2012

Service Life Prediction of Residential Interior Finishes for Life Cycle Assessment

Can B. Aktas Ph.D.
University of New Haven, caktas@newhaven.edu

Publisher Citation

Aktas, C.B., Bilec, M.M. (2012). Service life prediction of residential interior finishes for life cycle assessment. International Journal of Life Cycle Assessment, 17(3): 362-371. doi: 10.1007/s11367-011-0367-6.

Service Life Prediction of Residential Interior Finishes for Life Cycle Assessment

Can B. Aktas[a], Melissa M. Bilec, Ph.D.[b]

[a] Doctoral Candidate, Department of Civil and Environmental Engineering, University of Pittsburgh, 3700 O'Hara Street, Pittsburgh, PA 15260, USA. Email: cba5@pitt.edu, Phone: 412-624-9870; Fax: 412-624-0135.
[b] Assistant Professor, Department of Civil and Environmental Engineering, Mascaro Center for Sustainable Innovation, University of Pittsburgh, 3700 O'Hara Street, Pittsburgh, PA 15260, USA. Email: mbilec@pitt.edu

Abstract
Service life of building products has an important influence on life cycle assessment (LCA) results of buildings. The goal of this study was to propose a systematic approach to estimate service life of building products by including both technical and social factors. A hybrid service life prediction method, combining the statistical approach described in American Society for Testing and Materials (ASTM) standard G166, with the Factor Method adopted by International Organization for Standardization (ISO) standard 15686 was proposed. In their current forms, the two methods are not suitable to provide accurate lifetime estimates for the wide variety of products that are used in buildings. Statistical analysis was preferred over a deterministic approach. Regression analysis was used to define Weibull distribution parameters for each product. These distributions were then used to calculate the mean estimated service life of products with an 80% confidence interval. Using actual lifetime observed from practice instead of design lifetime for reference service life was preferred. This enables the use of a smaller range of coefficients for each factor affecting service life, which decreases subjectivity and increases reliability of results. Example service life estimates were demonstrated for common residential interior finishes that are replaced more frequently, and therefore require more maintenance planning and potentially have significant environmental impacts. Unless additional data points were gathered for investigated products, the presented lifetime distribution results can be directly applied to LCA studies.

Keywords: Service life prediction, life cycle assessment, interior finish, factor method

1. Introduction

The construction industry and the built environment are two key areas if we are to achieve true sustainable development. The sheer size of the construction industry and the dependence of other industrial sectors on the built environment makes them critical for the social and economic development of many countries [1]. However, the built environment is also a primary source of environmental impacts, not just due to initial construction phase, but also from emissions occurring during the use phase to provide comfort and serviceability to occupants. The existing building stock requires continuous investments for repair and renovations, which increases life cycle impacts [2].

Life cycle assessment (LCA) is a tool that can quantify the environmental impacts of products, processes, and also buildings [3]. However, many building LCA studies do not adequately address service life, the period for which the product is actually in use, for buildings and building products but rather assume typical values, e.g. 50 years for residential building lifetime [4-7]. Such assumptions for building and building product lifetimes introduce additional uncertainty into the study and have the potential to alter results.

Compared to the structural frame or permanent components of a building, interior finishes such as paint or flooring overlays are replaced more frequently over the life cycle of a building, and potentially have significant environmental impacts. Lifetimes of interior finishes are affected by consumer behavior to a much higher degree compared to permanent components of a building, such as roofing or exterior insulation. Therefore, it is vital to accurately estimate service life of interior finishes in an LCA study. This study proposes a tool to estimate service life of products that are affected by consumer behavior.

Knowledge about expected service life of building products is a key component for sustainable construction, as well as maintaining infrastructure assets [8]. Asset managers are responsible for a significant amount of construction and maintenance work. Costs accrued during the use phase of a building may be comparable to or even exceed initial design and construction costs [9]. Service life prediction of building products offers great benefits for facility managers in terms of providing a means of foreseeing future expenditures related to renovation. The ability to predict future expenditures would reduce budgetary pressures and would also allow construction work to be scheduled accordingly. Service life is a key metric that is utilized for economic decision–making for return on investment or investment planning for maintenance [10].

This study addresses a gap by modifying the commonly accepted service life prediction method, namely, the Factor Method, to determine service life of building products that can be used within LCA. Statistical use of published lifetime data that inherently includes both social and technical factors that influence lifetime would improve the reliability of calculated service life estimates. Including accurate lifetime information into LCA allows a better understanding of life cycle impacts, ultimately enhancing the accuracy of LCA studies. The discussions herein were supported by examples for residential interior finishes.

1.1. Service life prediction and LCA

For building products, lifetime has the potential to influence LCA results and even alter the results of product comparison studies. The extended use duration of buildings and building products compared to daily consumable products necessitate that service life be taken into account during analysis. Therefore, reliable data on service life of building products would improve LCA results [11].

Due to lack of service life data and a systematic method to predict the service life of interior finishes, LCA practitioners rely on limited data, or use arbitrary product lifetimes in their analyses. In addition to providing a more engineered approach to the problem of service life prediction, the proposed method and results calculated for interior finishes would also find applications within building LCA. LCA and service life prediction can be used in conjunction to identify and optimize service life and environmental impacts of building products [2].

