SERVICE LIFE ESTIMATION OF BUILDING COMPONENTS: METHODS FOR DURABILITY ASSESSMENT IN USE CONDITIONS

[1]Lupica Spagnolo, S., Daniotti, B., Paolini, R.

[1]Politecnico di Milano – Building Environment Science and Technology (BEST) Dept., Via Ponzio, 31 – 20133 Milano - Italy
sonia.lupica@polimi.it, bruno.daniotti@polimi.it, riccardo.paolini@mail.polimi.it

ABSTRACT

The Estimated Service Life (i.e. in the condition of use, different from reference conditions, in which RSL has been determined) of building components is an essential input for maintenance planning, LCA and any other sustainability evaluation, LCC, Due Diligence and any assessment of overall building performance, especially over time ones.

Nonetheless, the estimation of Service Life of a building component can be affected by significant transport errors from reference to in use condition. Actually, in ISO 15686, a method for calculating the Estimated Service Life is presented, the Factor Method, which is nevertheless subjective and lacks in validation and benchmarking. Consequently, several studies have been carried out in order to limit subjectivity, but only a few merge indeed objectivity and validation.

Thus, in this paper is portrayed a proposal, developed by Politecnico di Milano, for enhancing the Factor Method. The suggested procedure aims both to maintain the simplicity for the end user (i.e. manufacturers, designers, public administration and real estate managers) and to improve objectivity and reliability and it consists of several steps. Firstly, are selected the most relevant factors affecting the Service Life of a given building component and their effect on durability is studied; secondly is build up a grid for the Factor Method (hence fixing input data); thirdly the relationship between the sub-factors and their influence on Service Life is assessed by means of multiple regressions and hence the values for the sub-factors are determined. On one hand, input data for the isolation of degradation mechanisms mostly influencing SL are provided by the synthesis of all knowledge about that specific building component, achieved by means of the procedure for Reference Service Life Prediction. On the other hand, input data for sub-factors non in reference condition are given by means of modelling (the isolated degradation mechanisms) and data collected in databases by all the stakeholders and validated by the database administrator.

1.- Introduction

The Estimation of the Service Life of Building Components is a challenging task, which is relevant because of two main reasons: data about Service Life are needed and methods for adapting available data to the specific conditions are needed too.

Firstly, data regarding the Service Life of a Building Component are needed because they are required for proper maintenance planning, Life Cycle Assessment (and any other sustainability evaluation), Life Cycle Costing, Due Diligence and any assessment of overall building performance, especially over time ones (for instance, the energy performance of a building cannot be consistently assessed adopting stable and constant properties). Furthermore, the European Commission should release by 2009 the new Construction Products Regulation, which will comprise the

Essential Requirement of “Sustainable Use of Natural Resources” (subdivided in recyclability, durability and use of compatible raw and secondary materials in the construction works). Since this new regulation, within the EU the assessment of performances over time will take place more and more rapidly. In addition, many countries will adopt “Zero Carbon” regulations for new buildings and this will lead to the need of more reliable and precise data of the building over its life cycle.

Secondly, having data concerning the Service Life of Building Components in all possible assets and solicitation conditions is almost impossible; consequently, there exists the need of methods for deriving information from a limited number of milestones (i.e. the provided set of Reference Service Lives) and estimating the behaviour in conditions different from the ones in which the Reference Service Life was achieved. Consequently, research about this topic is being carried out since many years and there already exists the umbrella standard for Service Life Prediction and Planning (i.e. ISO 15686 [1]). In literature [2], the Service Life estimation methods are distinguished into probabilistic methods, engineering methods and deterministic methods. Bourke and Davies [3] pointed out that a Service Life Prediction system should have defined properties, namely it should be:

- Easy to learn, to update and to communicate;
- Easy and quick to use;
- Accurate;
- 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.

Nonetheless, there is no method fulfilling all these requirements. In fact, there are on one hand the probabilistic methods, which are very accurate and reliable, but do require a large amount of input information and are often very specific for the data set for which they were built, hence they are not very adaptable.

On the other hand, the deterministic methods - the most diffuse is the factor method - are very simple, but largely affected by subjectivity and consequently not very reliable (actually the Factor Method was originally thought as a check list of factors affecting the durability of a material, of a building or a building component).

