Evaluation of Residual Service Life methodologies using refurbishment projects as case studies

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Abstract

One of the key issues facing public asset owners is the decision of refurbishing aged built assets. This decision requires an assessment of the “remaining service life” of the key components in a building. The remaining service life is significantly dependent upon the existing condition of the asset and future degradation patterns considering durability and functional obsolescence. Recently developed methods on Residual Service Life modelling, require sophisticated data that are not readily available. Most of the data available are in the form of reports prior to undertaking major repairs or in the form of sessional audit reports. Valuable information from these available sources can serve as bench marks for estimating the reference service life. The authors have acquired similar informations from a public asset building in Melbourne. Using these informations, the residual service life of a case study building façade has been estimated in this paper based on state-of-the-art approaches. These estimations have been evaluated against expert opinion. Though the results are encouraging it is clear that the state-of-the-art methodologies can only provide meaningful estimates provided the level and quality of data are available. This investigation resulted in the development of a new framework for maintenance that integrates the condition assessment procedures and factors influencing residual service life.

Key words: Residual Service Life, Reference Service Life, Facade, Re-Life,MEDIC,ISO.

1. INTRODUCTION

Most of the public asset buildings in Australia that are around 40 years old have undergone significant changes in their functional use and utility. With the recent technological advancements and changing user expectations, the asset owners are facing a major issue; whether to refurbish the existing building and bring it back to its life or to completely demolish and rebuild? The option of demolishing and rebuilding seems to have practical issues like decanting, access during construction, recycling of wastes and unforeseen costs besides many others. It is also noted that the refurbishment costs in many cases are approximately half of the costs of new construction. Furthermore, with the increasing focus on the sustainability of the built environment, the option of bringing back the serviceable life (Re-life) of buildings (with minimum investments) is finding favour amongst asset owners. In achieving the re-life option, one of the important considerations is to ascertain the residual service life (RSL) of the building as a whole or some of its components. In generic terms, the residual service life is an estimation of the remaining useful service of a building or component taking into account of its present condition and future functioning. This paper addresses the issues in estimating the residual service lives of some of the public asset buildings in Melbourne, Australia.

The need for service life design has been well recognized over the past decade.(Frohnsdorff, 1996, Frohnsdorff and Martin, 1996). Subsequent research efforts culminated in the form of residual service life models such as the ISO, 15686 Part 1, 2000 and Part 2, 2001, MEDIC (Method d Evaluation de sc'nearious de Degradation probables d'Invessissements Correspondants) by Flourentzou, *et. al* (2000) and in the form of conceptual methodologies as demonstrated by Bamforth, 2003. Note that these models or methods require significant forms of data that are not readily available to the user. One of the issues is that the history of the building maintenance is documented in some form that needs to be processed before the aforementioned methods could actually be applied. This presents considerable challenges in linking the past history of the building components, ascertaining their present condition and in using these informations to reliably predict RSL. Furthermore, the definition of RSL seems to vary across the range of methods. Since the RSL is significantly dependent upon the durability and functional levels of an element, the aforementioned approaches seem to be suitable in particular situations and conditions. Thus a generic approach towards estimating RSL is generally lacking. Although the ISO methods were intended to cover a wide variety of situations and conditions, it appears that the model needs further improvement (Hovde and Moser, 2004).

In order to evaluate the residual service life methodologies in the context of re-lifing public assets, one case study building was considered (as noted earlier). Possible data has been collected and residual service life methodologies (ISO, MEDIC, Bamforth) have been applied. RSL estimates obtained from these methodologies were evaluated against the expert opinion. The results show that the average estimates of RSL are fairly in agreement with the expert opinion. However, the level and quality of data required to undertake this research suggests that a proper framework is required for estimating RSL values taking into account element condition and the variables driving the RSL of chosen elements. In this process, results from DELPHI studies have been used to identify the variables that significantly influence the RSL estimates.

