR on the prediction of service life.

The module ‘component life’ is the main situated CBR engine. It calculates service life estimates based on previous cases and information from the combined databases. An information server (Prolog application) module serves as an interface between the CBR engine and the combined databases. The information server provides the CBR engine access to the databases and corrosion model through five methods, as shown in Fig. 4. The five methods are:

- *getSalt*—provides access to an historical salt deposition database, and salt transport and deposition model.
- *getToW*—provides access to a 'time of wetness' database derived from climate databases.
- *getModel*—provides access to the holistic corrosion model.
- *getData*—provides access to historical corrosion data.
- *getSurvey*—provides access to the results of the Delphi study.

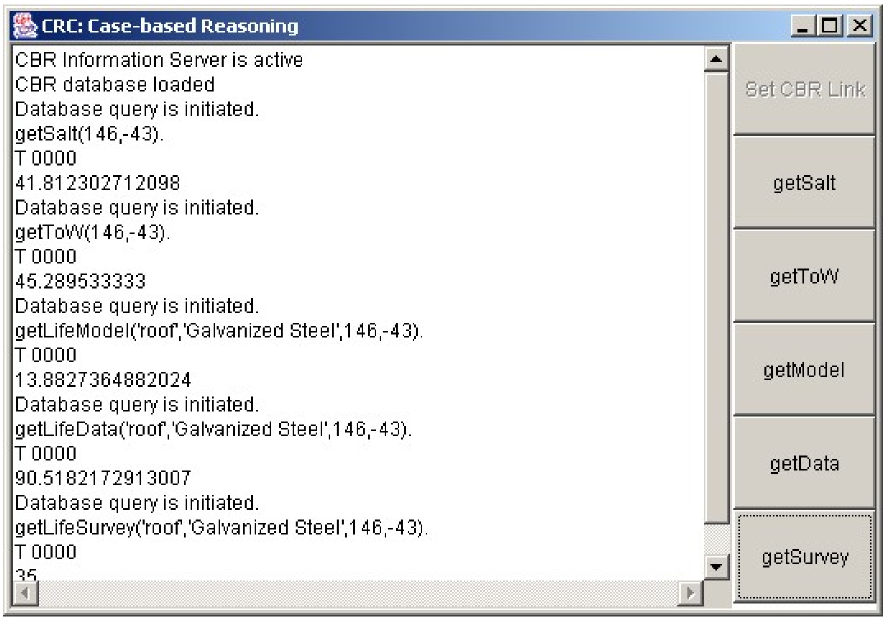

Figure 4. Java client illustrating the five interfaces to the information server.

Both the historical corrosion and holistic corrosion model databases are spatially referenced. On the other hand, the Delphi survey results are not referenced spatially. Hence, an environment classification module is needed, as shown in Fig. 5. This module is used to classify a given location (e.g. longitude–latitude coordinates or official place names of a geography gazette).

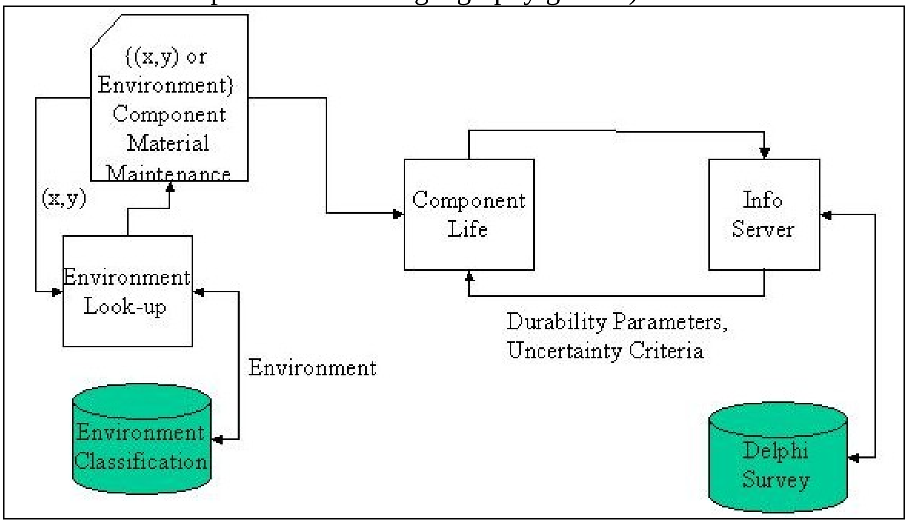

Figure 5. Using the results of a Delphi survey in a situated CBR context.

The CBR engine, which has access to the corrosion information server, is able to estimate the service life of a given building component in a particular use–case scenario, by combining the information from previous similar cases together with the information provided by the historical database, survey result and the holistic model (see Fig. 6).

