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The Factor Method For Service Life Prediction From Theoretical Evaluation To Practical Implementation

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Summary: **This paper presents a brief summary of a state-of-the-art-report which has been worked out within CIB W80/RILEM 175-SLM "Service life methodologies" on the so called Factor Method for service life prediction of building materials and components. The Factor Method was presented in ISO 15686 Part 1, and has gained considerable interest as a simple tool for service life prediction of building materials and components. The paper contains a description of expressed needs for service life prediction methods, requirements which have been described for such methods, description of the Factor Method itself and a presentation of several theoretical and practical evaluations of the Factor Method. Finally, it shows some needs for further development if the method is going to be applied as a practical tool in the different phases of a building structure.**

Keywords. Service life, prediction method, Factor Method, ISO 15686 Part 1.

1 INTRODUCTION

Buildings and constructed assets constitute a major part of the real value of a country. The planning, construction, use, management and demolition of buildings and constructed assets therefore play a very important role in the development of more sustainable societies. And an important part of this development are the efforts to obtain optimal service lives of the buildings and constructed assets.

Knowledge about service life of building materials, components and buildings has been developed in many countries for many years, and different kinds of tools for service life prediction have been established. During the last decade, international standardisation of service life prediction tools has taken place by the International Organization for Standardization (ISO). The actual subcommittee being responsible for this work is SC 14 “Design life”. Most of the development in advance of the standardisation takes place within working groups.

In 2000, ISO published a standard ISO 15686 Part 1 (ISO 2000), which is the first part of a series of standards dealing with service life of buildings and constructed assets. As a part of the standard is a description of a service life prediction method, the socalled Factor Method. This is presented as a simple, deterministic method which should be very simple in use, provided that the necessary input data are available. The method is based on similar factorial methods which have been developed in Japan (Principal Guide 1993), and it has been under discussion and evaluation for several years within the international committee CIB W80/RILEM 175-SLM “Service life methodologies”. Most of the discussion and evaluation has been on a theoretical basis, and so far there has been limited experience in using the method in practice. However, there is a great interest in the method, and during the last few years some practical examples in trying to apply and evaluate the method have been published.

2 NEEDS FOR SERVICE LIFE PREDICTION METHODS

Over the last decades, there has been an increasing focus on the needs to determine durability and service life of materials, components, installations, structures and buildings. This has been based on two important aspects:

- **environmental issues**; lack of material and energy resources and the building and construction sector as a big consumer of these resources, and the environmental impact caused by buildings.
- **economical issues**; the total value of the built environment on a national level and the value of each specific unit of it (buildings, structures, roads, bridges, quays, etc.) for the specific owner (authorities, private companies or individuals). The conditions of the built environment, the annual costs of management and maintenance and the life cycle costs are of major importance for the economy and the competition.

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The importance of these aspects is reflected in several initiatives and activities at both the international and the national level. Many of the activities have ended in publishing regulations or standards, and in these documents the needs for service life prediction of building products and components are stated. Most of them are describing requirements at a national or regional level, but at the same time they reflect an important and increasing trend to focus on this issue. Some of the specific requirements that have been published are briefly mentioned below, as an illustration of how they are expressed.

In Europe, the Construction Products Directive (CPD 1988) has now been implemented in the European Economic Area (EEA) countries. In the CPD it is stated that any construction product which is covered by the CPD, shall have such properties that the building or structure is able to fulfill six specific essential requirements. The requirements shall be fulfilled during an economically reasonable working life of the products. The term working life is corresponding to service life. Each of the six essential requirements are explained more in detail in six corresponding Essential Requirements (Essential Requirements 1994), and these documents also contain a specification of what is meant by working life and how to take care of durability issues for the construction products. The following explanations are given for the working life in all the Interpretative Documents:

> ***"1.3.5 Economically reasonable working life:***
>
> *(1) The working life is the period of time during which the performance of the works will be maintained at a level compatible with the fulfillment of the essential requirements."*

The Construction Products Directive is now a basis for introduction of performance based building regulations in European countries, and thereby requirements for durability and service life of construction products are implemented into national building regulations in Europe.

In 1992, a new building code was published in New Zealand (NZBC 1992) which contains quantitative requirements for the service life of various parts of buildings or for construction products. The clause B2 Durability contains specific requirements both in a qualitative and a quantitative formate.

