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Appropriate use of the ISO 15686-1 factor method for durability and service life prediction

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ABSTRACT

Developing the detailed design life of a building or other constructed work is a key stage in service life planning. To predict the design life for the overall works in detail the design lives of the individual elements and systems need to be configured in a hierarchy, building up from the smallest elements to the whole works.

The proposed components and materials can then be considered. Failure modes and the causes of loss of serviceability need to be established along with their effect on the service life, and where relevant the risk and likely cost impact of premature failure established.

ISO 15686-1 recommends that, as far as possible, this analysis is based on service life prediction data generated using the approach set out in ISO 15686-2. However, where such data is lacking, the Factor Method described in ISO 15686-1 may be used as a means of generating the data required to develop the service life design.

Whilst the Factor Method may be helpful in developing the design life, it is important to appreciate the difference in quality of data between the two approaches. This has important implications for the development of design lives, and this paper considers how the data source influences the quality of design life prediction.

The paper demonstrates the application of the Factor Method to a specific element. It includes a critique and qualification of the approach and suggests that more attention should be given to the degradation both in terms of likelihood and consequences of risks of unacceptable loss of serviceability, and proposes an appropriate course of action.

KEYWORDS

Design life, service life, reference service life, failure mode, factor method.

1 INTRODUCTION

Developing the detailed design life of a building or other constructed work is a key activity in service life planning. Probabilistic design is widespread for major, usually infrastructure, projects and service life prediction is an accepted part of the design. This is not often the case for many smaller scale works, for example low rise domestic construction, where the use of the factor method may be appropriate.

Since the draft ISO 15686-1 first appeared in 1997 a number of papers have been presented at Durability of Building Materials and Components conferences and at CIB Congresses. Interest has focused mainly on ISO 15686-1, (ISO, 2000) and particularly the so-called "factor method" described in clause 9. However, this focus may be at the expense of the service life prediction approach described in clause 8 of the same standard, which is the subject of the entire ISO 15686-2, (ISO, 2001).

Ideally, to predict the service life of a component or element within a building, the micro climate needs to be known, the performance of the component or element under the specified climatic conditions should be accurately characterised by data from real life exposure in identical conditions, and the construction and maintenance regime for the building should be clearly specified and likely to be delivered in practice. It is, however, idealistic to expect this.

In practice service life prediction is based on judgement. This might relate to the actual microclimate to be experienced, or to the expected performance of the materials and components incorporated within the building. ISO 15686-2 is devoted to the testing of materials and components for the purpose of deriving data to support such judgements. In the absence of service life data from real life or from testing to ISO 15686-2, then the factor method outlined in ISO 15686-1 may be a useful tool.

The 'factor method' originated in the Architectural Institute of Japan (1993), and was further developed by Bourke and Davies (1997). It involves modifying a "reference service life", which is the expected service life of a product, component, or system under known conditions, using a series of "factors". The factors take account of the environmental exposure (internal and external) and anticipated installation, in-use and maintenance regimes. The purpose is to provide an empirical estimate of the likely service life. ISO 15686-1 is clear that it does not provide an assurance of a service life. Because the factor method could be applied in an almost infinite variety of situations there are no "standard" factors, although Appendices to ISO 15686-1 provide some examples of how the approach might be used.

When ISO 15686-1 was drafted the Factor Method was seen as a second choice approach in the absence of more precise, or even 'scientific' data. The basic factor method philosophy is one of estimating based on performance of a similar system under different conditions. The factors are 'rough and ready modifiers', addressing all the key aspects of the design which may affect its performance.

The factor method may be described as a means of "producing an answer by Friday". This is not to minimise or devalue the approach, rather to put the factor method into the context in which it is intended to be used. This paper looks at the development of a service life prediction with reference to both Parts 1 and 2, and considers how the source of the data used in the prediction influences the quality of the overall service life design. It uses as its example the detailed design and service life prediction of a roof.

