A RELIABILITY BASED APPROACH FOR SUSTAINABLE MANAGEMENT OF PUBLIC BUILDINGS

S.Setunge[1] and K.Zhang[2]

[1]Associate Professor Sujeeva Setunge, Discipline Head, Environmental Engineering,
RMIT University, Melbourne, Australia
[1]E-mail: sujeeva.setunge@rmit.edu.au
[1]Telephone: +61 3 9925 2182 ; Fax: + 61 3 9639 0138

[2]Senior Lecturer, Civil Engineering, RMIT University, Melbourne, Australia
[2]E-mail: Kevin.zhang@rmit.edu.au
[2]Telephone: +61 3 9925 3824: Fax: + 61 3 9639 0138

Abstract: Management of aging community buildings is a major cost to many local government organizations in Australia. One of the major challenges is integrating physical or engineering condition ratings with the sustainability issues and community service driven parameters. A new research project continuing at RMIT University in Melbourne is exploring an innovative reliability based approach for deterioration prediction and decision making for sustainable management of community buildings.

The paper will present the practices adopted in management of community buildings by six local government agencies in Australia, identifies the community needs and gaps in knowledge. A new integrated methodology for management of community buildings is presented as well as the development of a software tool for implementation of the methodology in local government. The tool covers a building hierarchy, condition monitoring method, deterioration prediction and a decision making process.

Keywords: *infrastructure management, sustainable buildings, Markov process*

1. Introduction

Infrastructure and public assets belonging to Australian community represent a major investment built up over many generations, and are valued at approximately 60 billion dollars. Out of these, community buildings are the second largest class of assets. A major issue currently faced by local government agencies is their inability to predict maintenance and replacement expenditure with a reasonable accuracy within reliable confidence limits, which creates situations where emergency repairs could use the funds kept for routine maintenance creating a vicious cycle of deterioration. Even when the cost is estimated with a reasonable accuracy, funding available is always inadequate to cover the total cost of keeping buildings at an optimum condition. Furthermore, without an overall understanding of the performance of building assets, there is very little opportunity at this stage to link previous performance data to design of new and sustainable buildings.

A research project funded by Australian research Council and six local councils in Australia is aimed at developing a methodology and a software tool for sustainable management of community buildings. In developing the methodology, the current practices of six partner councils were reviewed in detail, gaps identified and a basic methodology has been developed based on a review of major literature. The developed practice has been presented to the partners and comments have been obtained through three workshops of partner organizations. The work presented here covers the research methodology adopted, innovative approaches being developed and the management framework developed.

2. Proposed research methodology

Following steps were adopted in developing the model for sustainable management of community buildings;

- Review of literature
- Analysis of current practices of partner organizations
- Collection of existing condition data
- Developing an integrated framework for the management model
- Developing methods for quantifying each of the stages of the management model.
- Validation of the model

3. Review of the previous work on building deterioration prediction and condition rating

Prediction of building deterioration requires integrating the behaviour of a number of discrete elements with a vast range of significant influencing factors. As observed by Frangopol et al (2004) life cycle prediction of infrastructure systems under no maintenance or under various maintenance scenarios is quite complex. Current body of knowledge can be summarised as:

1. Approximate methods where conditions of different elements were rated at levels A, B, C and D or 1, 2, 3, 4 through condition inspections. Deterministic life cycle analysis is conducted assuming the time period of progression of deterioration to be fixed in one state.
2. Deterministic methods with modifications for exposure conditions and usage through fixed factors calibrated with data -ISO factorial approach. (Bamforth, 2004, ISO, 2000 and 2001).
3. Semi-empirical methods where probability of elements being in a given condition at a given age is calculated from condition data- MEDIC method (Flourentzou, 2000)
4. Reliability index methods using the mean value first-order second moment (MVFOSM) or the first-order reliability method (FORM), failure rate or time dependent reliability index.
5. Stochastic process models such as Markov decision process and renewal models (Frangopol et al, 2004).
6. Predicting life cycle of assets considering an integration of three drivers such as Market forces, physical deterioration and functional obsolescence – mainly a deterministic approach.