Following this introduction, RSL methodologies have been described in Section 2. Application of the methodologies to building components has been described in Section 3. Comparison of RSL estimates with expert opinions has been described in Section 4. Framework resulting from the investigation has been presented and discussed in Section 5. The paper concludes with Section 6 summarising research results and identifying future research requirements.

2. BRIEF DESCRIPTION OF RESDIUAL SERVICE LIFE METHODS

2.1 ISO FACTORIAL METHOD

By far the widely accepted and widely criticised RSL method is the ISO factorial method. The method is based on the formula noted in below:

$$ESL = RSL \times f_A \times f_B \times f_C \times f_D \times f_E \times f_F \times f_G \qquad \text{(Eqn - 1)}$$

Where,
ESL = Estimated Service Life
RSL = Reference Service Life (This shall be denoted as RFSL for clarity)
f_A : Quality of component
f_B : Design Level
f_C : Work execution
f_D : Indoor environment
f_E : Outdoor environment
f_F: In use conditions
f_G: Maintenance

It is expected that any one (or combination) of these factors can affect the chosen service life. Thus suitable factors can be assumed (or derived) to estimate the ESL. Hovde and Moser, (2004) have shown that the ISO methods can be used to incorporate a probability distribution for these factors and thus specify a distribution for ESL rather than deterministic estimates. Even under the conditions of rigorous analysis it has not been possible to verify the accuracy of these predictions (Hovde and Moser, 2004). Thus the shortcomings in the ISO approach have prompted other researchers to develop new methods or models. One such model developed by Flourentzou, et.al, 2000 is discussed in the next section.

2.2 MEDIC METHOD

The MEDIC method is based on a typical classification of a given element into four degradation schemes that quantify the past and future degradation behavior. Thus the predictions are based on the combination of a priori defined probability distribution curves. Note that developing these curves requires considerable level of expertise and judgment. The application of this method has been demonstrated in the next section.

2.3 BAMFORTH'S METHOD

Bamforth, 2003, stated that the service life can be defined by *the time to achieve a maximum acceptable probability of the serviceability of a limit state being reached*. That is the margin against safety is no longer achievable. This method although conceptually sound, does not specify the time at which the serviceability criteria would be reached.

Thus all the methods described thus far, seem to have significant shortcomings despite their scientific basis. The application of these methodologies to case study buildings is discussed in the next section.

3. APPLICATION OF RESDIUAL SERVICE LIFE METHODS TO CASE STUDY BUILDING

DESCRIPTION OF CASE STUDY BUILDING

The case study building is a 40 year old office building of 7 occupied floors built over an older 4 level car park. It is believed that a majority of services within the building are at or beyond their economic life time and they have been in subsistence maintenance for quite some time. The building in its present stage is believed to be below standards in terms of acceptable indoor air quality levels, lighting, and energy consumptions besides some other issues. Consequently, the need to redevelop the building or demolishing and rebuild are presently being considered by the decision making authorities.

Structural aspects of the building in its present condition appear to be sound. However, signs of cracking, efflorescence, water stains, corrosion of reinforcement, spalling in concrete and minor deflections in slabs are noticeable. The facades have exhibited pronounced problems over the years and subsequent maintenenace actions has been undertaken. The façade of the building has been constructed from precast panels with a washed sand finish. The windows are inset into the precast as picture windows approximately 2 m high The authors collected the inspection reports, mainteneance reports, drawings and all relevant data on the condition monitoring of facades that dates back to late 1980’s. Photo 1 presents typical elevations of the building.

Case Study Building:
- 40 years old
- 7 Floors including a 4 level car park
- Façade – Precast panels with washed sand finish

West

South

Photo removed due to memory requirements. Available in the original version

Photo 1. Typical elevation of case study building and facades

RESIDUAL SERVICE LIFE OF CASE STUDY BUILDING FAÇADE AND NORTH WALLS USING ISO FACTORIAL METHOD

Estimation of Reference Service Life

Referring to the formula recommended in the ISO method, it is clear that the "Reference Service Life" (RFSL) forms one of the key inputs in estimating the RSL. The valuable informations collected by the authors were processed to identify a reference service life for building façade and walls. The methodology was published by Venkatesan, et.al, 2006 and is presented in below for clarity.