2 THE DESIGN LIFE

It is important to have a macro context for the design life of the constructed facility and to ensure that the design life is appropriate. That is to say that the design life should reflect the existing needs of the owner and occupiers, and should also be able to meet future challenges that may arise from, for example, carbon based accounting and other sustainability criteria. This overall context will provide the basis for the design life of the works.
The objective of service life planning is to 'provide reasonable assurance that the estimated service life of a new building on a specific site with planned maintenance will be at least as long as the design life' (Clause 5.1 ISO 15686-1 2000).

In practice there are a range of stated design lives in any constructed work. These all influence the service life planning outcome during both the design and construction and during the subsequent operation of the asset. For example, a housing client may opt for a "Public Private Partnership" Contract for 35 years using an off site factory produced system, with a service life insurance scheme such as that operated by Construction Audit 1999, 2003. In this case the design life is 35 years.

ISO 15686-1 Clause 6.2 addresses "the brief", and requires a decision establishing the design life of the building and leads into the actions set out in Table 1. For the service life estimation stage the designer should 'identify the components requiring service life prediction'. Whilst the idea that the designer determines the design and service life may be implied in ISO 15686-1, it is important not to take a component out of context, but to set its design life in the context of the whole works.

3 CLUSTER MAPPING

The definition of context or configuration of the components can be assisted by the technique of cluster mapping. The components and materials are sorted by element or system within the works. Buildings are made up by combining components or materials into assemblies of elements and systems (Figure 1).

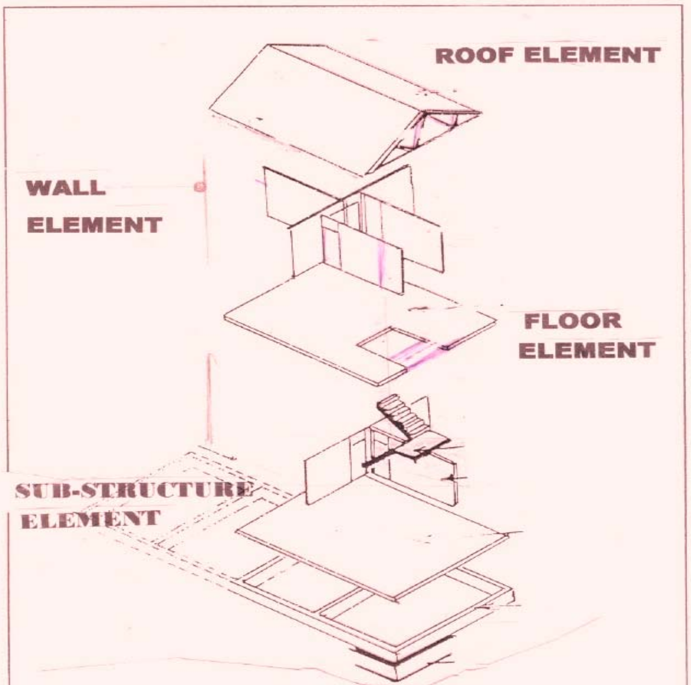

Fig 1 The Constructed Work's Configuration Breakdown

In cluster mapping the constructed work is broken down from its General Arrangement, Elevations and Sectional drawings into its respective elements and systems. The concept of the cluster map is illustrated in Figure 2. The cluster map is developed in the following stages:

Stage One identifies the overall design life of the works.
Stage Two identifies the individual Elements and Systems.
Stage Three establishes the design life for each element and system
Stage Four identifies the cluster of materials and components within each Element and System.