1.2. Existing Service Life Prediction Methods

As suggested by Masters and Brandt [12], service life prediction methods should be generic enough to be applicable to a wide range of materials, should clearly state their boundaries and document assumptions, and should guide users for interpretation of results. In addition, service life predictions need to be made by using standardized methods to ensure objective and comparable results [13]. There are different approaches to service life prediction that can be grouped under four categories, each having unique applications and limitations: analytical models, statistical models, empirical methods, and experimental methods [14].

The analytical models proposed by various researchers to estimate service life of building products or components include predictive equations to estimate deterioration progress of building materials, methods that use Markov chains or Laplace transformation of time dependent variables, computer programs that use adaptive importance sampling and fault tree analysis [2]. Statistical models that predict the amount of deterioration based on data from laboratory test results were also proposed. However, unless a large dataset is available, the use of a purely statistical approach may not be the best approach [15]. The Factor Method originally developed by the Architectural Institute of Japan and later adopted by International Organization for Standardization (ISO) standard 15686 for service life prediction is an example of an empirical method. The lifetime of a product can also be determined experimentally by testing for expected in-use conditions or unfavorable conditions for accelerated testing [14]. Daniotti and Cecconi have published a state-of-the-art report on test methods for service life prediction having a focus on accelerated laboratory test procedures and their correlation to service life data [16].

The two American Society for Testing and Materials (ASTM) standards on statistical analysis of service life data, namely, ASTM G166 and ASTM G172, provide guidance on estimating service life of products when an adequate sample size has been obtained through testing, either under normal conditions, or in an accelerated test setup [17, 18]. The two standards were not developed for service life prediction and are more suited towards lab testing of products to obtain lifetime distribution curves. However, a detailed description was presented for a statistical procedure to define service life distributions from lifetime data, which was used in this study.

Although there are a multitude of different methods and approaches, the existing trend in service life estimation has been to focus on material durability as a means of estimating service life [14, 19-23]. This represents a purely technical approach, where subjective behavior of consumers is excluded. Although such a technical approach may be valid for structural frame of a building, it is limited in scope for interior finishes where consumer behavior may influence product lifetime to a much higher degree.

Among the listed methods, the Factor Method stands out as a versatile tool that can incorporate consumer behavior to assess service life. In addition, the method has been adopted by ISO 15686 for service life prediction and therefore was used in this study. Another contributing factor was that LCA, also described by the same standardization organization (under ISO 14040), would be a primary area for application of results.

Existing service life prediction studies focus on structural frame elements such as concrete, steel, and wood, or on external building components such as roofing or exterior insulation [16, 24-26]. Building products that are replaced more frequently, therefore having the potential of higher environmental impact over the life cycle of a building, currently lack viable service life research results. The goal of this study was to integrate existing techniques, standards, and reports and apply them to residential interior finishes to estimate service life that can then be used to improve LCA studies.

1.3. Factor Method

In ISO 15686, the Factor Method is defined as a way of bringing together various factors that influence service life of products in order to make lifetime estimates. The purpose of the Factor Method is to provide an estimate of service life, which is different than service life prediction. By definition, estimated service life is calculated for a set of specific in-use conditions, whereas predicted service life is recorded past performance which should ideally be equal to the reference service life used during calculations [2, 24, 27, 28].

In order to estimate service life by using the Factor Method, the reference service life of a product is multiplied with coefficients that are assigned to factors A through G given in Eq. 1 (see Table 1 for definition of factors). A coefficient of 1.0 is assigned to factors that are found not to influence service life. Coefficients can be increased or decreased according to the specific application in comparison to the reference case. Conditions that should be considered while assigning coefficients to residential interior finishes have also been presented in Table 1. According to ISO 15686, the user is free to choose a suitable coefficient for factors that affect service life. Product specific guidelines have not been developed until now due to the complex nature of the problem [27]. Selection of a suitable starting point, the reference service life, is thus crucial to obtain reliable results.

$$ESLC = RSLC \times A \times B \times C \times D \times E \times F \times G \qquad (1)$$

where *ESLC* is estimated service life of a component or product, and *RSLC* is reference service life of a component or product.

In the comprehensive state-of-the-art report by Hovde and Moser [2], estimation of reference service life has been identified as a topic that needs improvement. Establishing reference service lives for commonly applied residential interior finishes has been one of the outcomes of this study.

Table 1. Definition of factors and their relation to residential interior finishes [12, 27, 29]

Agents	Factors	Conditions relevant to residential interior finishes
Inherent quality characteristic	A – Quality of components	Manufacture, storage, transportation phases
	B – Design level	Sub-layer, physical incompatibility
	C – Work execution level	Level of workmanship
Environment	D – Indoor environment	Biological factors, condensation, sustained or random stress
	E – Outdoor environment	Solar radiation
Operation conditions	F – In-use conditions	Occupant demographics, wear and tear
	G – Maintenance level	Quality and frequency of maintenance/cleaning

ISO 15686 requires service life estimations to be given with an 80% confidence interval [27]. The use of confidence intervals facilitates interpretation of the reliability and accuracy of results and provides a more statistical approach to the method. However, the current form of the method, where the user decides deterministic coefficients to each factor affecting lifetime would not produce meaningful results since reliable probability distributions cannot be setup from a single value assigned to a factor. Therefore, the use of confidence intervals together with deterministic values would create a false sense of accuracy in lifetime estimates [29]. Statistical distributions were defined and used for reference service life calculations in this study. Distributions defined from multiple data points allowed the use of an 80% confidence interval as suggested by ISO 15686.