Between these two categories there is a third one: the engineering methods. They are referred in literature as the methods which have complexity comparable to the one normally faced by engineers in design process. Engineering methods, in many cases (see Moser in [2] and Hovde [4]), assume probability distributions for the considered variables – managed with Monte Carlo Method – and assume a Markov model for the deterioration process (i.e. the deterioration is a stochastic process governed by random variables). Other Engineering Methods aim to simulate the deterioration process and consider when the performance limits of critical performances are reached, hence when is the end of Service Life.

2.- Factors Grids for Service Life Estimation

In this paper is presented the proposal of an enhanced Factor Method, based upon driving grids useful both for the collection of data and for providing a procedure in the calculation of the ESL. In a certain sense, the method interface is the one of the simple Factor Method (with some detailing), whilst the calculation procedure is based on Engineering Methods. The aim is to try to save both FM easiness and accuracy of more complex methods. The grids, for each building component, are based upon the structure of seven factors of the simple FM proposed in ISO 15686-1 and, for each factor, most relevant sub-factors affecting durability are detected. They are shared through a database (already available at www.servicelifeplanningplateform.eu) developed by CSTB and Politecnico di Milano [5]. Thus, the construction procedure of the database consists of four main steps, namely:

- A grid is built for a given building component by a panel of experts (procedure described in detail below);
- The grid is shared among the stakeholders of the Construction Sector;
- Information regarding properties and service lives is collected by the stakeholders for all comprised sub-factors;
- Information is validated by the platform administrator.

In this way more Reference Service Lives are available and a first assessment of a building component in a given context is possible just thanks to comparison. Nonetheless, as mentioned above, it is almost impossible that available data perfectly mirror the required ones. The aim of having more RSLs is to limit the transport error from reference condition (i.e. the condition in which the Service Life or performance-over-time function has been determined) and the estimation condition (i.e. the specific project condition, different from the reference one).

There are, thus, two foreseen uses for the grids supplied by the database:

- Static – reference conditions are isolated and the Service Life of a given building component is assumed as the RSL provided for the set conditions [already available];
- Dynamic – the user can calculate the ESL inserting the required data in the grid describing the specific design condition and the ESL is calculated by a procedure not visible to the user, but validated and based on the correlation between basic properties and SL, studied with the other cases already inserted in the database and thus used as benchmarks [to be developed];

As already stated by Daniotti *et al.* [6], the system of equations ruling the Service Life estimation is a higher order problem and cannot be solved analytically; besides, it is a very sensible system (bad conditioned system i.e. little variations in input produce large variations in output). On the other hand, a precision of the order of 2% (e.g. accuracy of 6 months for a RSL of 25 years) can be accepted for most part of building applications. As a result, the objective of a Service Life Prediction method should favour robustness instead of extreme precision.

Consequently, it was chosen to isolate the factors actually affecting the Service Life and the performance-over-time of a given building component; this means that for each different kind of building component, different aspects will be taken into account. Thus, the construction process of each grid - thus the grid structure evolution - can be identified as follows:

- First draft of the grid – description of the building component and the context variability in terms of FM factors. In this phase the driving grid is still objectual (i.e. descriptive)
- Second draft – isolation of the only relevant factors. Thanks to literature analysis, laboratory and outdoor testing (in one word SLP) it is understood which elements actually influence the durability of that kind of building component
- Definitive draft – after validation process.

In other words, as the buildings should be performance based, so the factors grids should be "performance(s)-over-time based". The advantages of a method which takes into consideration only aspects truly influencing Service Life are several:

- To limit the information collection time by the user. As a consequence the method applicability is increased (not only for big construction works);
- To limit the divergence trend of the system of equations (improvement of robustness);
- To facilitate the comprehension of the durability of that building component by designers, thus to facilitate design for durability.

2.1.- Construction of the Factors Grids

The process for the construction of the Factors Grids (fig. 1) consists of twelve main steps. The starting point is the identification of the Building Component type; the aim of this task is to detect which Building Components can be considered together and compared in terms of Service Life. It is important to emphasize that this decision is crucial and not always automatic; in facts, considering together a wide group of Building Components may produce relevant errors when assessing elements at the boundaries of the group. On the other hand, if the considered groups of Building Components are too small, there may be difficulties in widely adopting the method and there may be fragmentation of the method itself.

