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Método de análisis comparativo para la estimación de la vida útil en el diseño arquitectónico durable

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Abstract: A comparative analysis of durability by design of two similar architectural projects from the point of view of the architect is presented to understand factors that affect their service life by means of a methodological approach consisted in analyzing several variables that affect and determine the response variable which refers to the Estimated Service Life (ESL) of the building. The results show that one of the projects complies with the premise that ESL is greater than Reference Service Life (RSL), therefore, it does not require re-design and can move directly to the construction phase; on the contrary, in the other project, ESL does not exceed RSL, and in this way, it is recommended to return to the design phase to be improved once durability key points are identified. It is concluded that it is an approximate method that can be very useful in the early stages of design and also to plan the maintenance phase.

Keywords: Service life, Durability, Life cycle design, Degradation, Sustainable architecture.

Resumen: Un análisis comparativo de diseño por durabilidad de dos proyectos arquitectónicos similares desde el punto de vista del arquitecto es presentado para entender los factores que afectan su vida útil mediante una aproximación metodológica que consiste en analizar distintas variables que afectan y determinan la variable de respuesta que se refiere a la Vida Útil Estimada (VUE) de cada la edificación. Los resultados muestran que uno de los proyectos cumple con la premisa que la VUD es mayor que la Vida Útil de Referencia (VUR), por tanto, no requiere de rediseño y puede pasar directamente a la fase de construcción, por el contrario, la VUE del otro proyecto no excede la VUR, de esta manera se recomienda regresar a la fase de diseño para ser mejorado una vez que los puntos clave de diseño por durabilidad han sido identificados. Se concluye que es un método aproximativo que puede ser muy útil en las etapas tempranas de diseño y asimismo para planear fase de mantenimiento.

Palabras clave: Vida Útil, Durabilidad, Diseño por ciclo de vida, Degradación, Arquitectura sustentable.

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Background

Over the process of architectural design, a value in years that refers to the service life of a building is required to start from a reference point and be able to estimate and predict service life, understood as the period of time after installation or construction over which a building or its parts meet or exceed the performance requirements for which they were designed and built. Additionally, significant corrective maintenance and reparations of materials and components have to be carried out and will have a different economic and functional impact from the one originally planned (International Standards Organization, 2000), *i.e.* , the expected service life of a building.

This is convenient in order to make decisions over the entire life cycle of the project, from planning, pre-design, design and construction to use, operation and maintenance, as well as the end of service life; all this with the intention of reaching the requirements of the project, mainly in its phases of use, operation and maintenance with an approach of durability by design.

Not only does durability by design involve protecting the most vulnerable elements, but it also offers savings in the building's preventive and corrective maintenance, which in an integral manner can also significantly reduce environmental impacts caused by the building as it is important to achieve some degree of sustainability in projects (Ding, 2004).

Life Cycle Assessment (LCA) is a suitable method to explore environmental impacts; which are linked to relevant inputs and outputs of the system, such as raw materials, use of energy and water, emissions to air, land and water, waste, by-products and other releases (Crawford, 2011). Similarly, we can calculate the overall environmental impact of a house (or any building) if we know the amount of impact that results from its day-to-day use and the manufacture and delivery of its construction and building components (Roaf *et al* ., 2007), which implies learning the service life of the building.

For instance, estimated service life can be very useful to calculate the consumption of resources such as energy and water, within the life cycle evaluation of products and inputs used in buildings (Rauf and Crawford, 2013), it is also an indispensable datum to calculate the carbon footprint of buildings and construction components.

The concept of durability is understood as the capacity that a building or a component has to reach the optimal performance of its functions within a determinate environment for a certain amount of time with neither corrective maintenance nor significant reparations (Canadian Standards Association, 2001) and which from risks of mechanical, physical, chemical or geometric nature there is certain degree of vulnerability in the building that may affect its durability and service life (Monjo, 2007).

The problem in many architecture firms is that both the planner and the person responsible for the project sometimes do not consider service life or durability by design in any of the phases of the building's life cycle, particularly in planning and design, so they always have trouble, namely: reduction in service life, increase in costs of maintenance and replacement of constructive components; or even worse, it is detrimental to the structure, comfort and functioning of the building as a whole and in parts. Consequently, it causes heavier impacts on the environment and public health over its service life.

From the perspective of architects, this paper's main research questions are, in the first place, which method can be used to properly estimate the service life of buildings? Secondly, how could we improve the most commonly used existing methods to estimate the service life of buildings?