Applications of service life prediction techniques, and of the Factor Method in specific, have been fairly limited. One aspect that limits the use of the method is a lack of knowledge of the tool and its capabilities by potential practitioners such as architects, consultants, building owners and managers [2]. Additionally, the current deterministic approach gives too much independence to users and is another barrier preventing the widespread use of the method. Accurate and reliable results cannot be obtained by using the Factor Method in its current form. In this study, these shortcomings of the Factor Method have been improved by the use of statistical distributions, in addition to determining reference service life by including consumer behavior as an additional factor.

1.4. Impact of consumer behavior on service life

Product service life is affected by two categories: durability related factors, and social and economic factors [30, 31]. Products may be replaced due to failure or poor performance, as in the case when a painted surface fades excessively or starts to blister or peel. On the other hand, some durable products that are functioning from a technical standpoint could also be replaced due to social and economic factors, such as when an occupant wishes to change the color or tone of a painted surface. The existing Factor Method successfully captures factors related to durability, but excludes social factors and occupant behavior.

Service life of building products are seldom determined by their durability [2]. Research on repair projects have found that only 17% were initiated due to deterioration [32]. The subjective perception of a building was identified as the main cause of renovations. Therefore, the reference service life of a building product cannot be solely based on its design life or technical properties. Consumer behavior, which is not currently covered within the Factor Method has significant influence on product service life [33].

2. Methods

The proposed method in this study is a hybrid approach combining the statistical procedure outlined by ASTM G166 to define reference service life distributions, together with the use of triangular distributions to define factors that influence lifetime given by ISO 15686. Using a range of values or a distribution to define coefficients instead of deterministic values is a necessary step towards improving the reliability of results obtained from the Factor Method [10, 34, 35]. A triangular distribution defined by a minimum, maximum, and the most expected value is suggested. The straightforward form of a triangular distribution provides an advantage for the interpretation of results by users that may be from a wide range of backgrounds. In addition, when distributions are defined based on judgment or experience of the user, the use of more complex distributions may be unnecessary from a practical point.

The proposed method in this study decreases the range of coefficients necessary for modifying factors, thus decreasing the sensitivity of results to variations assigned to each factor by different users. For building products that are used for extended durations, choosing a suitable starting point, reference service life based on average practices that take consumer behavior into account, becomes a crucial first step in lifetime estimations.

Data sources used to demonstrate examples for interior finishes together with the procedure used to define distributions were described in this section. A hypothesis test conducted to check the relationship between calculated service life and the probability of renovation was also described.

2.1. Data Sources

Multiple data sources were used to collect information on service life of interior finish products. Lifetime values suggested by trade associations as well as values used in peer-reviewed journal articles were used as data points in the current study. The fact that the majority of research papers found to contain product lifetime information were related to LCA signifies that service life prediction and LCA are interconnected and can be used together to improve the reliability of results.

Design lifetimes and product guarantee durations published by manufacturers were not included into the dataset in this study. Lifetime data based on actual service life was used to define distributions. Actual service life of products inherently includes the effects of consumer behavior as well as technical criteria or durability. Therefore, the proposed method incorporates consumer behavior into reference service life calculations, and thus into the results of the Factor Method.

2.2. Products Investigated

Service life prediction of products should be differentiated according to type of building. Residential and commercial buildings have different occupant demands and renovation cycles. Residential buildings have been proposed to have a renovation cycle of 20-50 years, whereas the interval decreases to 10-20 years for offices and 5-10 years for department stores [36]. Industrial buildings also have different occupant needs depending on the type of industry. In addition to the design life and durability of interior finishes, the building type also determines service life and therefore cannot be disregarded when making lifetime estimates.

Interior finish products that are commonly applied within residential buildings were investigated in this study. Interior building paint, together with multiple flooring alternatives were studied. Table 2 provides the list of interior finishes studied, data points, and their sources. Some sources indicated that hardwood flooring was expected to last as long as the building itself, therefore not necessitating any interior renovation [37]. Due to the large uncertainty associated with predicting building lifetime, the lower lifetime limit was selected, i.e. 50 years was used when lifetime was given as 50 or more years. The average was used when a range of lifetime values was given.

ASTM G166 requires a minimum of 10 data points in order to properly fit a distribution [17]. This criterion was adhered to in this study as well. Reliable lifetime data for interior finishes were not readily available in large quantities. Therefore data points were collected from multiple sources for each product.