The second step is a preliminary study of the Building Component type. This phase includes both a preliminary breakdown of the technology and a deep analysis of the degradation factors and ageing mechanisms. Useful tools for this step can be techniques such as FMEA (i.e. Failure Mode and Effects Analysis). Normally, this step should be included in the Reference Service Life Prediction process given in ISO 15686-2 [7], but it may be possible that the factors grid and the Service Life Prediction studies could have been carried out by different people and this analysis is necessary for assessing if information given by SLP is suited and complete.

After this, it is crucial to set the Reference Condition for each factor. In order to avoid relevant transport errors from Reference to specific conditions, it is preferable to choose as Reference the most probable set of conditions. In other words, choosing a condition which is a "centre of mass" for the considered domain (i.e. the most frequent condition and also the most "average") as Reference Condition could allow limiting number and entity of errors. Due to this reason, as well as for the Building Component Type, is better to deal with many domains, hence more Reference Service Lives for the same Building Component type, limiting divergence. This is particularly evident for Factor E (i.e. Outdoor Environment). It is preferable to have more RSLs for many climatic zones instead of, for example, only one RSL for all Europe and then having to translate the data to very different climates, thus solicitation combinations. More explicitly, for instance, data about RSL of concrete structures achieved with an experimental programme carried out in Norway (many freeze – thaw cycles), cannot be translated to Andalusia (no freeze – thaw). In other words, there should be as many RSLs as many climatic zones, where a climatic zone could be identified as an area within which degradation agents are the same, even if not in the same proportion and a comparison between their intensity in different parts of the climatic zone itself is possible.