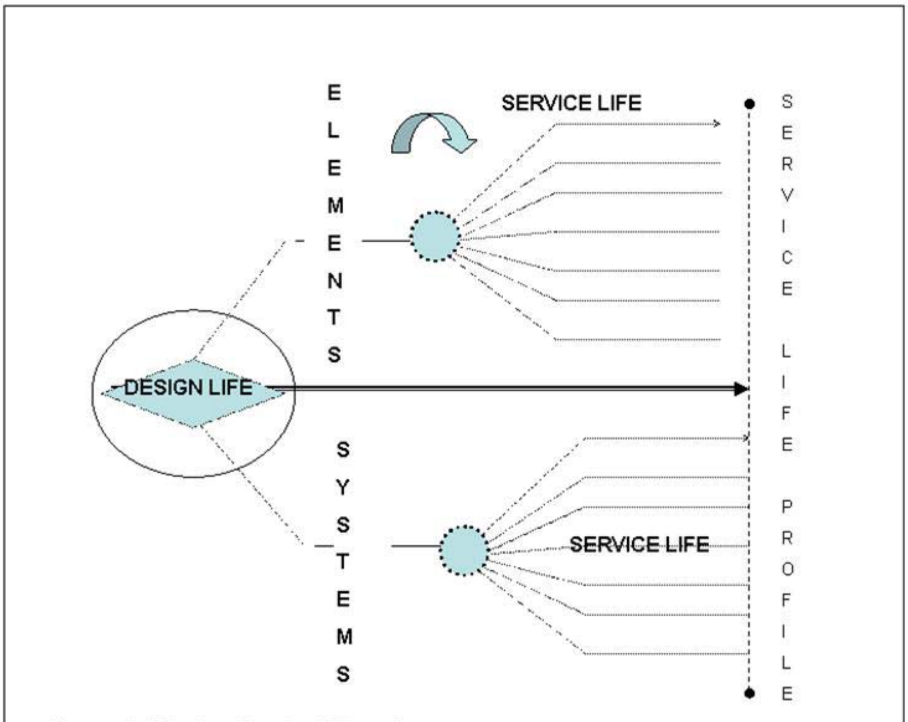

Figure 2 Cluster Context Mapping

The importance of Stages Two and Three is illustrated in Figure 2. The design life of the whole works drives the design life of the elements and systems, and requires an analysis of each element and system within the whole building. From the cluster map it becomes clear which elements and systems must have the same design life as the works, because replacement is not an option. It is also possible from the cluster map to identify elements and systems which may be replaced during the design life, such as rain screen cladding, waterproofing, sealants, boilers or air conditioning units.

This is important for sustainable construction. Reducing resource use in construction requires more flexible buildings, better able to be adapted and reconfigured or re-used. Such re-use may require changes to systems and elements in the building, such as facades and internal partitions. The design life of such elements and systems needs to be specified with a view to the possible future use of a building.

It is important to identify each component and material in turn within each element and system. The location and use affects the service life, and each material or component will have its own varying decay characteristics depending upon their configuration, environment and potential for maintenance. In the case of systems such as boilers there is also a need to consider their reliability and serviceability. As well as considering the failure modes, probability techniques such as the mean time to failure and survivorship analysis may also be used for such mechanical systems.

The overall design life has implications for all the different elements and systems. For example, whilst the foundation system may remain in service throughout the design life it may face aggressive ground

water or contaminated ground conditions that will result in protective membranes being of limited value, concrete durability being impaired or the compressive medium used to accommodate ground movement rendered ineffective. Ultimately failure of such critical elements may spell the end of the service life of the whole building – otherwise described as "service death".
Such implications exist for all elements and systems, particularly when moving from empirical based construction to performance based designs with limited or non existent data. In all situations however, it is essential to map and formalise both the building context and its individual elements and systems configuration before a detailed analysis can be undertaken. It should also be understood that this process may need to be repeated as life cycle assessment and whole life costing are brought into the service life planning process, and may lead to the conclusion that a particular element or system cannot meet the design life requirements, and must be changed.

4 APPLICATION OF THE ISO 15686 APPROACH IN PRACTICE

A roof element has been selected to explore the relationship between ISO 15686-1 -2. The ideal scenario for predicting the service life of any component or element within a building is one in which the micro climate is known, the performance of the component or element under the specified climatic conditions is accurately characterized by laboratory, or better still, real life data and the construction and maintenance regime for the building clearly specified and likely to be delivered in practice.