"One of the reports in the case study building describes the major defects observed in building façade some 10 years ago. Initially visual inspections using binoculars had been undertaken, followed by close up inspections and tests using approved abseiling techniques. Electronic covermeter tests were then conducted over selected regions to determine the depth of cover to the reinforcement. Concrete samples had been extracted at different levels for laboratory examinations. Results and observations were then collated and analysed in arriving at a decision.

During the visual inspection, spalls such as the ones presented in Photo 2 had been observed. In several cases this dangerously loose spall had been observed. In addition, other defects such as cracks due to concrete shrinkage, exposed reinforcements and honey combing had been observed. Test results from covermeter and carbonation tests indicated that the average depth of carbonation was greater than the average cover at various locations. The tests considered the relationship between the depth of carbonation and the thickness of cover to the reinforcement as an important indicator of durability and cause of corrosion. Additional tests such as chloride ion concentrations were also undertaken to identify the most probable cause of distress. Samples from nearby sites were also extracted and tested. It was then concluded that carbonation was the single most dominant factor that led to the development of loose spalls. The authorities considered the threat of loose spalls hanging at significant heights from the ground level as a public safety issue. Based on this criterion of public safety, major repairs were undertaken some 10 years ago. The authors have gone through all the other reports of the case study building façade to arrive at genuine conclusions.

From the above discussions, it can be noted that the decision of repairing facades has been based on the public safety issue. It is appropriate to state this as a limiting condition. That is the façade has reached the limiting condition of public safety. The authors wish to note that this is not their opinion but an analysis of what has happened in the case study building. Conceptually, it is now possible to develop a Bamforth model for this case study façade. This has been presented in Figure 1."

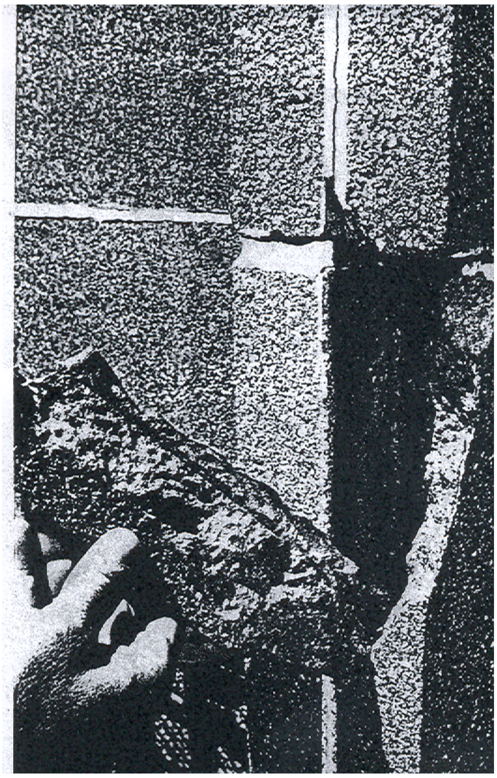

Photo 2. Typical loose spalls in case study building facades, year 1996.