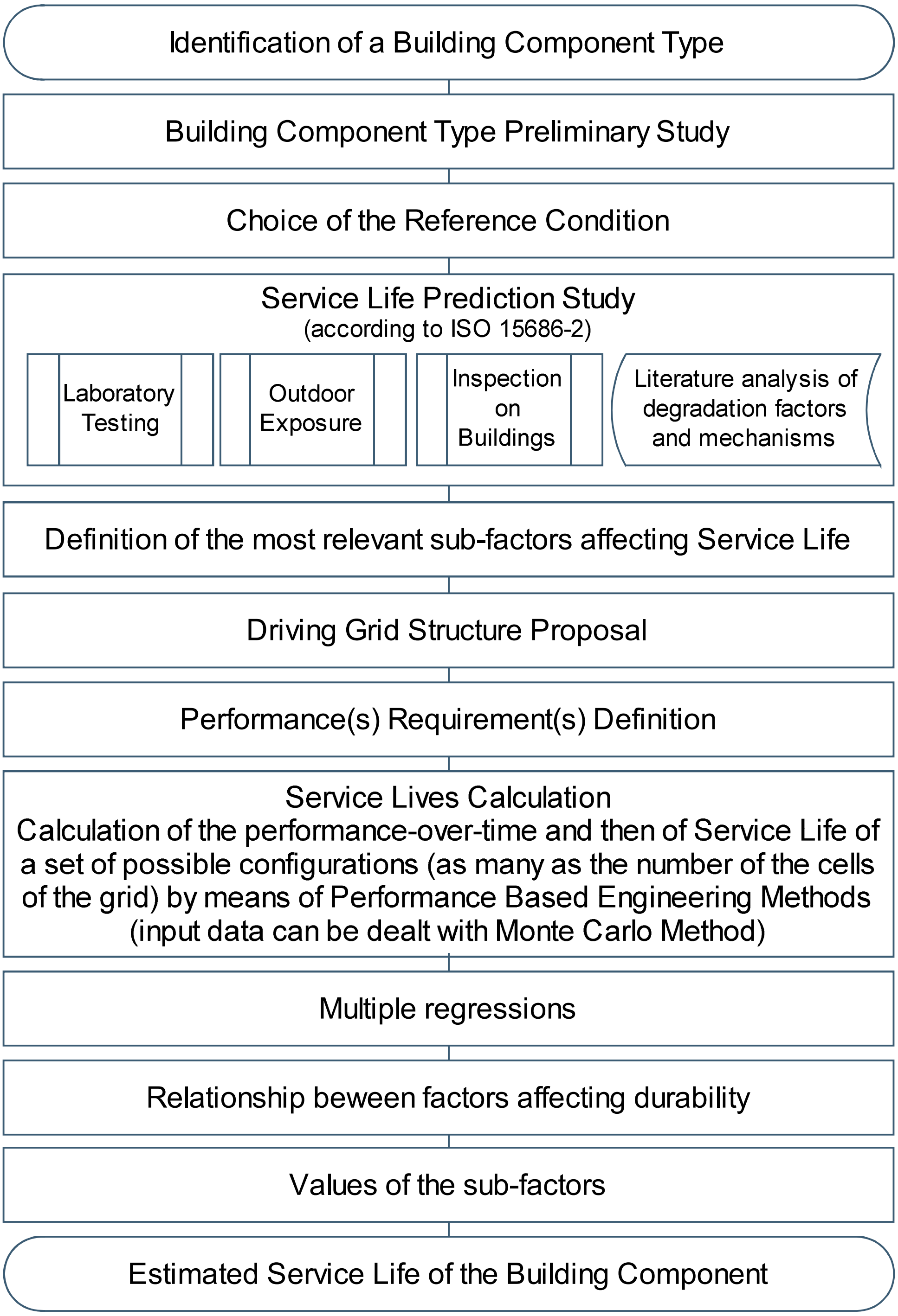


Fig. 1 – Process for Factors Grids design

The fourth block in this procedure is the collection and synthesis of all available information regarding the Service Life of the studied type of Building Component. Attention must be paid in merging the information achieved with different methods. In particular, it should be considered if the laboratory testing and the outdoor exposure do reproduce the same conditions and can be compared giving time re-scaling for the accelerated ageing cycles reproduced in the lab. In facts, not all agents can be reproduced in the lab and not all agents can be accelerated.

After this, among all possible factors and sub-factors, the ones which more influence the Service Life of the Building Component type should be selected; this operation too is in order to limit divergence of result due to uncertainty in input data and helps the designer in understanding which aspects actually affect the durability of the considered Building Component. In this sense, the driving grid may be helpful in design phase too. Thus, the structure of the Factor Grid can be defined.

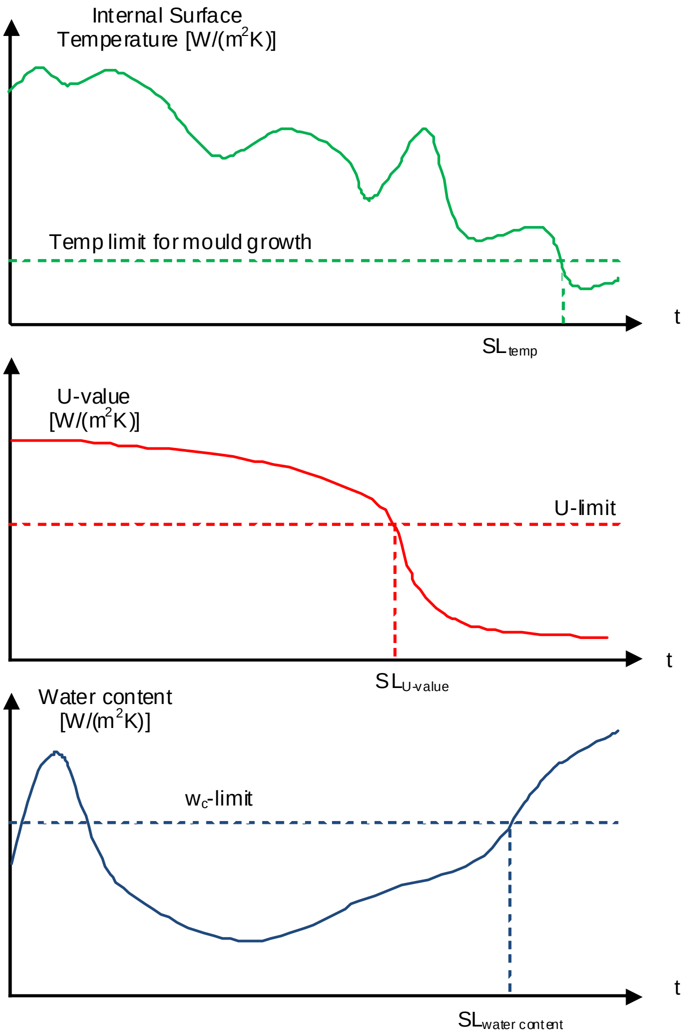


Fig. 2 – Service Life Calculation after critical performances. The Service Life is the minimum among the ones calculated with regard to each single critical performance.