Many variables are known to affect the durability and service life of a building, so these must be sorted out so that they include all the possible factors that deteriorate the components of buildings.

To do so, the present work proposes a particular method to reliably estimate the service life and durability of buildings taking into account the experience and opinion of specialists in construction and architecture, e.g., architects, builders, manufacturers of materials and real estate agents. Table 1 in, Results, summarizes the variables and consensus opinions of specialists (68 architects, 14 civil engineers, 18 manufacturers of materials and 32 real estate agents) regarding the incidence value of the factors that affect service life and durability of buildings.

The aforementioned, in view of unifying the criteria of the factors that influence durability and service life of buildings and having a hierarchical organization of these variables in order to perform a better assessment prior to the application of the proposed method, which will be detailed in the methodology section.

The most important terminology in relation to service life is summarized as Reference Service Life (RSL), which is the service life baseline value to begin to design. It is a reference value taken from the experience of the designer or from technical specifications by the manufacturer in the case of building components (this value can also come from tests of accelerated aging in laboratories and others tests).

Estimated Service Life (ESL) understood as service life, calculated by means of a method, is the expected duration of the project over its use, operation and maintenance, due to certain conditions and factors related to the building itself.

In order to estimate and calculate service life there are several methods and models both statistical and predictive (Sjöström and Jernberg, 2001); for example, the method of historical record. This method shall only be used in very similar buildings and building components that have been successfully used under the same technical and environmental conditions; it will also depend on the experience of the designer, planner or builder. This method has to offer basic descriptive solutions such as: protection against the sun, dampness, dimensions of some architectural elements or buildings, specific details of design and requirements of direct maintenance.

The ISO 15686 method by factors, which is a method that also depends on the experience of the builder with an engineering background to organize information in such manner that service life can be estimated based on variables that refer to building components and assess each variable following the same procedure and the same hierarchical category. This makes it a subjective and inaccurate method, leaving quantitative methods aside.

For their part, predictive methods such as simulation and mathematical modeling for new components or already-tested building components, but in slightly different environments, should only be carried out by experts in this discipline, since these are specialized numerical and predictive methods (Hovde and Moser, 2004).

Finally, methods based on physical tests of accelerated aging (applied at any element or building component) by means of laboratory tests of induced aging shall only be based on approved international norms (Daniotti and Cecconi, 2010). These are tests in which building components or materials are subjected or exposed to factors believed or known to cause degradation - the deterioration of components or materials is intentionally accelerated (Master and Brandt, 1989).

The problem also lies in that both sorts of tests must be run by experts in materials science; physical test methods in laboratory are justified when there are new materials never before applied or applied for the first time in a different environment, however, they are limited to buildings' components only, leaving the estimation of the service life of entire buildings aside.

All these methods come in handy to assess the service life of building components, however, statistical models are noticed to have a certain degree of uncertainty, since they heavily depend on frequently outdated information (Daniotti and Cecconi, 2010), or on references by the manufacturer, which are sometimes not reliable, and as previously mentioned, they are only applicable to building components. Predictive models require information from laboratory tests or from mathematical models, which are not always accessible for architecture firms. Moreover acquiring this information takes longer and is limited to a few constructive components, and the utilized time can be crucial in certain situations in the development of projects.

Therefore, the present paper considers that the previous methods can be improved by means of a proposal with an architectural approach using both quantitative and qualitative information to determine the service life and durability of the projects. Because of this, the present work proposes a methodology to estimate the service life of a building or a set of buildings using quantitative and qualitative information to calculate an estimated service life that reaches as much as possible a design service life from the standpoint of the architectural requirements.

Figure 1 shows the necessary conditions for the estimated service life of a project to move on to the construction phase, this is, the estimated service life is grater or equal to design service life; on the contrary, the project will have to be re-designed in such manner that in the re-design process durability by design would be more strictly approached.

Therefore, the aim of this paper is to make a proposal to improve the method by factors of ISO , which is the most suitable from the standpoint of architects. In this paper the scope of the research is limited to exemplify the proposed method with a comparison between two projects and does not represent a statistical sample or a survey, but only one representative case of study, in which the method's steps are exemplified highlighting the proposed procedure and its probable use in estimating the service life of buildings in the early stages of design and project planning.