In the Canadian Standard CSA 478-95 (CSA 1995), a description is given of the relation between design life of a building or a building component, and the durability of the component. The requirements for durability are expressed in terms of design service life, and typical dersign service life categories for buildings are given in the standard.

In 1999, the European Union (EU 1999) published a Guidance Paper containing a table of assumed working lives of works and construction products. The table is shown in Table 1. The table has also been published by the European Organization for Technical Approvals (EOTA) (EOTA 1999), and it is another example of how quantitative values are given for service life which architects, consultants, authorities and manufacturers of building products have to take into consideration and be able to fulfill.

Table 1 Design lives of works and construction products for various categories of buildings. (From EOTA (1999))

Assumed working life of works (years)		**Assumed working life of construction products (years)**		
Category	**Years**	*Category*		
		Repairable or easily replaceable	**Less easily repairable or replaceable**	**Lifetime of works ****
Short	10	10 *	10	10
Medium	25	10 *	25	25
Normal	50	10 *	25	50
Long	100	10 *	25	100

* In exceptional and justified cases, e.g. certain repair products, a working life of 3 or 6 years may be envisaged.

** Products not repairable or economically replaceable.

In a similar way, recommendation for minimum design life of a building or building components are given in the international standard ISO 15686 Part 1 (ISO 2000). This recommendation is shown in table 2.

Table 2. Suggested minimum design lives for components. (From ISO (2000)).

Design life of building	Inaccesible or structural components	Components where replacement is expensive or difficult (incl. below ground drainage)	Major replaceable components	Building services
Unlimited	Unlimited	100	40	25
150	150	100	40	25
100	100	100	40	25
60	60	60	40	25
25	25	25	25	25
15	15	15	15	15
10	10	10	10	10
NOTE 1: Easy to replace components may have design lives of 3 or 6 years NOTE 2: An unlimited design life should very rarely be used, as it significantly reduces design options.				

3 REQUIREMENTS FOR SERVICE LIFE PREDICTION METHODS

As mentioned in the Introduction, there has been much evaluation and discussion of service life prediction methods over the years, and mostly on a theoretical basis. As specific service life prediction methods have been published and the different users have got some experience, the requirements have been more specific.

Already in 1987, Masters (1987) expressed some general requirements to a service life prediction system in the way of ten commandments. In documents describing durability and service life prediction methods (Principal Guide 1993, BS 1992, CSA 1995, Sarja and Vesikari 1996, ISO 2000), there are also recommendations and explanations of what is needed both as input for the use of the methods and for a safe and reliable evaluation and use of the outcome. In many of the documents it is stressed that prediction of durability and service life is subject to many variables and can not be an exact science. Such variables are material quality, environmental conditions, installation, operating and maintenance procedures. The results have to be treated as an indication of what will be the service life, when taking the actual factors and circumstances influencing the durability and service life into consideration.

Martin et al. (1995) have carried out a comprehensive study on methodologies for predicting the service life of coating systems. They present a set of criteria for judging the adequacy of any proposed service life prediction methodology. These criteria include the ability to:

1. Handle large variability in the times-to-failure for nominally identical specimens
2. Analyze multivariate data
3. Discriminate among these variables. That is, the service life prediction methodology should be able to separate the few significant variables from the many insignificant variables
4. Fit both empirical and mechanistic failure models to short-term laboratory-based exposure results
5. Establish a connection between short-term laboratory-based and long-term in-service results
6. Provide mathematical techniques to predict the service life of a coating system exposed in its intended in-service environment

Finally, we should mention a discussion paper by Bourke and Davies (1997), where a list of essential and/or desirable characteristics of a service life prediction system is presented. They state that

> *"the relative importance of each is arguable, but important features may be considered to include the following:*

- easy to learn
- easy to use
- quick to use
- accurate

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- easy to update
- easy to communicate
- adaptable
- supported by data
- links with existing design methods and tools
- free of excessive bureaucracy
- recognises the importance of innovation
- relevant to diverse environments
- acceptable to practitioners and clients alike
- reflects current knowledge
- a flexible level of sophistication for either outline or detailed planning"

4 DESCRIPTION OF THE FACTOR METHOD

The Factor Method as described in ISO 15686 Part 1 (ISO 2000) is based on a variety of factorial methods being developed in Japan (Principal Guide 1993). One one hand, the ISO Factor Method represents a simplification compared to the Japanese methods. On the other hand, this simplification gives less opportunity to take care of important issues as material used, special climatic conditions and other circumstances.