Table 2. Data points for lifetime of interior finishes

Interior finishes	Lifetime (years), [source]
Paint	3 [38], 4 [39], 5 [40, 41], 7 [42], 8 [43], 10 [4, 5, 44, 45]
Carpet	5 [46, 47], 8 [4, 48], 8-10 [37], 9 [49], 10 [42], 11, 15 [39], 12 [41, 43], 17 [5]
Linoleum	7-40 [46], 15 [48, 49], 20 [50, 51], 23 [49], 25 [37, 52, 53], 30 [39]
Vinyl	7-40 [46], 8 [48], 9, 23 [49], 17 [43], 18

	[41], 20 [4, 42, 51-53], 40 [39], 50 [37]
Hardwood	10 [54], 20 [47, 54], 25 [54], 40 [52, 53], 45 [49, 55], 50 [5, 43, 54], 50+ [46], 100+ [37]

Notes: The sign '+' after a number indicates that expected lifetime was more than the given value. Multiple references after a data point indicate multiple occurrences in different studies.

2.3. Distributions

The use of distributions to model variables enables a more elaborate analysis of events compared to arbitrarily choosing deterministic values. Statistically, multiple distributions can be used to represent data, but the selection should be based on how well the distribution fits existing data and whether it leads to logical projections when extrapolated beyond existing data [17].

Normal distributions are widely used to describe naturally occurring distributions. However, ASTM G166 advises caution when using normal distributions for service life data [17]. The symmetrical shape of a normal distribution facilitates calculations and interpretation but creates a shortcoming for use on service life data since most distributions are skewed, not symmetric [17]. The use of Weibull distributions were supported by other studies as well and was adopted in the current study [15, 29, 32, 56, 57].

There are two parameters necessary to define a Weibull distribution, namely shape and scale parameters, analogous to using mean and standard deviation to define a normal distribution. The statistical analysis method described in ASTM G166 was applied separately to each interior finish product to determine Weibull distribution parameters necessary to estimate service life based on actual conditions [17].

The original form of a Weibull distribution shown in Eq. 2 can also be written as given in Eq. 3. This is in the form of an equation describing a line, y=mx+n.

$$F(t) = 1 - e^{-\left(\frac{t}{c}\right)^{b}} \tag{2}$$

where *F(t)* represents probability that an interior finish would be replaced by time *t*. *t* is service life of products given in years. *b* and *c* are shape and scale parameters, respectively, necessary to define a Weibull distribution.

$$\ln\left[\ln\frac{1}{1-F(t)}\right] = b\ln(t) - b\ln(c) \tag{3}$$

The set of equations in the form given in Eq. 3 would be solved for parameters *b* and *c* in order to calculate probability of renovation, *F(t)*. This creates a recursive problem which was overcome by using the median rank estimate given in Eq. 4 to initially estimate *F(t)* [17].

$$F(t) = \frac{j - 0.3}{n + 0.4} \tag{4}$$

where *j* is the order of data point when lifetime dataset is sorted in ascending order and *n* is the total number of data points in the dataset.

Since there are multiple data points for product lifetime, linear regression analysis was used to determine shape and scale parameters of a Weibull distribution. After a product-specific Weibull distribution has been defined, probability of renovation with respect to observed service life was plotted using the cumulative distribution function.

ISO 15686 also suggests an 80% confidence interval in estimated service life results [27]. This limit is set for maintainable components, which would apply to interior finishes. An 80% confidence interval was used in this study to determine the lower and upper bounds of reference service life estimates.

2.4. F-test hypothesis testing

Hypothesis testing is a statistical procedure to decide whether to reject or not to reject a hypothesis. In this study, hypothesis test was applied to determine whether the correlation between probability of renovation calculated from the dataset and the independent variable of product service life occurred by chance.

The term alpha is used to denote the probability of rejecting a true hypothesis; in this case concluding that there is no strong relationship when it is otherwise. A typical value of 0.05 was chosen for alpha.

The critical F value ($F_{critical}$) can be read from F-distribution tables by using the assigned alpha value together with degrees of freedom of the dataset [58]. If the calculated F value ($F_{calculated}$) greatly exceeds $F_{critical}$, then it is unlikely that strong correlation among variables occurred by chance. The probability of a higher $F_{calculated}$ occurring by chance (P-value) was also calculated.

3. Results and Discussion

The proposed method has been applied to multiple interior finish products to determine reference service life that can be used in the Factor Method described in ISO 15686. Regression analysis has been used to determine the coefficients necessary to define Weibull life distribution for each product. These coefficients together with the resulting Weibull distributions are given in Table 3.

Table 3. Weibull life distributions of interior finishes

Interior finishes	Shape parameter, b	Scale parameter, c	Weibull life distribution
Paint	2.44	8.24	$F(t) = 1 - e^{-\left(\frac{t}{8.24}\right)^{2.44}}$
Carpet	2.92	11.4	$F(t) = 1 - e^{-\left(\frac{t}{11.4}\right)^{2.92}}$
Linoleum	4.71	24.3	$F(t) = 1 - e^{-\left(\frac{t}{24.3}\right)^{4.71}}$
Vinyl	2.23	25.3	$F(t) = 1 - e^{-\left(\frac{t}{25.3}\right)^{2.23}}$
Hardwood	1.88	48.4	$F(t) = 1 - e^{-\left(\frac{t}{48.4}\right)^{1.88}}$

Parameters and distributions in Table 3 should not be taken as definitive solutions. Reliable and publicly available sources were used in this study. Distributions were defined by using at least 10 data points.