Of the aforementioned modeling methods, no single approach has yet proven to be generally applicable and each method has its advantages and disadvantages (Frangopol et al., 2004). Most powerful methods are reliability based models which are calibrated using data from non destructive testing, which gives continuous physical deterioration curves (Maheswaran et al, 2005, Frangopol et al, 2004). However, these are only available for a few known deterioration mechanisms such as corrosion of reinforcing steel in concrete, sulphate exposure, carbonation etc. On the other extreme, deterministic models which are based on discrete condition rating methods are widely available. A building is a complex system with a large number of discrete elements and often the condition rating is done using a visual inspection which categorises the condition into a discrete rating (ISO, 2000 and 2001). A method which offers a reliable prediction requires a large collection of validation data in order to cover different scenarios, categories of buildings, exposure conditions and element types. Since non destructive testing of all building elements to rate the condition of a building is almost impossible, a method which provides the best accuracy in deterioration prediction and is combined with a decision model based on condition data collected using the traditional discrete approach is the most practical.

4. Current practices of partner organisations

There are three distinct practices adopted by the six partner organizations as summarized below:

4.1 Reactive maintenance, building valuation and a spreadsheet used for forecasting

The first approach observed is a maintenance strategy with a reactive decision making model. Building valuation data is used for the decision making. A list of 24 elements is used with a 1 to 5 scale condition rating in valuation. A spreadsheet based model is used in cost forecasting. Decision making process takes stakeholder needs in to account even though politically influenced decision making is also possible.

4.2 Physical condition assessment and spreadsheet based forecasting, data used for maintenance

This method adopts a building maintenance strategy which is at a higher level than the basic reactive strategy. Councils collect the building condition data annually through a contracted inspector. The data collection method used is visual inspection. The data is used in maintenance decision making.

Cost forecast and decision making are based on a spreadsheet tool that considers stakeholder, scoping and design, permits, cost estimation, timeline, community, strategy, commitment, economic, environmental, and social aspects in capital budgeting decisions.

4.3 Physical condition data used to derive a deterioration curve

This method is similar to method 2, however, instead of using condition data just to plan maintenance activities, data is used to generate deterioration curves as well. Curves are generated for five different categories of building components.

4.4 Combined assessment of physical condition and valuation

This method uses a combined approach comprising of valuations and physical condition rating. Physical condition rating of the building is integrated with other influencing factors such as environmental, amenity – equity, service, children's services, grounds & gardens, sewer storm water, housekeeping and safety. Hence, the model finally uses an integrated condition rating for buildings. Maintenance plan and decision making is done based on building categorization, building priority and building weights (e.g. buildings of state significance, regional significance, municipal significance, neighbourhood significance and minor associated). Further, it is interesting to see that the budget allocation process uses involvements of appropriate committees and their consultation.

5. Existing condition data

Table 1 shows a sample set of condition data collected form one partner organization. These were collected by a council adopting the methods described in 4.2 above.

Table 1: Sample of condition data collected by a local council

Building ID	Room Number	Room Function	Component	Ht.	Perimeter	Qty	Unit	Condition Rating
B001	B001_000	External	External Walls	3.5	86.82	303.89	m2	2.5
B001	B001_001	Change Room	Ceiling			42.45	m2	1
B001	B001_001	Change Room	Flooring			42.45	m2	3
B001	B001_001	Change Room	Internal Walls	3	28.21	84.63	m2	2
B001	B001_002	Shower Room	Ceiling			24.83	m2	1
B001	B001_002	Shower Room	Flooring			24.83	m2	2.5
B001	B001_002	Shower Room	Internal Walls	3	23.5	70.5	m2	2
B001	B001_003	Kitchen	Cabinetry, Benches & Shelves			3	Item	2
B001	B001_003	Kitchen	Ceiling			13.65	m2	1.5

The data given in table 1 have been collected using the criteria shown in table 2. The criteria shown are quite generic and don't differentiate between critical and non-critical elements. Some of the other councils use a scale between 0 and 10.