Once all the variables have been identified and the structure set, the calculation of Service Life for all the considered combinations is to be performed. In particular, Performance(s)-over-time and consequently the Service Life can be calculated using Performance Based Engineering Methods. These methods allow assessing the evolution of essential performances and when these encounter the limit for serviceability. An example could be identified in a particular use of HMA models (i.e. Heat Air and Moisture Transfer models). With these tools is possible to evaluate the thermal resistance over time in dependence of the water content and therefore assess when the performance limit (e.g. given by energy regulation or by users' needs) is encountered and the Service Life is over. Another example of such Performance Based Engineering Methods is the PLM (i.e. Performance Limits Method) developed by Politecnico di Milano. It allows assessing for which values of the properties of Building Components the Environmental Requirements are no more fulfilled. Furthermore, it may be possible to introduce stochastic assessment by means of Monte Carlo method in two ways: introducing the statistical distribution of input data for critical properties (incredibly complex due to the complexity of the models) or assessing the most probable distribution, once the values of the sub-factors have been calculated (simpler). In this last case, it is preferable that the distributions are attributed taking into account the distributions of the critical properties leading to that sub-factor value (see Re Cecconi [8] and [9]). The user (advanced user) can assign the shape of the triangular distribution (it can be demonstrated that a triangular distribution can in this case be suitable to approximate the normal distribution adopted by the Monte Carlo method). It can be defined the maximum, the minimum and the most probable foreseen values. For instance, if the value of a sub factor is 1, and it is proved that the related characteristic has a symmetric distribution and 1 is the most probable value, the maximum and the minimum can be set respectively as 1.05 and 0.95, according to the shape of the distribution of the critical property.

A critical point, stressed by this procedure, is that the performance critical thresholds and, as a result, the Service Life cannot all be defined a priori. Actually, this is intrinsic in the concept of Service Life pointed out in ISO 15686-1, where it is meant as the "period of time after installation during which a facility or its component parts meets or exceeds the performance requirements". The performance requirements, indeed, can be defined in different ways and at different levels: by law regulation (e.g. national regulations derived by EBPD); by standards (e.g. ISO 13786 for surface temperature); by limits detected by laboratory testing (e.g. limit of water content which leads to weakening of a mortar mix, then sensible to thermal variations); by the designer(s) and by the user(s). Consequently, a method producing only one result for the Service Life, regardless the users' requirements, it could not be properly defined as a Service Life estimation method.

As outcome, the procedure cannot be carried out once for all and general results valid in all cases calculated, but the end user of the method should be required to define the performance limit, allowing the calculation engine (the Performance Limits process, which may not be visible to the user, even if it must be declared and evident) to determine the SLs. Of course, most probable performances requirements and default values should be suggested to the user of the grid in order to facilitate the process and save calculation time. After the Service Life has been calculated within all considered combinations, thanks to multiple regressions techniques the values of the sub-factors can be determined.

In this sense, the proposed method is an Engineering Method with a Factor Method interface. In fact, even having all data of SL for a large number of configurations, it may be difficult for the end user of the SL data to detect the estimation condition and most of all to understand the influence that each aspect has on SL.

3.- Examples of Factors Grids for Service Life Estimation

In the tables below, some examples are put forward for different grids. The first example deals with ETICS showing two stages of the grid: a preliminary one and a compact one, including only the factors mostly influencing Service Life. The second example is relative to Sandwich Panels. All the grids have been developed thanks to knowledge achieved with a two years Italian Research Programme (MIUR 2003-2005) about the experimental durability assessment of Building Components and then validated by the administrator of the database (from CSTB).

3.1.- An example of creating a factors grid: the application on ETICS

A first example of the structure of Factors Grid specific for a building component is presented (tab. 1). The studied case is about ETICS (i.e. External Thermal Insulation Composite Systems with rendering) in the environmental context of Milan (or similar ones). The information for the construction of the grids has been collected thanks to an experimental programme for the accelerated ageing of ETICS (see [10] and [11]), thanks to literature analysis [12] and in cooperation with CSTB. The condition chosen as Reference is highlighted and the references for the detection of the conditions are given in the notes. The grid presented in Tab. 1 is a first step in defining sub-factors classes.