However, future research supported by a trade association, or involving a residential survey to determine product lifetime would be able to collect additional data points. The above given values are expected to change slightly when such findings are incorporated into the existing dataset.

Fig. 1 shows the cumulative distribution function of each interior finish. It can be used to determine the cumulative probability of renovation for a given service life. This data would find applications in the field of investment planning for buildings or in economic cost benefit analysis.

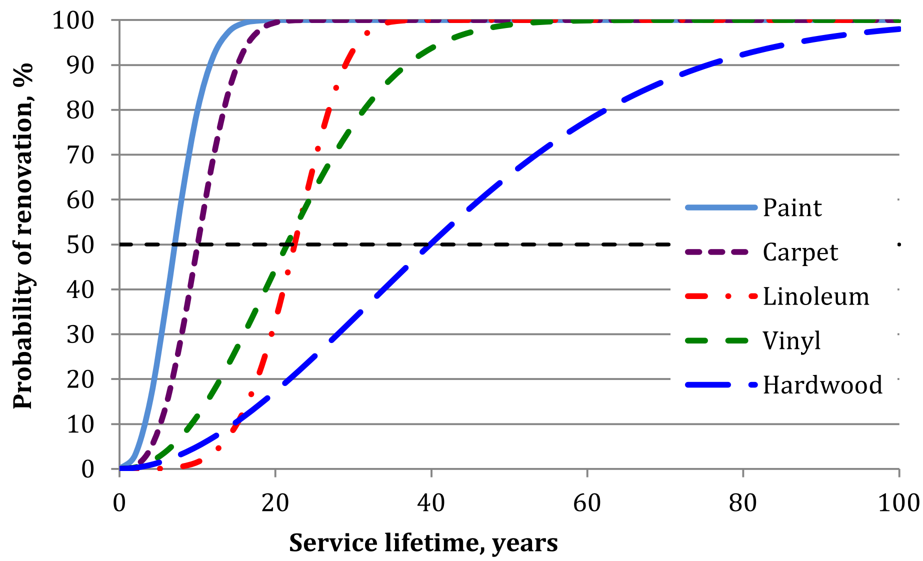

Fig. 1. Probability of renovation cumulative distribution functions for interior finishes

Use of distributions enables a detailed analysis for estimating product lifetime. Especially when combined with the Monte Carlo method, distributions can provide a robust statistical analysis that cannot be captured with the use of deterministic values. Statistical properties of a distribution could be reported to enhance interpretation of the variable. For normal distributions, the calculated mean point also corresponds to the midpoint, which also has the highest probability of occurrence. This is not the case for a Weibull distribution since probability distributions are not symmetric around the midpoint. Median service life of products can be estimated by drawing a horizontal line at the 50% probability of renovation in the cumulative distribution functions presented in Fig. 1. Average service life of interior finishes estimated from the median of these distributions is given in Table 4. The 80% confidence interval required by ISO 15686 was used to locate upper and lower boundaries of the range of results. The given distributions or the corresponding average and range values can be used in the Factor Method for reference service life to depict real life conditions when analyzing residential buildings.

Table 4. Average service lifetime of interior finishes with an 80% confidence interval

Interior finish products	Lower bound (years)	Average service lifetime (years)	Upper bound (years)
Paint	3.3	7.1	12
Carpet	4.1	10	16
Linoleum	15	22	29
Vinyl	9.2	21	36
Hardwood	15	40	73

The guarantee period provided by the manufacturer may be the only indicator of design life for some products [30]. Paint products that are guaranteed for lifetime can be encountered in the market today. A painted surface must be kept under ideal conditions (e.g. low to no UV radiation, water damage, biological factors, wear and tear etc.) in order not to require repainting over the lifetime of the building. In addition to difficulties in achieving such conditions in real life, the influence of social factors on lifetime of products cannot be disregarded. A new or an existing occupant might wish to change the color or tone of a painted surface, even though the existing layer of paint may technically be performing satisfactorily. An average repainting interval of 7 years for residential buildings was presented in Table 4 based on reported past experience. The example for paint demonstrates the potential difference between actual service life and design life or guarantee duration provided by manufacturers. Using design lifetime as reference service life for interior finish products in the Factor Method would necessitate the use of a wider range of coefficients to account for real-life, average conditions. The use of theoretical reference service life combined with the need to use a larger range of coefficients increases subjectivity and decreases accuracy of results. The proposed method and examples presented in this study were based on average conditions and therefore provide a more reliable starting point for service life estimations.

Service life estimates have applications in various other fields including LCA studies, facilities management, or in an economic analysis for asset planning. When analyzing a building assuming average conditions, or in cases where detailed information may not be available, reference service life calculated based on average conditions could be used which would be equivalent to setting lifetime influencing factors equal to 1. However, when project specific data are available, the reference service life should be modified by coefficients described in ISO 15686. Triangular distributions, defined by a minimum, maximum, and an expected value can be used for each coefficient in the Factor Method. A Monte Carlo analysis would then provide the mean estimated lifetime together with a confidence interval, which would allow the user to interpret the reliability of results.