Table 2: The condition rating criteria adopted for the data given in table 1

1	Excellent	The element is as new and can be expected to perform adequately to its full normal life
2	Satisfactory	The element is sound, operationally safe, and exhibits only minor deterioration
3	Unsatisfactory	The element is operational but major repair or replacement will be needed soon, that is within one to three years
4	Failing	The element runs a serious risk of imminent breakdown

6. Integrated framework for building management

After analysis of the current practices, condition rating methods and a comprehensive literature review, the integrated framework shown in Figure 1 has been developed by the research team as a generic flow chart for management of infrastructure. The model is divided into six stages described below.

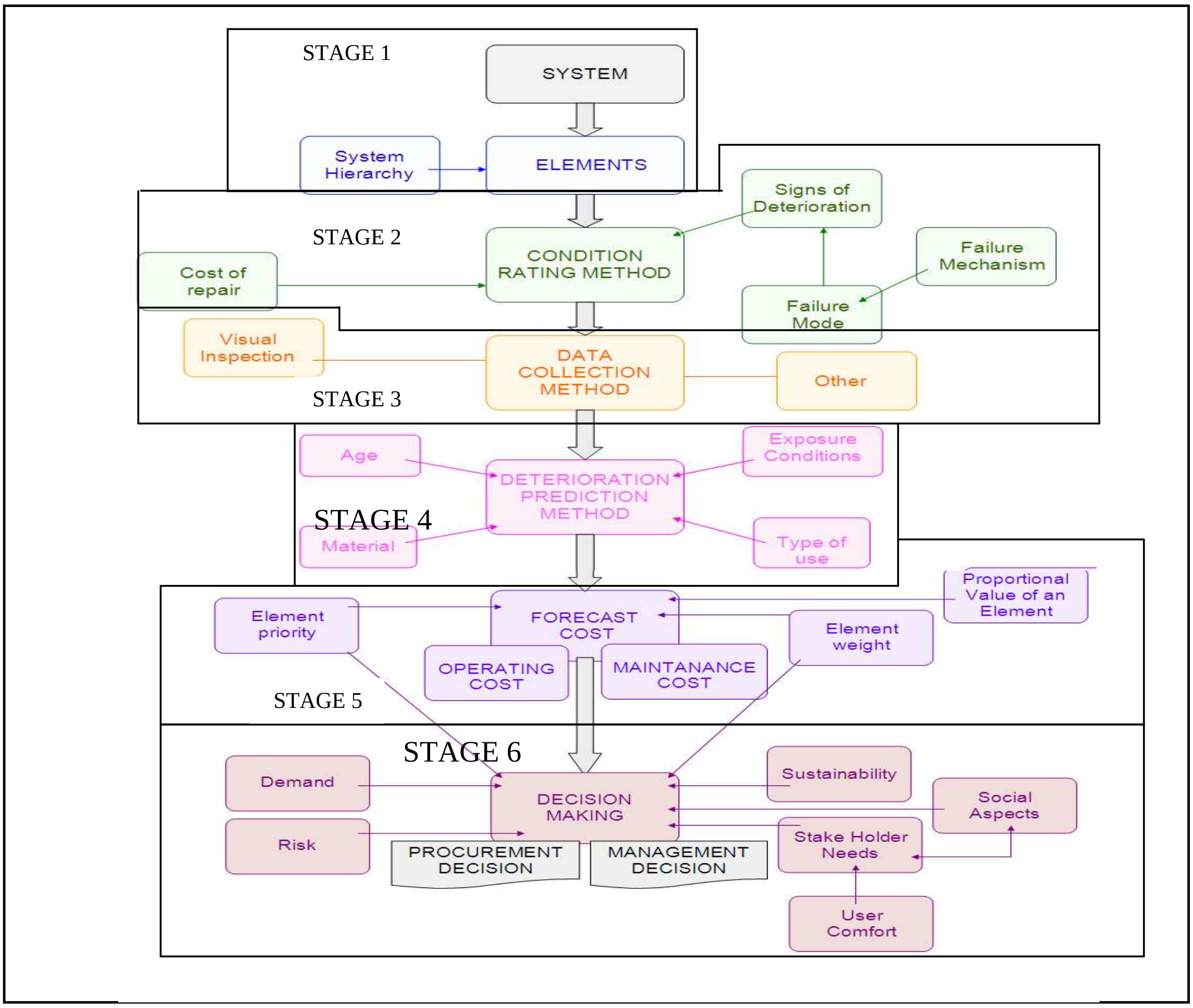

Figure 1. Infrastructure Management Process.