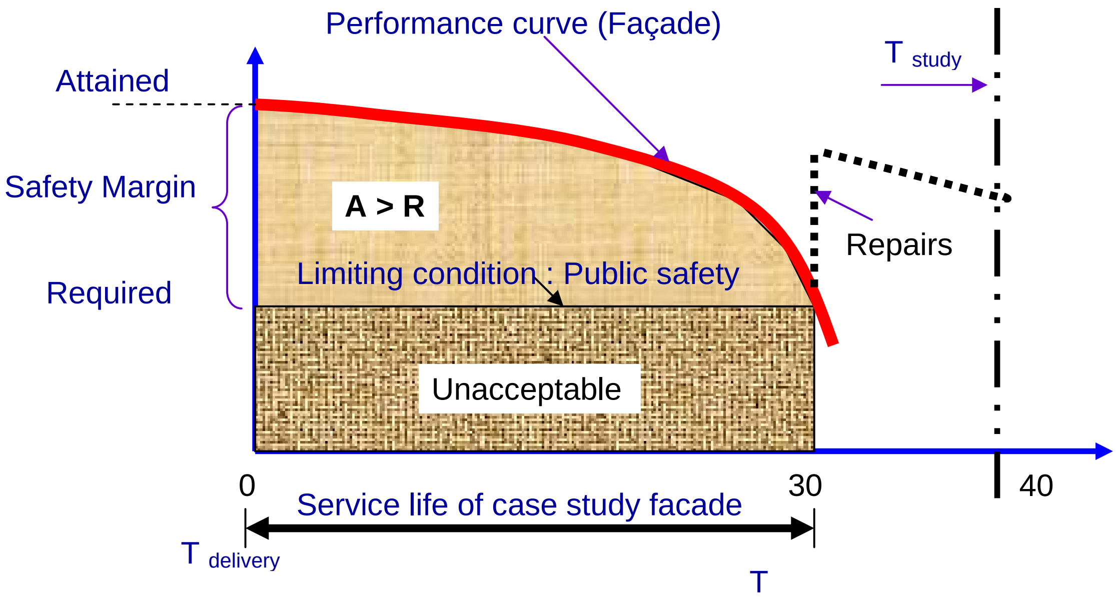

Figure 1. Bamforth's service life model for case study building facade

Preliminary estimates of RSL based on ISO factor method

Results from the previous section indicate that a reference service life of 30 years can be used as a basis for estimating the remaining service life. In particular, note that the repairs undertaken 10 years ago have improved the condition of the façade and walls, which are probably experiencing deterioration since then. This is denoted by the dotted line (Repairs) in Figure 1. Therefore the issue is to investigate the time at which these elements would reach similar limit states in future. For this purpose, it is important to establish the factors that would affect the RSL of these elements. It was decided that the "Outdoor environment" (factor f_E) and "In-use conditions" (factor f_F) are the two most dominant factors that would influence the RSL. Note that the carbonation has been identified as the single most dominant factor that caused the disintegration of façade elements. The rationale behind the analysis was further subdivided for each of the wall faces and factors arrived based on discussion and consensus opinions. This is summarized in Table -1.

Factor	Face	Relevant condition	Value
f_A : Quality of component	All	Generally good	1
f_B : Design Level	All	Generally good	1
f_C : Work execution	All	Generally good	1
f_D : Indoor environment	All	Generally good	1
f_E : Outdoor environment	North South East West	Not at risk due to rain leaks At a higher risk due to rain leaks (more windows) Heats up in summer Cools up in winter	0.9 0.7 0.95 0.95
f_F: In use conditions	S N,E,W	Frequent use / repair Consistent	0.8 1
f_G: Maintenance	All	Consistent	1

Thus plain application of the ISO factor method results in the following:

ESL (South) = 25 x 1 x 1 x 1 x 1 x 0.7 x 0.8 = 14 years

ESL (North) = 25 x 1 x 1 x 1 x 1 x 0.9 x 1 = 22.5 years

ESL (East) = 25 x 1 x 1 x 1 x 1 x 0.95 x 1 = 23.75 years

ESL (West) = 25 x 1 x 1 x 1 x 1 x 0.95 x 1 = 23.75 years (Eqn - 2)

Note that a RFSL of 25 years has been used instead of 30 years. This is considered as a conservative option. Therefore, RSL based on (2) can be estimated as follows:

ESL (South) = 14 -10 = 4 years

ESL (North) = 22.5 – 10 = 12.5 years

ESL (East) = 23.75 – 10 = 13.75 years

ESL (West) = 23.75 – 10 = 13.75 years (Eqn - 3)

The above results suggest that the given elements may have an estimated Residual Service Life of 4 years (on the lower side of the estimates) and 13.75 years (on the higher side of the estimates) with an average of 12.5 years.