3.1. Hypothesis test

The F-test was applied as the hypothesis test to check the correlation between the interior finish service life as the independent variable, and the probability of renovation calculated from the dataset. $F_{calculated}$ values were found to be much higher than $F_{critical}$ values found from F-distribution tables, as shown in Table 5. The calculated P-values show the minute probability that results occurred by chance, indicating that there is a strong relationship between product service life and the probability of renovation distributions calculated in this study.

Table 5. F-statistic values for interior finishes

Interior finishes	$F_{calculated}$	$F_{critical}$	P-value
Paint	112	5.32	5.5×10^{-6}
Carpet	181	4.96	1.0×10^{-7}
Linoleum	93	5.3	1.1×10^{-5}
Vinyl	64	4.75	3.8×10^{-6}
Hardwood	129	4.6	2.0×10^{-7}

3.2. Actual life compared to design life

The proposed reference service lives are based on average use conditions and environments. They inherently include an average amount of unfavorable conditions observed in real-life. This needs to be taken into account when deciding on coefficients to calculate the estimated service life of a product. Unless it is known that the product would be used in a significantly different environment or use conditions compared to the average, it is suggested to use 1.0 as the coefficient for modifying factors in the Factor Method.

An added benefit of using actual life instead of design life as reference lifetime is that the user is required to make fewer assumptions regarding factors affecting lifetime. In addition, the chosen coefficients are limited to a narrower range. Both of these help reduce subjectivity of results.

An analysis involving hardwood flooring could use the 100+ years design lifetime as suggested by the National Association of Home Builders [37]. However, average service life distribution shows that 50% of hardwood flooring is expected to be renovated within 40 years and the probability of flooring being used for 100 years is low. The 40 years service life estimated for hardwood flooring was based on existing practices. Although it is possible to modify the 100-year design life down to 40 years of actual use, the range of coefficients necessary to do so is larger than using actual lifetime as the reference service life. Furthermore, actual life calculated using distributions that are based on past experience inherently includes social factors that may be as important as durability for some products. It must be stressed that the effect of consumers may not be completely captured within the existing coefficients of the Factor Method, and that the proposed method would be a viable approach to overcome this problem.

4. Conclusions

There is a need for service life prediction of building products both from industry and academia. Facility and asset managers would benefit from a greater ability to foresee and plan for future expenditures, and for economic decision-making to make informed decisions on investment planning. Researchers studying building LCA would be among those that can apply service life estimates in their analysis.

The Factor Method is the most promising method available to estimate service life of products. However, the current deterministic approach is an important barrier preventing the widespread use of the Factor Method. Objective and reliable results cannot be obtained by using the method in its current form. Without a systematic approach, applications of the Factor Method would be limited.

A hybrid method combining statistical procedures described in ASTM G166 with the Factor Method adopted by ISO 15686 was proposed. The proposed method has several advantages. Existing service life prediction models do not capture the effects of social factors on lifetime of products. However, for certain building product categories including interior finishes, social factors may be as important as durability. Excluding social factors reduces the accuracy and reliability of results. The proposed method inherently includes social factors in the dataset used to define lifetime distributions. Another advantage is that choosing reference service life based on real-life conditions decreases the range of coefficients necessary for modifying factors in comparison to when design lifetime is used, thus decreasing the subjectivity of results due to variations in assigned values by different users.

The proposed approach has been presented with example calculations for several interior finish products. The individual lifetime distributions of these products have been developed. Average estimated service life together with an 80% confidence interval was also presented. Reliable sources including peer-reviewed research articles were used to gather data. However, the need for further reliable data points must be stressed in order to improve the accuracy of coefficients used to define distributions. Since both the dataset used during calculations, and the resulting parameters of the

Weibull distributions have been presented, it is possible to update distribution parameters given that additional data points are collected through a residential survey or through trade associations. Although the Weibull distribution parameters would differ somewhat, the overall method would remain the same. The proposed hybrid method can also be applied to other products that are studied within the Factor Method. Products whose lifetimes are influenced by social factors are prime candidates to apply this method.