This case study explores the need to analyse the composition of the element and the practicality of predicting its service life. It is preferable to predict performance based on laboratory or real life experience data. No more clearly is this shown, than in meeting performance requirements in the roofing element now being considered in Figure 2. For once the roof starts to fail there is a risk of internal damage both within an element like a warm roof and to the interior, which may result in premature failure of other elements, however good the detail or specification was.

4.1 The case study building

The building is exposed, facing westerly winds on its long face for up to 30 days a year. It is an earth stone wall barn structure of some 100 years or more in age but has a structurally decaying roof carcass and areas of roof covering are missing. The roof surface area during the summer months also receives strong sun rays for a significant part of the day with temperatures up to the low 30s Centigrade.

The project described is the conversion of an existing 5M X 20M two storey barn into a dwelling. The client requires a design life of 40 years. The site is in a marine coastal environment with wind speeds that may exceed 135km per hour for between 2 and 5 days a year. The building's roof covering requirement has been defined by a Local Authority planning condition as an approved natural slate as the dwelling is in a conservation area.

To meet Building Regulations requirements a warm roof supported by plate connected truss rafters at 600 mm centres, suitably braced, has been specified. The specification relies on the established guides and standards (BSI 2003). The service life has then been assessed using ISO 15686, identifying what factors were critical and where the ISO 15686-2 or the factor method are relevant.

Figure 3 shows the resulting cluster analysis for the roof element. It identifies the sub-elements – ridge, battens, slates, rafters, wall plates, rainwater drainage and the soffit cladding system. This analysis can be used to identify weak links in the design. It may reveal the need to redesign in order to meet the design life requirement. It places increasing reliance on material and engineering science in the wider context of service life planning. This will become more important as we move to performance based regulation of construction. The clusters and their subsets are all duly numbered and identified in Table 1 in the eight sections. The responses to the issues in the factor method as described in ISO 15686-1 Part 1 are addressed. The factor classes are as set out in the ISO, namely:

A	Quality of components
B	Design level
C	Work execution level
D	Indoor environment
E	Outdoor environment
F	In use conditions
G	Maintenance Level