<table>
<tr><td rowspan="6">A</td><td>ETA[1]</td><td colspan="6">Yes</td><td colspan="6">No</td></tr>
<tr><td>Type of insulator</td><td colspan="3">Moulded expanded polystyrene</td><td colspan="3">Extruded polystyrene</td><td colspan="3">Mineral Wool</td><td colspan="3">Wood Fibers</td></tr>
<tr><td>Fixing system</td><td colspan="3">Purely bonded system</td><td colspan="3">Bonded system with supplementary mechanical fixings</td><td colspan="3">Purely mechanical fixed system</td><td colspan="3">Mechanical fixed system with adhesives</td></tr>
<tr><td>PVC of render coating resin</td><td colspan="4">Resin added
95% ≤ PVC ≤ 98 %</td><td colspan="4">Resin added
PVC > 98 %</td><td colspan="4">Only cement mortar</td></tr>
<tr><td>Finishing color</td><td colspan="4">Bright (α = 0,3)</td><td colspan="4">Medium (α = 0,5)</td><td colspan="4">Dark (α = 0,9)</td></tr>
<tr><td>Finishing roughness</td><td colspan="4">Coarse grain[2]</td><td colspan="4">Average grain[3]</td><td colspan="4">Thin grain[4]</td></tr>
<tr><td rowspan="6">B</td><td>N°of fixing elements/sqm</td><td colspan="4">N<8</td><td colspan="4">8 ≤ N≤12</td><td colspan="4">N>12</td></tr>
<tr><td>Mechanical fixings</td><td colspan="6">Dimensioned considering wind load</td><td colspan="6">Not dimensioned</td></tr>
<tr><td>Presence of expansion joints</td><td colspan="6">Yes, max every 200 m^2 [5]</td><td colspan="6">No</td></tr>
<tr><td>Presence of protecting elements on surfaces potentially exposed to mechanical bumps</td><td colspan="6">Yes</td><td colspan="6">No</td></tr>
<tr><td>Exposed to rain</td><td colspan="4">Totally</td><td colspan="4">Partially</td><td colspan="4">Not exposed</td></tr>
<tr><td>Type of coating's treatment</td><td colspan="3">Rough finish</td><td colspan="3">Sanded finish</td><td colspan="3">Streaked finish</td><td colspan="3">Smooth finish</td></tr>
<tr><td rowspan="3">C</td><td>Insulator storage time in construction site</td><td colspan="6">Limited</td><td colspan="6">Long</td></tr>
<tr><td>Laying according to construction plan</td><td colspan="6">Yes</td><td colspan="6">No</td></tr>
<tr><td>Distance between panels</td><td colspan="3">D > 2 mm</td><td colspan="3">D < 2 mm with coating inside joints[6]</td><td colspan="3">D < 2 mm without coating inside joints</td><td colspan="3">D < 2 mm with tips of insulator inside joints</td></tr>
</table>

Continues on the next page

[1] A European Technical Approval (ETA) for a construction product is a favorable technical assessment of its fitness for an intended use, based on the contribution made by this product to the fulfillment of the six Essential Requirements, as stated in the CPD for the construction works in which the product is installed. For further information and to verify if the solution is equipped with an ETA, visit http://www.eota.be [13]

[2] Granularity of the biggest grains of granulates > 1,4 mm

[3] Granularity of the biggest grains of granulates between 0,7 and 1,4 mm (included)

[4] Granularity of the biggest grains of granulates < 0,7 mm

[5] In correspondence of structural joints

[6] Risk of formation of cracks

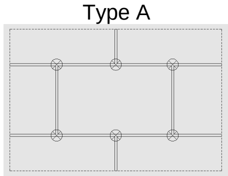
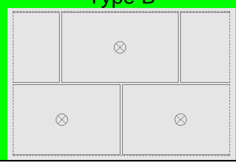
C	*T[°C] during laying*	T < 5 C°			5 C° ≤ T ≤ 30 C°			T > 30 C°		
	RH of substrate	RH ≤ 80%					RH > 80%			
	Substrate planarity	Yes (Δ ≤ 7 mm)					No (Δ > 7 mm)			
	Quantity of adhesive mortar	Q < 3 kg/sqm			3 kg/sqm <= Q <= 5 kg/sqm			Q > 5 kg/sqm		
	Mechanical fixing scheme	Type A 					Type B 			
	Laying team	Specialized					Not specialized			
D	*Indoor RH*	RH ≤ 65 %					RH > 65%			
E	*Climatic zone*	A		B			C		Special conditions	
	Rain class	High (>1200 mm/year)			Medium (between 500 and 1200 mm/year)			Low (< 500 mm/year)		
	Wind load zone	Zone 9	Zone 8	Zone 7	Zone 6	Zone 5	Zone 4	Zone 3	Zone 2	Zone 1
	Microenvironment	Urban area			Suburban area			Rural area		
	Exposure of the façade	North		West			South		East	
F	*Foreseen impacts*	Yes					No			
	Type of use	Residential		Tertiary			Industrial		Public equipment	
	Category of use	Category I[7]			Category II			Category III		
G	*Access for maintenance*	Yes					No			
	Maintenance frequency	f ≤ 10 years			10 years < f < 20 years			f ≥ 20 years		

Table 1. Grid for a Factor method suited for ETICS in Milan context. The highlighted cells are the ones identifying the Reference Condition.