The criteria of durability by design are summarized in table 1 (see supplementary material); in particular, the third column refers to observations and aspects related to durability and can be resorted to using the most vulnerable points to deterioration identified in any project and/ or building. Additionally, figure 1 can be useful to make a comparison between two or more projects such as in the application example of the present methodological proposal.

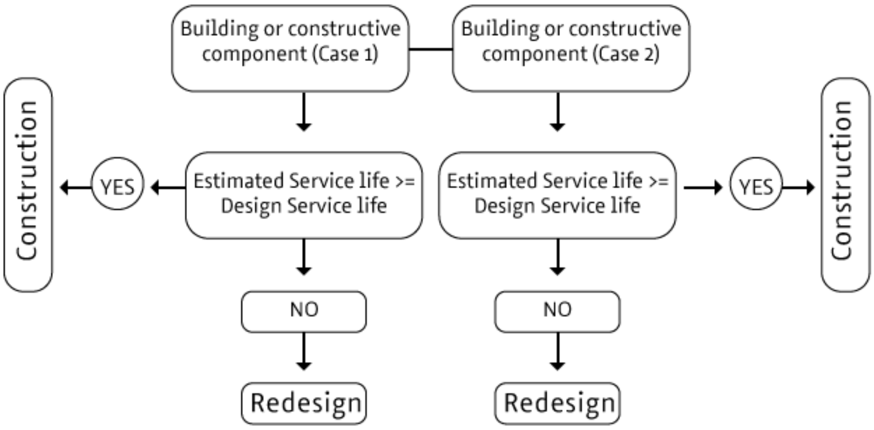

Figure 1.
Service life design estimated between two or more cases to help in decision making in the process of architectural design
Source: ISO , 2000.

If architects lack a particular method to calculate the service life of projects in the early stages of design, this allows us not only to estimate or calculate the service life of the project, but also to make decisions over the design phase to make quality proposals on durable architectural design in order to avoid damage to the building and its components from water, dampness, air filtration, condensation and evaporation, UV radiation, corrosion, plagues, natural disasters, external chemical agents, quality of workforce, quality of materials, sort of maintenance, use of the building, among other variables.

Methodology

The present work proposes a method by factors similar to that by ISO 15686, but improved in several technical aspects, mainly in the approach, because the objective of this study is to provide the architects with a tool to estimate service life and propose strategies for architectural durability by design that helps in the early stages of design and in decision making on key aspects of durability and maintenance of building projects.

As it was mentioned in the background section, the ISO 15686 method is one that depends on the experience of the builder, it has an engineering approach and, additionally, in architecture projects the experience of a planner or architect is needed; therefore, this method manages to join and unify the experience of an architect and durability-by-design approach.

Another issue improved by means of the proposed method in relation to ISO 5686 is that this method is not limited to estimate building components only, but extends to the calculation of service life of entire buildings and to improve the durable design of the project from the architect's point of view (see the observations and aspects related to durability by design in column 3 in table 1, which is also an improved issue), which makes it more reliable and versatile to make decisions in architectural projects.

It has also been observed that ISO and other similar methods assess the factors in the same manner for all projects. We consider this should be corrected by weighing the factors in a hierarchical order and by importance in the assignation of the value of each factor or durability variable depending on the sort of project and assigning a reliability index of 95% for qualitative values (which are subjective), 98% for mixed values (qualitative and quantitative) and 100% for quantitative values (which are objective and perfectly measurable values).

The object of study of the present research is a comparative analysis between two similar projects (housing) by means of a proposed method with an architectural approach to assess the service life and durability of architecture projects, in order to find out which project is the most durable under certain conditions and which specific factors are paid the most attention to, over the process of design to achieve durability and, if necessary, to redesign the project.

The first step is to define the object of study that refers to two sorts of housing intended for similar dwellers (middle income housing), located at the same place, with the same extension and construction levels, built by similar construction companies with a similar architectural starting point but using different materials and construction systems. The conditions of the comparative analysis are defined from two different scenarios: one for house 1 (h1) and another for house 2 (h2).

This point, closely linked to the object of study, describes the houses' technical specifications mainly in their constructive systems, materials, sort of maintenance, quality of workforce and architectural design, among other characteristics that will help us decide on the factors applied to the proposed method in order to estimate service life and durability key points.

The second step is to define the variables that take part in the estimation of the service life of a building. On the one side, we have the response variable that is the service life that has to be calculated for each house; on the other, we have the control variables that are the factors agreed upon from the experience of a number of specialists in architecture and construction (132 specialists: 68 architects, 14 civil engineers, 18 material manufacturers, and 32 real estate promoters) to unify criteria on the factors that influence the estimation of service life and the durability of the building.