References

[1] Fernandez JE. Design for change: Part 1: diversified lifetimes. Architectural Research Quarterly. 2003;7:169-82.
[2] Hovde PJ, Moser, K. Performance Based Methods for Service Life Prediction - State of the Art Reports Part A & Part B. CIB W080 / RILEM 175-SLM Service Life Methodologies Prediction of Service Life for Buildings and Components: International Council for Research and Innovation in Building an Construction (CIB); 2004. p. 95.
[3] Optis M, Wild, P. Inadequate documentation in published life cycle energy reports on buildings. The International Journal of Life Cycle Assessment. 2010;15:644-51.
[4] Keoleian GA, Blanchard, S., Reppe, P. Life-Cycle Energy, Costs, and Strategies for Improving a Single-Family House. Journal of Industrial Ecology. 2001;4:135-56.
[5] Adalberth K. Energy use during the Life Cycle of Buildings: a Method. Building and Environment. 1997;32:317-20.
[6] Thormark C. A low energy building in a life cycle - its embodied energy, energy need for operation and recycling potential. Building and Environment. 2002;37:429-35.
[7] Winther BN, Hestnes, A.G. Solar Versus Green: The Analysis of a Norwegian Row House. Solar Energy. 1999;66:387-93.
[8] Lacasse MA. Advances in service life prediction - an overview of durability and methods of service life prediction for non-structural building components. Annual Australasian Corrosion Association Conference. Wellington, New Zealand 2008. p. 1-13.
[9] Chown GA, Brown, W.C., Kyle, B.R., Lacasse, M.A., Vanier, D.J. Applying Service Life and Asset Management Techniques to Roofing Systems. Sustainable Low-Slope Roofing Workshop. Oak Ridge, Tennessee: Oak Ridge National Laboratory, U.S. Department of Energy; 1996. p. 103-15.
[10] Moser K, Edvardsen, C. Engineering Design Methods for Service Life Prediction. 9th International Conference on Durability of Building Materials and Components. Brisbane, Australia2002.
[11] Strand SM, Hovde, P.J. Use of Service Life Data in LCA of Building Materials. In: Lacasse M.A., Vanier, D.J., editor. Durability of Building Materials and Components 8: Institute for Research in Construction 1999. p. 1948-58.
[12] Masters LW, Brandt, E. Prediction of service life of building materials and components. Materials and Structures. 1987;20:55-77.
[13] Frohnsdorff GJ, Martin, J.W. Towards Prediction of Building Service Life: The Standards Imperative. In: Sjostrom C., editor. 7th International Conference on Durability of Building Materials and Components. Stockholm, Sweden: E & FN Spon; 1996. p. 1417-28.
[14] Shohet IM, Paciuk, M. Service life prediction of exterior cladding components under standard conditions. Construction Management and Economics. 2004;22:1081-90.

[15] Rudbeck C. Methods for Designing Building Envelope Components Prepared for Repair and Maintenance. Lyngby, Denmark: Technical University of Denmark; 1999.
[16] Daniotti B, Cecconi, F.R. Test Methods for Service Life Prediction - State of the Art Report on Accelerated Laboratory Test Procedures and Correlation between Laboratory Tests and Service Life Data. W080 - Prediction of Service Life of Building Materials and Components: International Council for Research and Innovation in Building and Construction; 2010. p. 102.
[17] ASTM. G 166 - Standard Guide for Statistical Analysis of Service Life Data. West Conshohocken, PA: ASTM International; 2005.
[18] ASTM. G 172 - Standard Guide for Statistical Analysis of Accelerated Service Life Data. West Conshohocken, PA: ASTM International; 2003.
[19] Sjostrom C, Jernberg, P., Caluwaerts, P., Kelly, S., Haagenrud, S., Chevalier, J.L. Implementation of the European Construction Products Directive via the ISO 15686 Standards. 9th International Conference on Durability of Building Materials and Components. Brisbane, Australia 2002.
[20] Shohet IM, Paciuk, M. Service life prediction of exterior cladding components under failure conditions. Construction Management and Economics. 2006;24:131-48.
[21] Hooper R, Bourke, K., Ferguson, W.A., Clift, M. An Integrated Approach to Durability Assessment throughout Construction Procurement. 9th International Conference on Durability of Building Materials and Components. Brisbane, Australia 2002.
[22] Sjostrom C, Jernberg, P., Frohnsdorff, G. International Standards for Design Life of Constructed Assets. CIB World Building Congress. New Zealand2001.
[23] Lacasse MA, Sjostrom, C. Advances in Methods for Service Life Prediction of Building Materials and Components – Final Report – Activities of the CIB W80. 10th International Conference On Durability of Building Materials and Components (DBMC). Lyon, France 2005.
[24] Lacasse MA, Sjostrom, C. Recent advances in methods for service life prediction of building materials and components – an overview. CIB World Building Congress. Toronto, Canada 2004.
[25] Abu-Tair AI, McParland, C., Lyness, J.F., Nadjai, A. Predictive Models Of Deterioration Rates Of Concrete Bridges Using The Factor Method Based On Historic Inspection Data. 9th International Conference on Durability of Building Materials and Components (DBMC). Brisbane, Australia2002.
[26] Pommersheim J, Clifton, J. Prediction of concrete service-life. Materials and Structures. 1985;18:21-30.
[27] ISO. ISO 15686-1:2000 - Buildings and Constructed Assets – Service Life Planning – Part 1: General Principles. Geneva: ISO; 2000.
[28] Davies H, Wyatt, D. Appropriate use of the ISO 15686 -1 factor method for durability and service life prediction. Building Research & Information. 2004;32:552-3.
[29] Marteinsson B. Durability and the factor method of ISO 15686-1. Building Research & Information. 2003;31:416-26.
[30] Nicastro DH, Surovek, A.E. Defects, Deterioration, and Durability. In: Ratay R.T., editor. Structural Condition Assessment: John Wiley & Sons; 2005. p. 3-23.
[31] Cooper T. Inadequate Life? Evidence of Consumer Attitudes to Product Obsolescence. Journal of Consumer Policy. 2004;27:421-49.