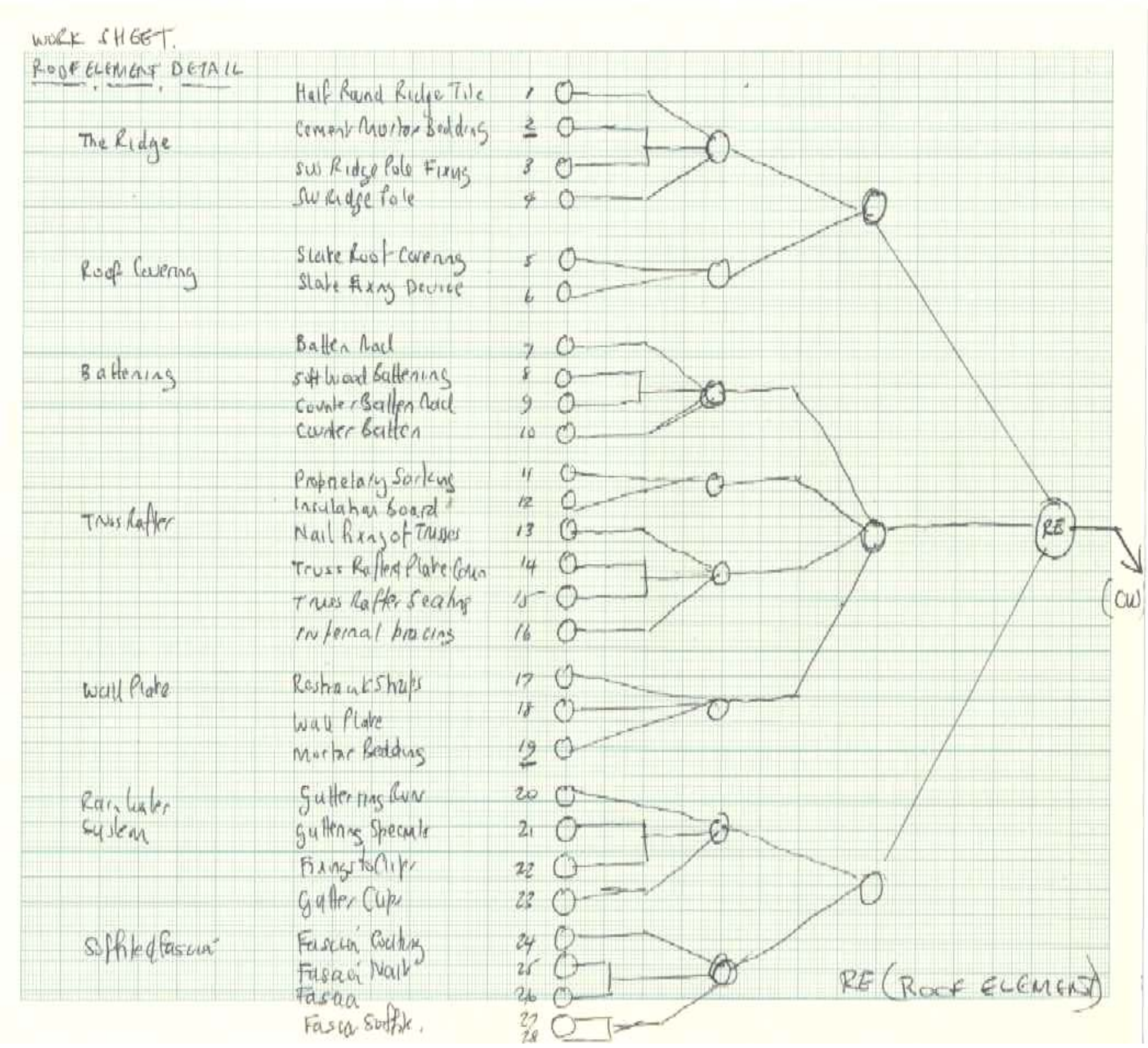

Figure 3 Cluster Mapping

Note: This Work Sheet originally had nine sub clusters. Eight are shown: the ninth is the chimney stack for a Combination Boiler. This has been omitted from the study as it was included in the analysis of the heating system. However, the interface with the roof was a consideration in practice.

Within each sub-cluster a specific action or response is noted, e.g. to respond to maintenance for the soffit, barge board and fascia area (Lines 23-28) whilst the treatment of the roof covering (Line 5) using the Factor Method needs considerable qualification.

Where relevant the risk and likely cost impact of premature failure is identified, along with those service life critical dependencies and possible failure modes or service losses that could arise in the element or constructed work. Based on this analysis, a reference service life (the expected service life under defined conditions) can be specified for each line in the table. This analysis can also feed into a life cycle assessment or life cycle costing analysis.