6.1 Stage 1

Stage 1 of the process covers the definition of the system and the division of the system into elements which can be inspected and recorded. A typical building system definition using a hierarchical framework is shown in figure 2. IPWEA (2009) guidelines have been used to develop a comprehensive building hierarchy for the project.

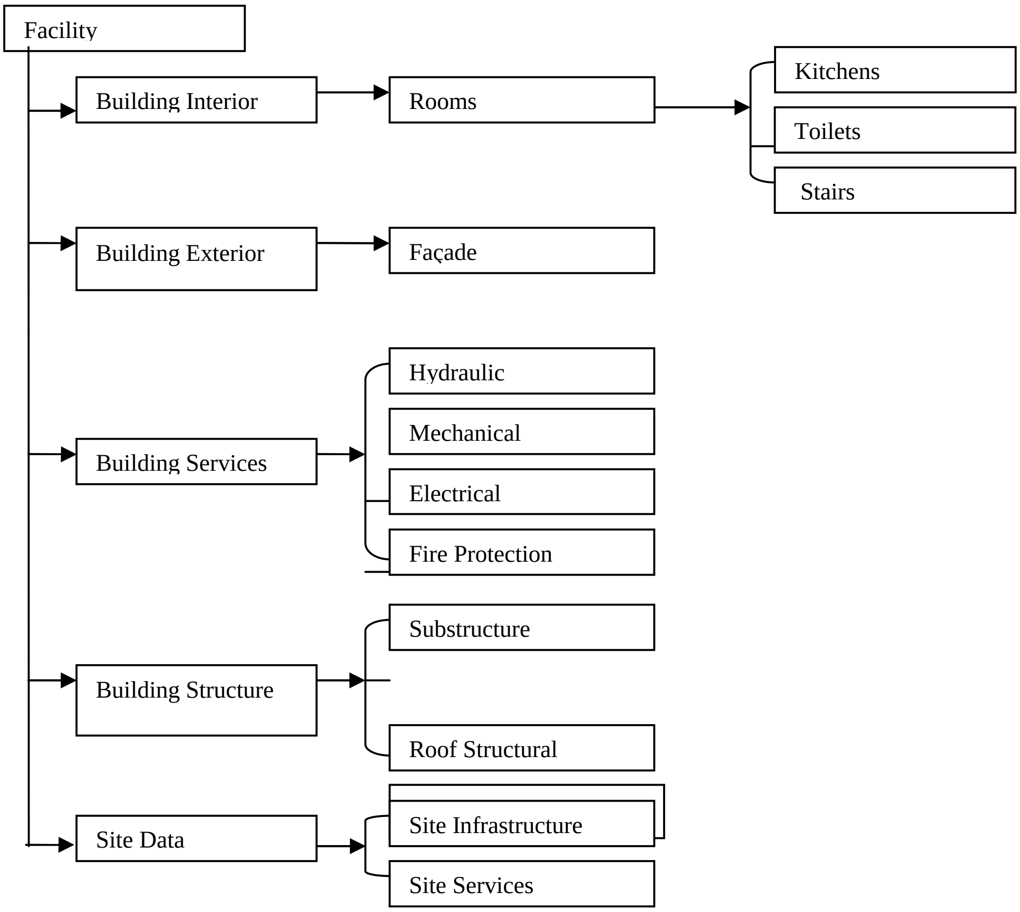

Figure 2: Building Hierarchy

6.2 Stage 2

Stage 2 covers the condition monitoring method which requires identification of the condition level, linking the cost of refurbishment/ maintenance to the given rating. After a review of number of approaches adopted and detailed consultation of stakeholders, a five scale condition rating scheme is proposed for the model. The proposed method is easy to implement due to a direct link to cost of work required to change the given condition to condition 1.