Rigorous estimates of RSL based on probability distributions of factors in the ISO method

Note that the above discussions were based on plain multiplication of some notional factors derived on judgmental basis. However, the factors influencing RSL are highly variable and therefore these factors should encompass a probability distribution as suggested by some researchers. (Hovde and Moser, 2004). The authors undertook rigorous efforts to identify the type of distribution for the factors and arrive at representative factors based on the first and second moments of the probability distribution curves. Software DATAPLOT was used in this application and in some cases, results from similar studies identified in the literature were extracted. Table -2 presents the results of this analysis.

Factor	**Type of distribution**	**Face**			
		South	*North*	*East*	*West*
ERSL	Deterministic	25	25	25	25
f_A	Normal	1 /0.1	1/0.1	1/0.1	1/0.1
f_B	Deterministic	1	1	1	1
f_C	Lognormal	1.05/0.1	1.05/0.1	1.05/0.1	1.05/0.1
f_D	Lognormal	1.05/0.1	1.05/0.1	1.05/0.1	1.05/0.1
f_E	Gumbel	1.25 / 0.2	1.25 / 0.2	1.25/0.2	1.25/0.2
f_F	Lognormal	0.8/0.2	1.05/0.1	1.05/.1	1.05/.1
f_G	Normal	1.05/.1	1.05/.1	1.05/.1	1.05/.1
RSL (years)		28.9	37.8	37.8	37.8

Note that the RSL values estimated for the North, East and West side of walls appear less meaningful. Therefore the RSL value of 29 years is chosen to be representative of the existing situation. RSL estimated by the ISO factor methods need to be verified and for this purpose the RSL estimated based on the MEDIC method was chosen for comparative analysis.

RSL estimates of case study building façade and walls estimated based on the MEDIC method

As noted earlier, the MEDIC method requires a priori defined probability distribution curves for a given element based on experience and judgment. The Reference Service Life of 25 years adopted in the previous sections was chosen as the basis of defining the four degradation schemes of the façade element. At the present stage the façade and walls are in a "Fair" condition with less signs of deterioration. This can be confirmed by revisiting Photo 1. Since the present time of study is about 10 years since the major repairs, the element is hypothesized into the four following schemes:

Element in "Good" condition (A): 0 -7 years;
in "Fair" condition (B) 5 – 14 years;
in "Minor deterioration" condition (C) 10 – 22 years and

in “Needs replacement or serious deterioration” condition (D) somewhere between 15 – 25 years.

Note that there is a significant overlap of these conditions which is of practical significance. Building elements may not be characterized by exact transition from condition to another; rather the transition happens over time. The probability “space” of a given element is another significant point. For this purpose, the probability space was divided into two zones 1 & 2; 1 indicating favorable conditions of the element sustaining the estimated life and 2 indicating unfavorable conditions for sustenance of the element. The authors decided to choose zone 1, since the asset is well maintained and monitored by the authorities. These results are presented in Figure 2.