A factorial method for evaluation of surface treatment of wooden windows and doors has been developed in Germany (Verband 1997). This method is used to evaluate the service life of the products, based on information about the material and surface treatment used and on the exposure conditions. The method has been developed independantly of the ISO Factor Method.

The ISO Factor Method is presented in the standard in the following way:

> ***"9. Factor method for estimating service life***
>
> ***9.1 Outline of the factor method***
>
> *The method allows an estimate of the service life to be made for a particular component or assembly in specific conditions. It is based on a reference service life (normally the expected service life in a well-defined set of in-use conditions that apply to that type of component or assembly) and a series of modifying factors that relate to the specific conditions of the case.*
>
> *The method uses modifying factors for each of the following:*
>
> *- factor A: quality of components*
>
> *- factor B: design level*
>
> *- factor C: work execution level*
>
> *- factor D: indoor environment*
>
> *- factor E: outdoor environment*
>
> *- factor F: in-use conditions*
>
> *- factor G: maintenance level*
>
> *Any one (or any combination) of these variables can affect the service life. The factor method can therefore be expressed as a formula:*
>
> *ESLC = RSLC x factor A x factor B x factor C x factor D x factor E x factor F x factor G."*

The reference service life of a component (RSLC) is defined as

> *"service life that a building or parts of a building would expect (or is predicted to have) in a certain set (reference set) of in-use conditions."*

In the standard there is also a brief discussion of the use of the Factor Method, and a discussion of the reference service life as well as each of the modifying factors.

5 EVALUATION OF THE FACTOR METHOD

Since the introduction of the Factor Method in the first draft of the ISO Standard, it has been evaluated in several papers, both on a theoretical basis as well as based on some practical appliactions. In this paragraph we will refer to some of the theoretical evaluations, whereas some examples of practical application and evaluation are presented in the next paragraph.

The Standard ISO 15686 Part 1 (ISO 2000) itself contains a chapter which describes the Factor Method. In that chapter, there is a general discussion as well as a discussion of the reference service life (RSL) and each of the factors. In the general comments of the Factor Method (chapter 9.2), it is said that

> *"The factor method is a way of bringing together consideration of each of the variables that is likely to affect service life. It can be used to make a systematic assessment even when reference conditions do not fully match the anticipated conditions of use. Its use can bring together the experience of designers, observations, intentions of managers, and manufacturers' assurances as well as data from test houses.*
>
> *The factor method does not provide an assurance of a service life: it merely gives an empirical estimate based on what information is available. It is different from a fully developed prediction of service life, which will ideally provide the reference service life for a factored estimate."*

A thorough discussion of the Factor Method has been presented by Bourke and Davies (1997). The report is intended to give a contribution to the further development of the method described in (ISO 2000). In the general summary and conclusions of the report, the authors state that

> *“The system would serve initially as a means of permitting objective comparison and analysis rather than as a firm prediction of anticipated years on service.*
>
> *This however should not disguise that the effect of adoption of such a system should be to optimise the selection of components, making large-scale, expensive and disruptive remediation unnecessary. Equally, excessively durable specifications for short-life buildings could be reduced. It would also highlight the ease with which durability could be improved “on the drawing board”, thereby achieving enhanced performance for minimal cost."*

Hovde (1998) has presented an evaluation of the Factor Method. It is based on considerations and discussions e.g. within CIB W80/RILEM 175-SLM. In the short range, there is a need for input data both for the quantification of the reference service life (RSL) as well as for the different factors in the equation. In the long range, there will be a need for a more comprehensive evaluation of the Factor Method, including possibilities of quantitative description of the RSL and the factors. Hovde also pointed out that the method should be evaluated according to the general requirements for service life prediction methods, like the requirements mentioned above. He gives a brief discussion of the following items which ought to be further evaluated:

- estimation of the reference service life (RSL)
- important factors
- necessary number and type of factors
- use of the factors in an equation
- reasonable span of the values of the different factors
- relative importance of the factors
- uncertainty of the factors
- factor dependency on material or component to be evaluated
- important considerations for practical use

The last item is illustrated in figure 1.