[32] Marteinsson B. Service Life Estimation in the Design of Buildings - A Development of the Factor Method. Gavle, Sweden: KTH Research School; 2005.
[33] Gaspar PL, de Brito, J. Service life estimation of cement-rendered facades. Building Research & Information. 2008;36:44-55.
[34] Aarseth LI, Hovde, P.J. Stochastic approach of the factor method for estimating service life. In: Lacasse M.A., Vanier, D.J, editor. 8th International Conference on Durability of Building Materials and Components (DBMC). Vancouver, Canada: NRC Research Press; 1999. p. 1247-56.
[35] Moser K. Towards the practical evaluation of service life – Illustrative application of the probabilistic approach. In: Lacasse M.A., Vanier, D.J., editor. 8th International Conference on Durability of Building Materials and Components (DBMC). Vancouver, Canada: NRC Research Press; 1999. p. 1319-29.
[36] Anderson T, Brandt, E. The Use of Performance and Durability Data in Assessment of Life Time Serviceability. In: Lacasse M.A., Vanier, D.J, editor. 8th International Conference on Durability of Building Materials and Components (DBMC). Vancouver, Canada: NRC Research Press; 1999. p. 1813-20.
[37] Seiders D, Ahluwalia, G., Melman, S., Quint, R., Chaluvadi, A., Liang, M., Silverberg, A., Bechler, C. Study of Life Expectancy of Home Components. Washington, DC: National Association of Home Builders; 2007. p. 1-15.
[38] NYC. New York Housing Maintenance Code - Subchapter 2: Maintenance, Services, and Utilities - Article 3: Painting. In: Board N.Y.C.R.G., editor. New York: New York City.
[39] Lippiatt BC. Building for Environmental and Economic Sustainability (BEES). 4.0 ed: The National Institute of Standards and Technology (NIST); 2008.
[40] Kelly DJ. BRE, Design life of buildings - A scoping study. Glasgow: Scottish Building Standards Agency; 2007. p. 40.
[41] Scheuer C, Keoleian, G.A., Reppe, P. Life Cycle Energy and Environmental Performance of a New University Building: Modeling Challenges and Design Implications. Energy and Buildings. 2003;35:1049-64.
[42] Pullen S. Energy Assessment of Institutional Buildings. 34th Annual Conference of the Australia & New Zealand Architectural Science Association. Adelaide, Australia 2000.
[43] Mithraratne N, Vale, B. Life cycle analysis model for New Zealand houses. Building and Environment. 2004;39:483-92.
[44] Hed G. Service Life Planning of Building Components. In: Lacasse M.A., Vanier, D.J., editor. 8th International Conference on Durability of Building Materials and Components (DBMC). Vancouver, Canada: NRC Research Press; 1999. p. 1543-51.
[45] Fay R, Treloar, G., Iyer-Raniga, U. Life-cycle energy analysis of buildings: a case study. Building Research & Information. 2000;28:31-41.
[46] Gunther A, Langowski, H-C. Life Cycle Assessment Study on Resilient Floor Coverings. The International Journal of Life Cycle Assessment. 1997;2:73-80.
[47] Anderson J, Shiers, D.E., Sinclair, M. The green guide to specification: an environmental profiling system for building materials and components. 3rd ed. Malden, MA: Blackwell Science; 2002.
[48] Potting J, Blok, K. Life Cycle Assessment of Four Types of Floor Covering. Journal of Cleaner Production. 1995;3:201-13.

[49] Petersen AK, Solberg, B. Greenhouse Gas Emissions and Costs Over the Life Cycle of Wood and Alternative Flooring Materials. Climatic Change. 2004;64:143-67.
[50] Gorree M, Guinee, J.B., Huppes, G., van Oers, L. Environmental Life Cycle Assessment of Linoleum. The International Journal of Life Cycle Assessment. 2002;7:158-66.
[51] Paulsen JH. The Maintenance of Linoleum and PVC Floor Coverings in Sweden. The International Journal of Life Cycle Assessment. 2003;8:357-64.
[52] Jonsson A, Tillman, A-M., Svensson, T. Life Cycle Assessment of Flooring Materials: Case Study. Building and Environment. 1997;32:245-55.
[53] Jonsson A. Including the Use Phase in LCA of Floor Coverings. The International Journal of Life Cycle Assessment. 1999;4:321-8.
[54] Nebel B, Zimmer, B., Wegener, G. Life Cycle Assessment of Wood Floor Coverings. The International Journal of Life Cycle Assessment. 2006;11:172-82.
[55] Scharai-Rad M, Welling, J. Environmental and energy balances of wood products and substitutes. Rome: Food and Agriculture Organization of the United Nations; 2002.
[56] Jernberg P, Sjostrom, C., Lacasse, M.A., Brandt, E., Siemes, T., Haagenrud, S.E., Kucera, V., Odeen, K., Lewry, A., Schwarz, H-J., Yates, T., Grondin, G.Y. Guide and Bibliography to Service Life and Durability Research for Building Materials and Components. In: Jernberg P., Lacasse, M.A., Haagenrud, S.E., Sjostrom, C., editor.2004.
[57] Lounis Z, Lacasse, M.A., Siemes, A.J.M., Moser, K. Further steps towards a quantitative approach to durability design Construction and the Environment - CIB World Building Congress. Gavle, Sweden 1998.
[58] NIST. e-Handbook of Statistical Methods. NIST/SEMATECH; 2010.