Table 1 Summary of the Roof Element's Constituent Parts

Roof Element		RSL	Factor Classes							Factor Class Comment
Ref	Constituent Part	Yrs	A	B	C	D	E	F	G	
1	Clay Half round ridge	40	*	*	*				*	Tile and mortar quality and workmanship play an important part here but some re-bedding might be expected on a maintenance repair basis
2	Bedding mortar	40	*	*	*		*		*	
3	Ridge Pole nail	-								No change of note expected
4	Ridge Pole SW Batten	-								No change of note expected
5	Roof covering	75	*	*	*		*		*	Environmentally exposed including during construction and in service access
6	**Slate fixing**	**Part 2**	*	*	*	*	*		*	Serious risk of corrosion compromises whole roof
7	**Batten nail**	**Part 2**	*		*	*			*	Performance is likely to be a core issue
8	Batten	75	*			*				Few known failures to date
9	**Counter batten nail fixing**	**Part 2**	*	*	*	*	*		*	Performance may be impaired if workmanship or specification is sub standard and risk of corrosion
10	Counter batten		*		*	*	*		*	Performance and reliability must be equal to the roof covering life
11	Sarking membrane			*		*				Performance over time not known but expected to remain serviceable
12	Insulating boards	N/K	*	*	*	*	*	*	*	Overstressing though hogging risk on installed EPS especially if wind loads increase due to climate change and risk of insect bird attack
13	Truss rafter	40	*	*	*	*		*	*	D some risk of deformation due to temperature and wind loading over time Poor installation/ fixing may impair whole
14	**Truss rafter plate connector**	**Part 2**	*	*	*	*		*		A, D, C Plate connector corrosion risk the longer the truss remains in service especially from a possible breakdown from the warm roof protection and/or RH
15	Truss rafter plate clip seating	-	*	*	*	*				Indoor environment might lead to some corrosion but not considered serious other than nailing
16	Internal bracing	-	*	*	*		*		*	The importance of workmanship and design method becomes critical over the climate change cycle and the area poses a risk
17	Restraint straps	-	*		*		*			
18	The wall plate	-								No change of note expected
19	Mortar bedding	-								No change of note expected
20	Guttering runs	20	*	*	*		*	*	*	Performance impaired if design/ installation is poor and annual maintenance is essential
21	Guttering + special components	15	*					*		Whilst there may be loss of serviceability it is likely as the parts age they will simply break whilst the gutter seating may drip. So in terms of the roof element one expects a cyclic replacement 15-20 years
22	Fixings to guttering brackets	15		*						
23	Gutter brackets	15			*					
24	Fascia protection	1-2		*			*			Extreme conditions where exposed timber may be the best solution
25	SW fascia and barge boards	30	*		*					Variable environment. Vent grill likely to suffer from marine and solar environment

26 27	Fascia soffit and grill	16 9	* *	* *	* *	*	* *			some replacement may be necessary on the Westerly Elevation and SW Barge Boards

* denotes factors critical to the performance and reliability of the cluster or of the element in service.

It can therefore be seen that the selection of the reference service life is critical to the success (or otherwise) of the whole approach. The cluster analysis leads to the conclusion that the performance of the whole roof structure is critically dependent on the truss plates and the nails used to fix the battens to the trusses and the slates to the battens. Because of the marine environment it is important to consider the potential corrosion risk arising from the salt laden atmosphere, and its likely effect on the performance and service life of the whole roof. Moser (2003) considered the impact of material degradation and its potential to impair the integrity of an element or component, leading to early unexpected replacement.

The cluster analysis enables identification of critical components and materials within the element, highlighting the significance of the service life data, and indicating which aspects of the data set require the greatest attention. In this case the performance of the metal fixings is vital, and the most accurate reference service life data is needed for these lines in Table 1. It is possible to take service life data from similar situations and apply factors, but there is a strong case for seeking the greater accuracy that data generated using ISO 15686-2 can offer. Service life data derived from quantified corrosion testing is likely be far more accurate in this case, and should be obtained if at all possible.

In the UK such data is available, although not obvious. The Code of Practice (BSI, 2003) for roofing and slating contains guidance on the appropriate fixings for use in a variety of environments, based on corrosion data and practical experience acquired over many years.

A further issue relates to the length of the design life and the consequent requirement for accurate data. The design life might only be 40 years, but it is important to know what it represents. It may be a period in which there is less than a given probability, say 5%, of failure, which is sometimes the case when it the basis for insurance against premature failure. It may be the length of time until a significant number of components or parts of a system need replacing. It may of course be the life of a structural element, failure of which ends the useful life of the building or works.

This context needs to be considered when using either the factor method or service life data derived using the approach in ISO 15686-2, as the context sets the requirements for accuracy of data. Table 2 shows the results of an analysis of the likelihood of the roof described above achieving three different design lives. It shows that certain aspects of the design may not be able to deliver a service life of 60 or 110 years. This shows once again that the reliability of the data used for service life prediction needs to be considered with care, and in the full knowledge of the overall context.