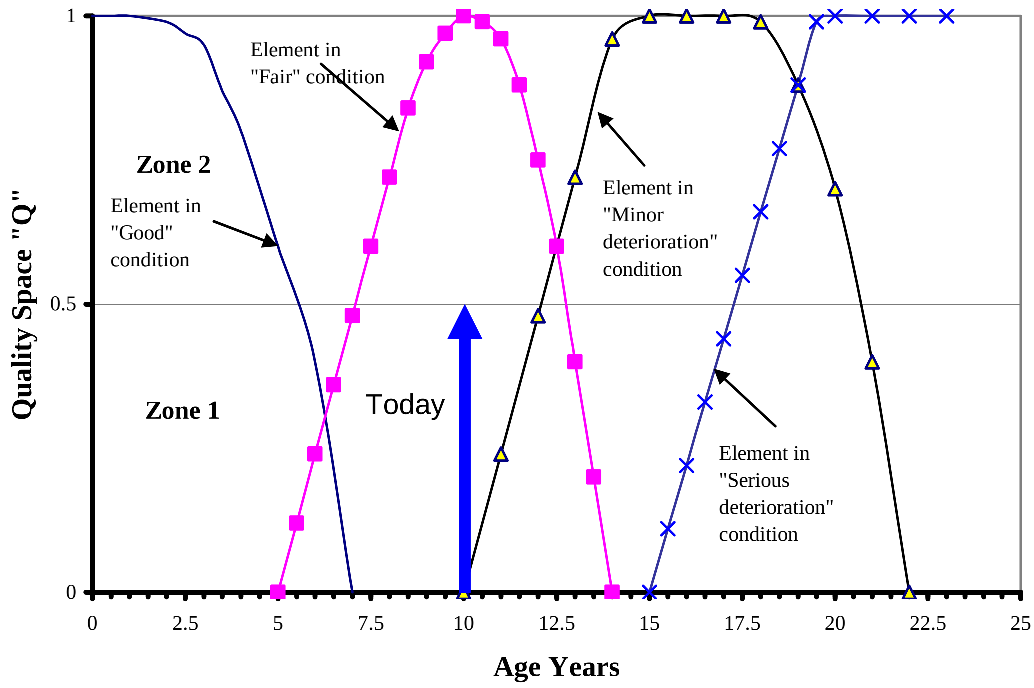

Figure 2. Typical conditional probablity curves for building façade based on a reference service life of 25 years

Following the deterioration curves defined in Figure 2 with the arrow representing the present time of study, it is possible to trace the future degradation stages of the elements. This is presented in Figure 3. Note that the RSL in this case is defined as the time at which the elements reach condition state “D” (i.e., major deterioration or needs replacement).

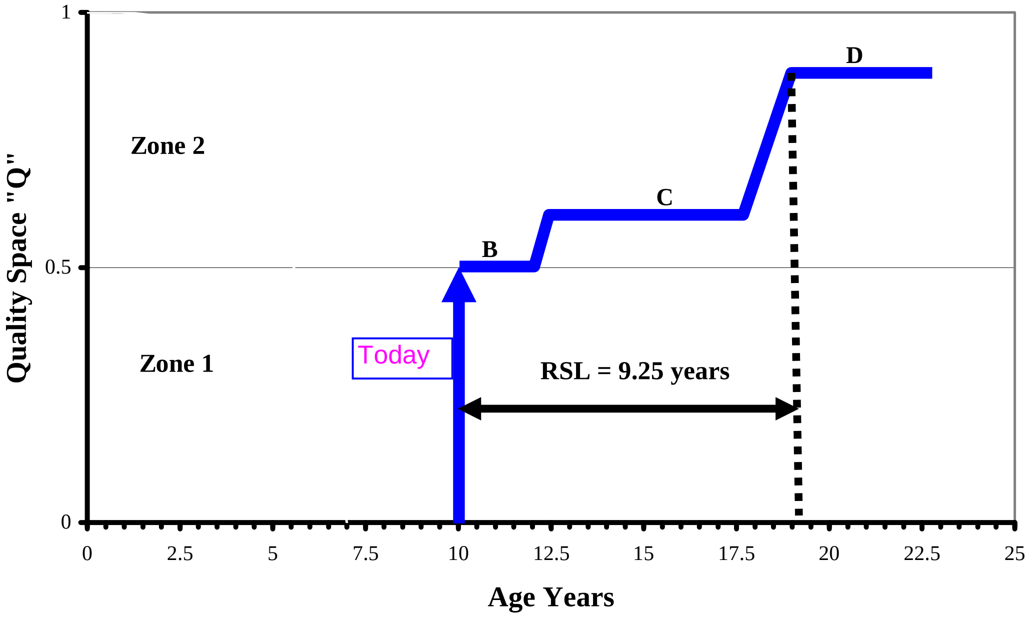

Figure 3. Future degradation pattern of the case study building façade and Residual Service Life estimation based on the MEDIC method

The above result shows that the Residual Service Life of the case study façade is 9.25 years. The RSL values estimated using the above methods has been verified with the experts, which is presented in the next section.