Aarseth and Hovde (1999) and Moser (1999) have tried to further develop the Factor Method by including a probabilistic approach in the selection of the factor values. Hovde and Aarseth are applying a "step-by-step" principle where the value of each factor is given by a triple estimate, i.e. a minimum, most expected and maximum value. In order to give a reasonably good statistical representation of the triple estimates, an Erlang density function is used. The modified Factor Method has been applied to estimate the service life of a wooden window, based on one of the examples given in (ISO 2000). In the example, factor values are chosen so that the estimated service life (ESC) becomes 62.2 years, i.e. 60 years. By applying the same factor values as the most expected values and guessing minimum and maximum values, the estimated service life becomes 50 ± 6 years. In the conclusions, the authors state that

> *“The “step-by-step” principle enables a stochastic handling of the modifying factors in the ISO factor method by performing a triple estimate for each factor. After the statistical calculation the estimated service life is expressed as three figures: the exptected value plus/minus one standard deviation.*

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> *The "step-by-step" principle also demonstrates a systematic approach to the estimating process, including the process of defining, subdividing and estimating the modifying factors in the ISO factor method."*

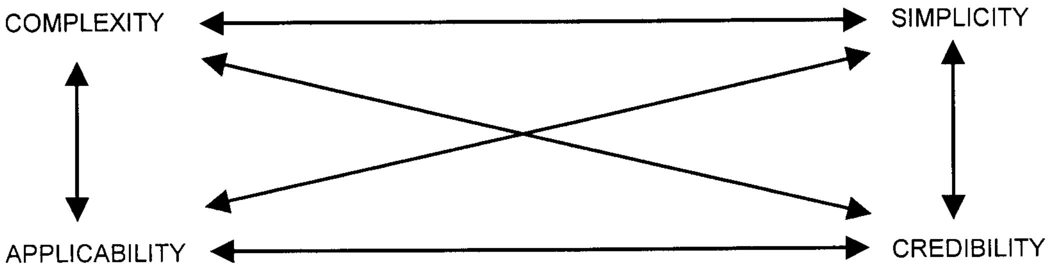

Figure 1. Relations to take into consideration in evaluation of the Factor Method. (From Hovde 1998)

Moser (1999) has applied an individual statistical treatment of each factor. This is done by using different statistical distributions for each factor (like deterministic, normal, lognormal or Gumbel), and by giving individual figures for the minimum, most probable and maximum value of each factor. In his conclusions, Moser states that

> *"The use of probabilistic tools for planning maintenance or replacement costs is no longer only restricted to projects having large funding requirements or numerous assets. Making full use of the information, e.g. given in ISO/CD 15686 and modified by professional opinion, permits the use of variables instead of deterministic factors in the equation for the estimated service life. The results give a much more detailed insight into the service life of building components involved and allow a far better planning of the investments required."*

Other evaluations and discussions of the Factor Method have been published by Lounis et.al. (1998), Teplý (1999) and Rudbeck (1999).

6 PRACTICAL USE OF THE FACTOR METHOD

As mentioned earlier, the Factor Method has attained considerable interest during the development stages, and several researchers have tried to apply it for practical purposes. This has given very valuable results and experience, and such practical application is an important basis for further development and improvement of the method. Most of the public cases are described in research papers or reports where the application is shown as examples. The practical application of the Factor Method has been limited due to little knowledge of the method among practitioners as architects, consultants or building owners and managers, or due to lack of input data for the various factors of the method.

There is also an extensive research and development going on regarding design for durability of buildings, sustainable construction and development of sustainable buildings. Several papers have been published during the last years describing different challenges in this area, and they show the necessity of implementing service life of materials and components into the overall methods. Wyatt and Lucchini (Wyatt 1998, Lucchini and Wyatt 1999, Wyatt and Lucchini 1999) have published several papers regarding design and construction of sustainable buildings. In Wyatt and Lucchini (1999) they conclude that

> *"Whilst there is a complex but important relationship between the building performance the designer may have pre-defined and the level of reliability achieved one cannot guarantee a building's life future. One can however, be prudent and accept the place of a service life practice and life care to at least seek a building product life.*
>
> *So adopting the service life approach that reflects materials, components and systems service loss and durability would help to improve cost certainty of building ownership and begin to address the challenges posed in striving for sustainable cities and buildings. For it has become clear that designing for durability has an immensely important contribution to make to both the work of CIB W94 and CIB W80 as well as ISO task group responsible for developing the Design Life of Building's Standard.*
>
> *It is now believed that service life and its practice will come to form and be seen as the corner stone of building asset management's life care."*

Strand and Hovde (1999) have carried out at study of how service life data of exterior surface materials (wood and brick) influence on the life cycle assessment (LCA) of the materials. The authors wanted to show how service life data are needed in LCA, how the data occur and how they influence the results. Building materials and components are used for a longer period of time than most other products. LCA of a building product therefore necessitates gathering of data that will be valid for a longer period of time. The authors apply the Factor Method as described in ISO 15686 Part 1, but with main emphasis on the factors E (outdoor environment) and G (maintenance level). LCA is carried out for two climates (industrial and rural inland) and for facades facing north or south. Different intervals for painting, cleaning and replacement are also used.