Table 3: The proposed condition rating scheme

1	The element is as new and no work required
2	The element is sound, operationally safe, and exhibits only minor deterioration With minor repair, it can be changed to condition 1
3	The element is operational but a medium scale refurbishment is needed
4	The element requires major refurbishment to change to condition 1
5	The element requires to be replaced

6.3 Stage 3

Stage 3 requires development of a data collection method, which links the specified condition rating and the building deterioration. In the initial stage of the project, the visual inspection methods adopted by the partners will be implemented. More sophisticated methods such as non-destructive testing is also explored.

6.4 Stage 4

The stage 4 of the model requires rigorous analysis to generate the deterioration curves from condition data. A stochastic model based on the Markov process has been proposed for this stage (Sharabah et al, 2008). Discrete Time Markov Chain is a finite-state stochastic process in which the defining random variables are observed at discrete points in time. This chain satisfies Markov property, which means that given that the present state is known, the future probabilistic behavior of the process depends only on the present state regardless of the past. If an element is in state "i", there is a fixed probability, Pij of it going into state j after the next time step. Pij is called a "transition probability". The matrix P whose ijth entry is Pij is called the transition matrix. Transition matrix consist of a set of finite set of state S (1,1,3….n) and a propriety pi j to pass from state i to state j in one time step t. In Markov chain pi j should satisfy two following conditions

$$p_{ij} \geq 0,$$

$$\sum_j p_{ij} \leq 1$$

This mean if an element is in state i, there is a (Pii) probability that this element will stay in state i, and (1- Pii) will move to the next state j.

Present state at time t is i: Xt = i

Next state at time t + 1 is j: Xt+1 = j

Conditional Probability Statement of Markovian Property:

$$\Pr\{X_{t+1} = j \mid X_0 = k_0, X_1 = k_1, \ldots, X_t = i\} = \Pr\{X_{t+1} = j \mid X_t = i\}$$

Discrete time means $t \in T = \{0, 1, 2, \ldots\}$

	State1	State2	State3	State4	State5
State1	0.476	0.523	0.000	0.000	0.000
State2	0.000	0.336	0.665	0.000	0.000
State3	0.000	0.000	0.290	0.710	0.000
State4	0.000	0.000	0.000	0.004	0.996
State5	0.000	0.000	0.000	0.000	1.000