4. COMPARISON OF RESIDUAL SERVICE LIFE ESTIMATES WITH EXPERT OPINIONS

Key results from the previous section can be summarised as follows:

RSL estimated by the ISO factor method using less rigorous techniques resulted in:

- 4 years on the lower side of the estimate
- 13.75 years on the higher side of the estimate
- 12.5 years on an average

RSL estimated by the ISO factor method using rigorous techniques resulted in:
- 19 years as the best possible estimate

RSL estimated by the MEDIC method resulted in:
- 9.25 years as the best possible estimate

Thus the above results can still be condensed into the following results of RSL estimated for the case study façade and wall elements:
- 5 years on the lower side of the estimate

- 20 years on the higher side of the estimate
- 10 to 15 years on an average

The above estimates of RSL were evaluated against expert opinions. For this purpose, persons who have worked in the case study building and involved in the maintenance regime were invited to provide their opinion on the above study. These experts on a collective basis believe that the façade and walls would require major repairs between 10 – 15 years. Thus the methodology adopted in the paper in estimating the RSL suggests that the models are capable of providing meaningful estimates which can then be compared with expert opinions to arrive at rationale decisions of refurbishing given elements.

5. A FRAMEWORK FOR ESTIMATING RESIDUAL SERVICE LIFE OF BUILDING ELEMENTS

The above discussions points out that the RSL methodologies developed state-of-the-art are applicable in only certain conditions. For example, the Bamforth's model could not be applied to estimate RSL, but was useful in estimating the Reference Service Life of the element. Similarly, the ISO methods could be used to identify the particular factors that were expected to influence the RSL. However, the MEDIC methods were not based on any particular criteria (such as the Outdoor environment) although the authors were able to develop the probability distribution curves. Note that the maintenance regime of the case study building façade and walls almost has no reference to any of these methodologies in particular. That is the current practice of maintenance is based on a condition rating scheme being rated on a scale ranging from an "Excellent" condition of a given element to an "Unserviceable" or unfit condition. The maintenance authorities are only concerned about the audit rating scale and do not take into account of the factors that might further influence the future degradation or functional levels. Thus it appears that an integrated framework of condition assessment towards estimating RSL and thereby resulting in an informed decision making for "Re-Lifing" the public asset is generally lacking. It is interesting to note that the case study building authorities have acknowledged the need to document specific data based on the experience gained from this research. This has motivated the authors in recommending a preliminary framework of condition assessment procedures and identifying RSL methodologies that are applicable to the given conditions. The framework is presented in Appendix – A.

6. CONCLUSIONS AND FURTHER RESEARCH

Based on the research undertaken in evaluating Residual Service Life methodologies in the context of Re-lifing public assets, the following conclusions can be drawn:

- A combination of Residual Service Life methods may be required in the actual estimation of the service life of buildings.
- State-of-the-art Residual Service Life methods can provide meaningful estimates, which can then be evaluated using expert opinions to arrive at informed decision making.
- An integrated framework of maintenance scheme that takes into account of the condition assessment procedures and identifying possible factors that influence Residual Service Life of elements is required.
- A new approach towards documenting (future) maintenance data has been suggested.

It has to be noted that the paper considered one specific case study building. The authors currently involved in investigating similar case study buildings comprising of a number of building elements and components. Identifying rigorous basis for ISO factor methods and documenting reference service life of elements under the particular conditions is essential for successful application of the existing RSL methodologies.

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Appendix – A. A basic Framework for condition assessment and choice of RSL methodologies