Table 2 Cluster Design Period Summaries

Cluster	Ref	40 years	60 years	110 years	Comment
Ridge	1-4	Ok	ok	Ok	Cyclic maintenance and replacement
Roof covering	5-6	Ok	ok?	No	Factor and Probabilistic Analysis required
Battening	7-10	Ok	no	No	Probabilistic Analysis required
Truss Rafter	11-16	Ok	no	No	Factor and Probabilistic Analysis required
Wall Plate	17-19	ok	ok	Ok	No response expected
Rain water system	20-22	Ok	ok	Ok	Cyclic maintenance and replacement
Barge Boards Fascia soffit	23-28	Ok	ok	Ok	Cyclic maintenance and replacement

Again, to assess the importance of this it is Aarseth & Hovde (1999) show that both the probability of an event and the frequency or occurrence must be considered in a risk based approach. Such methods are already being used in the maintenance and asset management field. When using the factor method for replaceable elements and systems it is important to consider the risk of failure as well as the element and system design life.

Questions often arise about "what the factors should be". Unlike partial safety factors in engineering documents, however, there is no "standard" set of factors. Instead the user needs to decide for themselves what factors to apply in a given set of circumstances. The analysis outlined above will be a great help in doing this, as it will identify those aspects of the service life planning which require greatest attention, and are most critical to an accurate prediction of the service life. For example, a product known to be highly sensitive to the skill and care of the installer probably should not be specified for use where such skill and care is not readily available. In the case study the service life of the insulation media poses a considerable challenge, as it may be shorter than the specified design life. . Likewise the service life of the battening and truss fixings requires a material corrosion response.

For these reasons it is not possible to produce "standard" factors. Indeed, if it were possible to produce standard factors the factor method would be redundant, as it would be possible to produce standard service life data instead. However, the range of in use conditions and environments renders that task impossible. Instead, service life prediction requires the skill and care of an experienced practitioner able to assess the key components within an element or system, and the most significant possible failure modes and deterioration mechanisms, and predict the likely performance of the element or system under the proposed in use conditions.

Finally, it is important to note that the basis on which service life data has been chosen needs to be acknowledged for reference in the performance review or audit stage (ISO 15686-3, 2003) and the limitations and assumptions that have been made need to be recorded.

5 CONCLUSIONS

Where accurate service life prediction data is required design life mapping has the potential to identify the key aspects of the design, enabling greater focus on them. Judgement and qualification must be exercised when predicting service life, with particular attention to the accuracy and reliability of the data used. As with computers, so with service life: garbage in – garbage out!

Perhaps it is time to suggest that all researchers who produce papers on ISO 15686-1 should be required to read ISO 15686-2 and to demonstrate the connection between their work on factors with part 2? Perhaps it is also time for a mild celebration that service life planning has moved from academic ideal to practical reality in the last decade, and to encourage researchers to seek practical experience of service life planning, and to use that experience to identify an agenda for service life planning research for the next decade

REFERENCES

Aarseth L Hovde PJ (1999) A stochastic approach to the factor method for estimating service life. 8th International Conference on Durability of Building Materials and Components, Vancouver, Canada

Architectural Institute of Japan (1993) The English Edition of Principal Guide for Service Life Planning of Buildings, Architectural Institute of Japan, Tokyo 38PP

BSI (2003) BSI Code of Practice for Slating and tiling including shingles BSI UK ISBN 0580 417409

Bourke K and Davies H (1997) Factors affecting service life predictions of buildings: A discussion paper. BRE Laboratory Report 320 Garston

Construction Audit Ltd (1999) HAPM Component Life Manual EF SPON 376PP

Construction Audit Ltd (2003) HAPM Building Services Component Life Manual EF Spon pp?

ISO 15686 (2000) Buildings and constructed assets- service life planning Part 1: General Principles. Geneva 59pp

ISO 15686-2 (2003) Buildings and constructed assets – service life planning – Part 2 Service Life Prediction Procedures Geneva 32pp

ISO 15686-3 (2002) Buildings and constructed assets – service life planning – Part 3 Performance audits and reviews Geneva 38pp

Moser K (2003) Design Methods or Service life planning Cib W080 Durability in the building process Milan Polytechnic di Milano 12pp