Hovde (1999) has presented the need for service life prediction of passive fire protection systems (fire retardants). He refers to the Factor Method as described in ISO 15686 Part 1. Passive fire protection has got an increasing interest and importance in relation to the introduction of performance based building and fire codes. This makes it important to predict the durability and service life of the fire protection systems, and this will be a specific area for application of service life prediction methods.

A joint RILEM and CIB committee (RILEM TC 172-EDM/CIB TG 22 “Environmental design methods in materials and structural engineering”) has been working on development of methods for environmental design of materials and structures. A progress report of the work has been presented by Sarja et al. (1999). In the presentation of the progress report it is explained that the incorporation of an environmental viewpoint into the design of materials and structures, it is necessary to reconsider the entire context of the design process in order to integrate environmental aspects into a set of other design aspects. Further, this kind of process is called integrated life cycle design, and it it is said that the aim of the process consists of assimilating, in a practical manner, the multiple requirements of functionality, economy, performance, resistance, aesthetics and ecology all into the technical specifications and detailed designs of materials and structures.

The joint RILEM/CIB committee is producing a manual which will provide methods and methodologies for structural design in order to meet the requirements of sustainable development over the entire service life of the structures. The scope of the manual includes both bearing and non-bearing structures of buildings, bridges, towers, dams and other structural facilities. In the description of the design process in the progress report, there is also a presentation of alternative methods which can be applied for durability design.

In the conclusions of the progress report, it is stated that

> *“Concerning materials and structures, new basic knowledge will be needed especially regarding environmental impacts, hygrothermal behaviour, durability and service life of materials and structures in varying environments. Structural design methods that are capable of life cycle design, multiple analysis decision-making and optimisation will have to be further developed. Recycling design and technology demand further research in design systematics, recycling materials and structural engineering. The knowledge obtained will have to be put into practice through standards and practical guides.”*

Hed (2000) has carried out a study of service life planning for a multi family building, which was built in Gävle, Sweden, in 1999. ISO 15686 Part 1 was used as a basis for the study. The service life planning was integrated into the design of the building and followed the building process from the design phase to the beginning of the construction of the building. The report comprises three separate papers, and in one of the papers are given a presentation and discussion of the application of the Factor Method as presented in ISO 15686 Part 1. The author states that

> *“A problem is that there are still few tests performed of material and component service life, comprising all the effects required of the building component when it is operation in the building, i.e. following the service life prediction methodology (ISO 1999).*
>
> *The accuracy of the estimated service life is of course suffering from this fact, so one has to discuss if it is worth the effort of doing the estimations or not. If the goal is to find a precise value it is clear that the goal is not reached. But if the goal is to improve the general situation in service life planning the answer is yes.*
>
> *The factor method in ISO/DIS 15686-1 is meant to be a tool to improve the estimation of the service life. It was found in the project that this method did not improve service life estimations. This opinion is summarised in the following.*
>
> *Uncertainty of RSLC and values of Factors. The factorial formula (1) comprises in the right side of a reference value (RSLC) and the adjusting Factors, A to G. If the reference value can not be determined accurately it is not appropriate to adjust these values with a set of uncertain Factors.*
>
> *Uncertainty of the effect by combination of Factors. The method does not support the thoughts that one needs knowledge of cause and effect to estimate the service life. The estimation will be based on uncontrollable occurences, which can act independently of each other.”*

In a Nordic Research Training Course funded by the Nordic Academy for Advanced Study (NorFA) which was carried out during 2001 regarding service life of buildings and building products, some of the participants gained interest in the Factor Method as a simple tool for service life prediction. The title of the course was "Service life of buildings - from theory to practice", and the research students carried out individual project tasks related to the main topic of the course. The project reports are at a preliminary stage, and the intention is that they will form the basis for papers to be published in journals, conferences, etc. In the reports are discussed the possibilities to apply the Factor Method for service life prediction of different building products, components, structures and installations, such as surface products, exterior wood products, external renderings, sulfur concrete, a solar collector and a fibre reinforced polyester pedestrian bridge deck. This clearly underlines the fact that there is a need for practical and simple service life prediction tools, and that the Factor Method may be evaluated for practical use on a wide variety of products in the future.