Figure 3: Transition Matrix derived for condition of walls

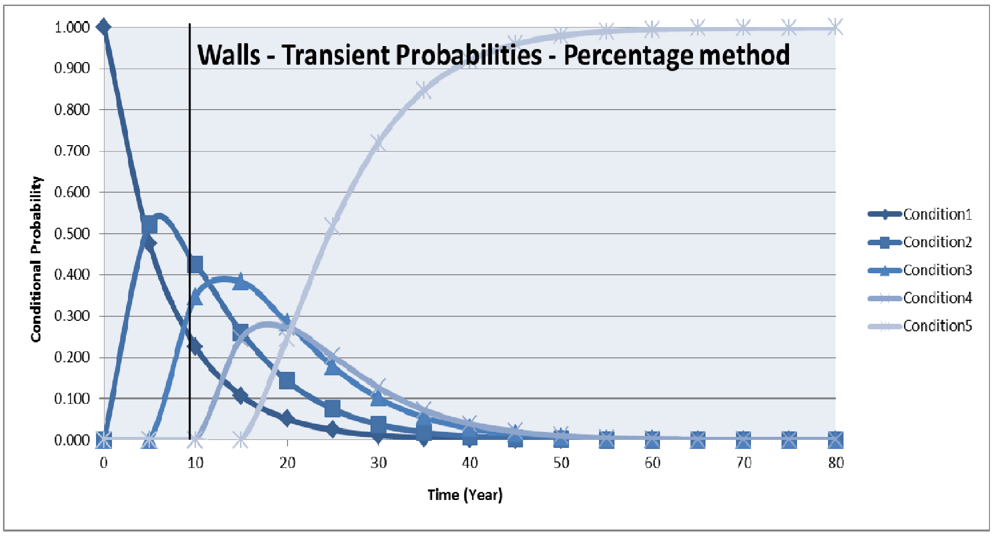

Figure 4: Transient probabilities derived from condition data

Figure 3 shows a typical transition matrix. An initial distribution 'v' is a single row matrix representing the number of elements in each state. In Markov chain after one time step the new distribution will be the result of multiplying initial distribution v by the transition matrix P

Distribution After 1 Step: vP
The distribution one step later, obtained by again multiplying by P, is given by (vP)P = vP2.`
Therefore distribution After 2 Steps = vP2
Similarly, the distribution after n steps can be obtained by vPn
Figure 4 shows the transient probabilities derived from the transition matrix shown in figure 3.

6.5 Stage 5

Economic modeling of the refurbishment cost and the maintenance cost are important elements of the model. Since the condition ratings are directly linked to the cost, using figure 4, the total cost at a given age can be determined for the walls analysed here. For example, from figure 4, at an age of 10, 20% of wall elements are expected to be in condition 1, 45% will be in condition 2 and 35% will be in condition 3. The total cost of renewal to condition 1 would be:
0.45 x cost of changing condition from 2 to 1 + 0.35 x cost to changing condition from 3 to 1

6.5 Stage 6

Integrated method for decision making forms the final stage of the proposed framework. A fuzzy logic based approach is currently being explored for integration of the economic and financial parameters.

7. Validation of the model

Validation of the model can be quite complex especially the decision making components. The fuzzy logic approach proposed will be used with a second set of data sourced from the Municipal association of Victoria to compare the model outcomes with the actual financials of one council over a given year. It is believed that with the availability of more data, as partners implement the methodology, the model can be further refined.

8. Conclusions

The paper presented the development of an integrated management model for council buildings in Australia. The method integrates a reliability based deterioration prediction model with a decision making model to provide local government agencies with a working model which can be used for managing community buildings.

References

1 Bamforth, P. and Alisa, M. (2004) Probabilistic approach for predicting life cycle performance of buildings and civil infrastructure, *Proceedings of the international conference Innovative Materials and Technologies for Construction and Restoration*, Lecce, Italy, June 2-9, pp 553-558.
2 IPWEA (2006) International Infrastructure Management Manual.
3 IPWEA-NAMS.AU (2009) Building Condition and Performance Assessment Guidelines - Practice Note 3- Buildings.
4 Flourentzou F., Brandt E. and Wetzel C. (2000) MEDIC - a method for predicting residual service life and refurbishment investment budgets: *Journal of Energy and Buildings*, 31, 167-170.
5 ISO 15686 (2000) Buildings and constructed assets - Service life planning - Part 1: General Principles, Geneva: International Organisation for Standardisation.
6 Setunge S. and Kumar A. (2009) Estimating residual service life of commercial buildings. P. Newton, K. Hampson and R. Drogemuller (Eds) *In Technology, Design and Process Innovation in the Built Environment*, Abingdon, Oxfordshire, UK, 439-454, Taylor and Francis.
7 Sharabah, A. and Setunge, S. (2008) Effective condition monitoring and assessment for more sophisticated asset management systems. *Proceedings of the Clients driving construction innovation - benefiting from innovation.* Icon.net Pty Ltd, Brisbane, Australia, pp. 174 – 181.