On the other hand, a more refined example is given (Table 2), which is a development of the former grid for ETICS.

A	*Base coat* Liquid diffusivity	A.1.1			A.1.2			A.1.3	
	Insulator material Water absorption coefficient Aw	A.2.1	A.2.2		A.2.3	A.2.4		A.2.5	A.2.6
	Finishing kind Durability of the finishing	A.3.1	A.3.2	A.3.3	A.3.4	A.3.5	A.3.6	A.3.7	A.3.8
B	*RH of substrate*	B.1.1		B.1.2		B.1.3		B.1.4	
D	*Indoor RH*	D.1.1		D.1.2		D.1.3		D.1.4	
E	*Driving Rain quantity*	E.1.1		E.1.2		E.1.3		E.1.3	
	Thermal Shock cycles per year	E.2.1			E.2.2			E.2.3	
	Freeze thaw cycles per year	E.3.1			E.3.2			E.3.3	
G	*Maintenance (Painting)*	G.1.1		G.1.2		G.1.3		G.1.4	

Table 2. Grid for a Factor method suited for ETICS in Milan context with only factors mainly affecting Service Life and that can be calculated.

This second draft takes into account only nine sub-factors and it is more “performance – oriented” than the previous grid. The values of the classes of sub-factors are not given yet, because they are under development. This second

[7] Zone easily accessible and vulnerable to the shocks of hard bodies but non subject to an abnormally use.

approach requires ICT interoperable tools for managing information related to material properties and climate solicitation.

Some factors, such as Factor C regarding the quality of construction, are not considered at all, but this is not because they do not affect durability. Actually, this type of grid considers a restricted domain. For instance, if there is not planarity of the substrate this is considered a building pathology and its effects cannot be foreseen and its influence on Service Life cannot be calculated. The same is for impacts and other aspects that may cause instantaneous or unforeseen failure.

3.2.- Factor Grid for Sandwich Panels

Another example is given for Sandwich Panels (tab. 3). With regard to traction resistance (Factor A), the assumed reference is EN 13165 [15]. On the other hand, with reference to indoor environment (Factor D), the assumed reference is the standard EN 10169-3 and, relatively to outdoor environment (Factor E), the adopted reference is the standard EN 10169-2.

Database for the evaluation of buildings' Service Life

Start page | External Thermal ... | Sandwich panels

Grid's Features Sandwich panels
Family : Superstructure, Category : Coverings, Sub Category : Elements of coverings

Failure ways: [List of the failure ways associated to the Grid]

	Factors	respective factors levels				
A	Products with CE mark	Yes	No			
A	ETA	Yes	No			
A	Production control	Yes	No			
A	Traction resistance	< 100 kPa	100 <= Rtr < 120 kPa	120 <= Rtr <= 150 kPa	Rtr > 150 kPa	
A	Compression resistance	< 100 kPa	100 <= Rtr < 130 kPa	120 <= Rtr <= 175 kPa		
A	Density	d < 34 kg/mc	34 <= d< 37 kg/mc	d >= 37 kg/mc		
A	Water permeability	Class C	Class B	Class A		
B	Design according to best practice indications	Yes	No			
C	Construction according to best practice indications	Yes	No			
C	Laying team	Specialized	Not specialized			
D	Indoor environment	A5: very aggressive	A4: aggressive	A3: middly aggressive	A2: not very aggressive	A1: not aggressive at all
E	Climatic zone	A	B	C	Special conditions	
E	Outdoor environment	Industrial	Marine	Urban	Rural	
F	Foreseen mechanical impacts	Environments with bumps against hard body	Environments with bumps against soft body	Environments with no frequent bumps	Environments with rare bumps	
G	Access for maintenance	Yes	No			
G	Plan of maintenace	Yes	No			
G	Maintenance level	High (f<= 10 anni)	Middle (10< f <20 anni)	Basso (f>=20 anni)		

Table 3. Grid for a Factor method suited for Sandwich Panels (realised in collaboration with Università degli Studi di Palermo, Research Group Leader Prof. G. Alaimo, Italian Network on Durability of Building Components).