One of the reports from the Research Training Course is mentioned here. Marteinsson (2001) has presented the results of a big condition survey of wooden windows in Iceland. He has applied the Factor Method to study the service life of the windows. In the report the results from the condition assessment and the house owners' answers to a questionnaire are combined, and the Weibull probability distribution is then used to evaluate the estimated service life of the windows. In the conclusions of the study, Marteinsson states that

> *"The results show that for some materials at least, the synergy between agents that affect the durability of materials is so great that it is difficult to give each and one of the factors in the standard a value even based on results gained by systematic study of the object in use. The results show furthermore that for materials where the durability gains very much from good careing and maintenance, then it is a good way to decide on the probability distribution of the service life from information from the user.*
>
> *The realistic span in multiplication factor is thus considerable and the user of the methodology will not be able to choose appropriate values for the factors without extensive knowledge about materials and local building practice. In any case he needs an information about the main factors for the component and material considered, (and) what span is normal for the factors. The methodology is far from easy to use correctly and at the risk of results being evalulated as being more precise than is reasonable at the present time.*
>
> *Handbook of worked examples would be of great value for the designer, without this freedom for each user to define the factors is too great."*

7 FURTHER DEVELOPMENT AND PRACTICAL APPLICATION OF THE FACTOR METHOD

The brief state-of-the-art of the Factor Method given above has underlined the fact that service life prediction of buildings or building elements, components or products in general is rather difficult and laborious. It is not an exact science, and the service life is dependent on various factors which also make a complete service life prediction an interdisciplinary activity. Service life prediction can be based on two different principal approaches:

- deterministic approach
- probabilistic approach

This gives the basis for development of service life prediction methods of various complexity and with different requirements of applicability and needs for input information. Three levels of service life prediction methods can be described as shown in figure 2.

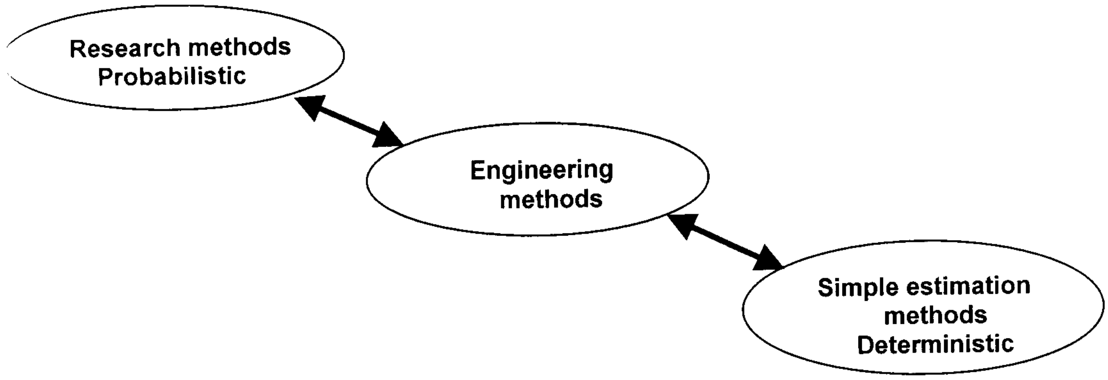

Figure 2. Relation between different types of service life prediction methods.

The Factor Method which is discussed in this paper is based on the deterministic approach.

The outcome of the theoretical and practical studies and evaluations described above should be a good basis for further development and application of such methods. The presentation also shows that there is a need for service life prediction methods in many areas, and that the Factor Method is regarded as a simple and easily accessible tool. However, there seems to be still many topics that have to be evaluated further before the method will come in to a wider practical application . The following topics will be of importance:

- determination and collection of data for the reference service life (RSL) and the individual factors
- development of a sound engineering method which combines the benefits of more sophisticated probabilistic methods and simple deterministic methods
- practical use of the method in case studies of specific building materials and components or of specific buildings
- application of the method in life cycle analysis of building materials and components and environmental evaluation methods for buildings
- application of the method in integrated life cycle design and design for durability of buildings

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