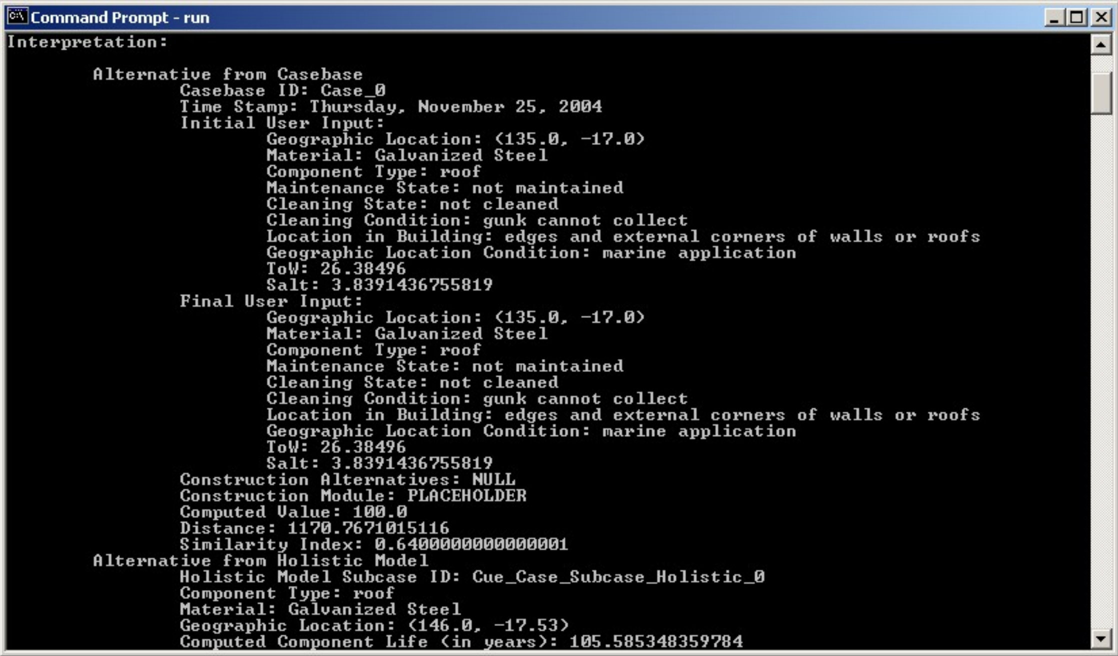

Figure 6. A screen showing output from the situated CBR engine in action.

8 SAMPLE APPLICATION WITH A GIS FRONT-END

A Cooperative Research Centre (CRC) for Construction Innovation [http://www.construction-innovation.info/] research program incoporates two case studies applying the concept discussed in this paper. The CRC for Construction Innovation is a national research, development and implementation centre focussed on the needs of the property, design, construction and facility management sectors.

The first test case involves implementing software that estimates the service life of roofs and gutters of school buildings in Queensland (see Fig. 7). The second test case is concerned with the prediction of the exposure environment of bridges in Queensland.

9 APPLICATION AND RELIABILITY OF MODEL

The integrated model will be applicable to the prediction of life of components of buildings throughout Australia while the general system is applicable for predicting component life wherever appropriate sources of data exist. The first application of the model is in the prediction of the life of gutters, as indicated above, however as this workis still in development it is not possible to define the accuracy of the model. However the accuracy of two components of the model – the Holistic Model of Corrosion and the Delphi Survey of Component life can be assessed. The predictions of the holistic model on mass loss of galvanised steel samples have been compared with data from over 40 field locations throughout Australia with the average error in prediction being 13% of the measured mass loss. Assessment of the reliability of the Delphi survey is more complex with a number of criteria being used including:

1. Internal consistency of the survey data.
2. Comparison against expected trends bases on material properties and environmental severity.
3. Comparison against other databases of component life.

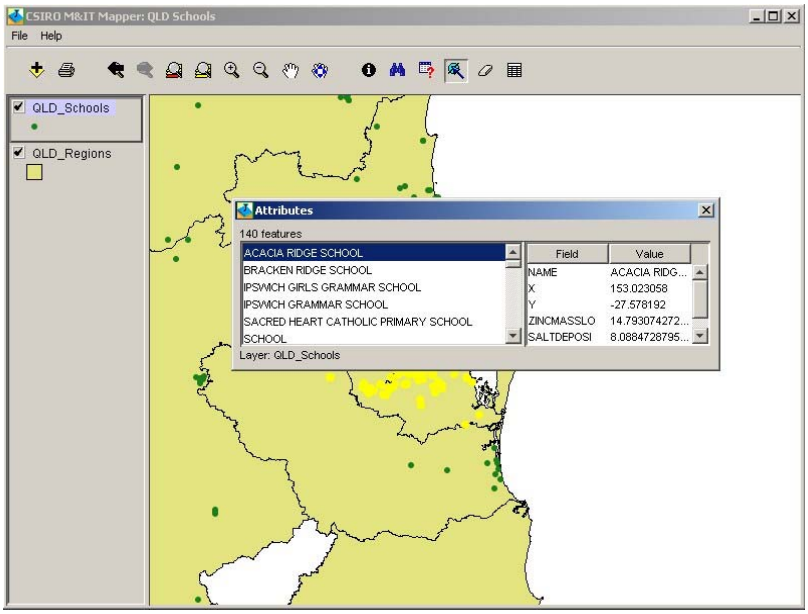

Figure 7. Early prototype software for estimating service life of roofs and gutters of schools in Queensland.

For many classes of components, data is not available in order to apply criterion 3. One class of components where data is available is roof sheeting with such a comparison being presented in Table 1. The table indicates that the predictions of the Delphi survey are close to those of other data sources.

Data	Environment	Mode (Years)	Mean (Years)	SD (Years)
Survey	Marine	10-20	12	6
Exp	Marine	5-10	14	12
Holistic	Marine	5-10	9	5
Maintenance	Marine		16	
Survey	Benign	30-50	35	13
Exp	Benign	>50	>50	
Holistic	Benign	>50	>50	
Maintenance	Benign		41	4

Table 1. Comparison of database and survey predictions for Service Life of roof sheeting. Survey refers to the Delphi survey, Exp to data from field exposures, Holistic to the holistic model, and Maintenance to maintenance data on roof replacement obtained from the Queensland Department of Public Housing

10 CONCLUDING REMARKS

This paper begins by outlining the difficulty of defining the reference service life for all the distinguishable components in a building. It argues that different types of information (e.g. historical data, process modelling and expert opinion) may play a role in developing these extensive databases. To integrate this information in a rigorous and efficient manner, a situated case-based reasoning engine has been developed. The situated CBR engine selects the appropriate information from diverse sources, including solutions in previous cases.

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