4.- Concluding Remarks

Service Life Estimation is a challenging research issue that will need to be faced for many years. The Factor Method was meant as a first evaluation technique and several enhanced versions have been proposed in the last few years. Nonetheless, in the future many applications will need input data regarding the performances over time and the related Service Life of building materials and components; in other words SL will be no more only an estimation parameter by itself, but will be the input for other evaluations. This will mean the stronger need of more reliable and accurate data about it.

In this paper is presented the structure of a method aiming to merge the simplicity of the Factor Method and the accuracy of Engineering and Stochastic Methods. The proposal herein put forward is based on the structure of the Factor Method, where the input data are collected through an international database and the Service Life is calculated thanks to a Performance Based engine.

Future work will regard the refining of the structure of the grids and the implementation of the calculation engine(s) for the determination of the Service Lives. Besides, other building components will be assessed and inserted into the database.

REFERENCES

[14] Accurso F. (2006), *Metodologie sperimentali di valutazione della durabilità di componeneti edilizi: affidabilità e durata del pannello sandwich (Experimental Methodologies for Durability Assessment of Building Components: Reliability and Duration of Sandwich Panels) ,* PhD Dissertation, PhD in Building Engineering: Design and Refurbishment, XVIII cycle 2004-2006, Università degli Studi di Palermo, Advisor: Prof. G. Alaimo.

[3] Bourke K., Davies H. (1997), *Factors affecting Service Life predictions of buildings: a discussion paper,* Laboratory Report - Building Research Establishment, Garston, Watford, UK.

[5] Daniotti B., Lupica Spagnolo S., Hans J., Chorier J. (2008), *Service Life Estimation using Reference Service Life Databases and Enhanced Factor Method,* “11th International Conference on Durability of Building Materials and Components”, Istanbul, Turkey.

[6] Daniotti B., Lupica Spagnolo S., Paolini R. (2008), *Factor Method application using factors grids,* “11th International Conference on Durability of Building Materials and Components”, Istanbul, Turkey.

[10] Daniotti B., Paolini R. (2008), *ETICS experimental programme*, “11th International Conference on Durability of Building Materials and Components”, Istanbul, Turkey.

[11] Daniotti B., Paolini R. (2008), *ETICS Performance decay and degradation evolution: laboratory tests results*, “11th International Conference on Durability of Building Materials and Components”, Istanbul, Turkey.

[12] Daniotti B., Paolini R. (2005), *Durability Design of External Thermal Insulation Composite Systems with Rendering*, Proceedings of “10th DBMC”, Lyon, France.

[4] Hovde P. J. (1998), *Evaluation of the Factor Method to estimate the Service Life of building components, Materials and Technologies for Sustainable Construction*, CIB World Building Congress, Gävle, Sweden.

[2] Hovde P.J., Moser K. (2004), *Performance Based Methods for Service Life Prediction - State of the Art Reports*, CIB Report - Publication 294.

[8] Re Cecconi F. (2004), *Engineering method for Service Life planning: the evolved factor method*, Proceedings of “CIB World Buiding Congress”, Toronto, Canada.

[9] Re Cecconi F., Iacono P. (2005), *Enhancing the Factor Method – Suggestions to Avoid Subjectivity*, Proceedings of “10th DBMC”, Lyon, France.

[13] ETAG 004 – Edition March 2000. *Guideline for European Technical Approval of external thermal insulation composite systems with rendering.*

[16] UNI 11156:06, *La valutazione della durabilità dei componenti edilizi*.
[15] EN 13165: 2001 - Factory made rigid polyurethane foam (PUR) products. Specification.
[1] ISO 15686-1:2000, *Building and constructed assets – Service Life planning – Part 1: General principles*.
[7] ISO 15686-2:2001, *Building and constructed assets – Service Life planning – Part 2: Service Life prediction procedures*.
[17] ISO 15686-7:2006, *Building and constructed assets – Service Life planning – Part 7: Performance Evaluation for Feed-back of Service Life data from practice.*
[18] ISO 15686-8:2008, *Building and constructed assets – Service Life planning – Part 8: Reference Service Life and Service Life estimation.*