The third step is to define the particular method to follow in order to carry out the estimation of service life in each study project (h1 and h2). The proposed method can be summarized in formula (1) as follows:

$$ESL_h = RSL_h \prod_{n=1}^{N} F_{n,h} \quad (1)$$

(1)

Where:

ESL_h = Estimated Service Life of house *h* , in years;

RSL_h = Reference Service Life of house *h* , in years, which can be obtained from a statistical record of similar houses;

Fn,h = Factor *n* influencing the service life of house *h* .

To obtain the service life of each project for each factor, depending on the type of information, either qualitative, quantitative or mixed data, a variable is applied in views of adjusting the reliability on the weighing of the projects to the most real conditions of the comparison between the two scenarios as follows:

F1: quality of materials and constructive components (it is quantitatively measured and its reliability is considered 100%).

F2: architectural and constructive design (it is qualitatively measured and its reliability is considered 95%).

F3: quality of workforce (it is quantitatively measured and its reliability is considered 95%).

F4: indoor environment (it is quantitatively measured and its reliability is considered 100%).

F5: outdoor environment (it is quantitatively measured and its reliability is considered 100%).

F6: conditions of use (they can be measured in a mixed manner and their reliability is considered 98%).

F7: degree or level of maintenance (it can be measured in a mixed manner and its reliability is considered 98%).

The fourth step is to assign values to the factors and obtain service life for each of the example houses (h1 and h2) by means of the aforementioned formula (1) (step3).

The fifth and final step is to carry out the comparison through the analysis of results of the valuing of the factors, identifying the lowest values for each house and then proposing the durability points in which the projects have to be re-designed, both qualitatively and quantitatively on the basis of figure 1.

Results

Definition of the object of study

House 1, a middle income house built with hollow ceramic masonry walls, reinforced with rebars (Ø 3/8"), fixed with cement-sand mortar (at a 1:4 proportion), on a foundation of a reinforced concrete slab with joist and beam floors and covers with a 5-centimeter compression layer, reinforced with an electro-welded steel mesh of (6X6-8/8) and waterproofed with an asphaltic membrane.

House 2, a middle income house, built with masonry load-bearing walls made of red bricks from the region, confined with beams and columns reinforced with rebars (Ø 3/8") and fixed with cement-sand mortar (at a 1:4 proportion) on a single shallow foundation of reinforced concrete, with floors and covers of plain concrete slabs (F´c= 210 Kg/cm2) reinforced with rebars (Ø 3/8") and waterproofed with an asphaltic membrane.

Assignation of values to factors and estimation of service life for each house (h1 and h2)

Table 1 (see supplementary material) shows the values assigned to the factors that determine service life in the case of h1 (organized and agreed upon by experts). For h2 the entire filling was obviated due to space constrains; only the summarized results are shown in table 2.

It is noticed that in table 1 the lowest values for h1 were in F1 (quality of materials) and F5 (outdoor environment), with values of 0.9272 and 0.9230, respectively, and so we observed that in these two factors the projects shall be re-designed to reach a more durable design, paying attention to the observations and durability aspects identified in column 3 in table 1.

In table 2, the summary of the analysis of the factors of service life for house h2 is presented. It can be noticed that the lowest values were F5 with 0.9230 (outdoor environment) and then F3 with 0.9833.

Table 2.
Summary of the factor analysis for house h2

Factors	Values
F1. Quality of materials and constructive component	1.0727
F2. Architectural and constructive design	1.04
F3. Quality of workforce	0.9833
F4. Indoor environment	1.125
F5. Outdoor environment	0.9230
F6. Conditions of use in the building	1.0333
F7. Degree and level of maintenance	1.1333

Source: author's own elaboration on the basis of the execution of the proposed method and on the general opinion of 132 specialists in construction and architecture.

In table 2, it is noticed that the lowest values occur in F5 and F3, therefore it is there where work has to be done in the design and re-design stages of the project in order to improve its service life and durability.

The following step is to obtain the service life of both houses using formula (1).

$$ESL_h = RSL_h \prod_{n=1}^{N} F_{n,h} \qquad (1)$$

(1)

The Reference Service Life (RSL) for this sort of building, use, maintenance and accessibility conditions is RSL = 60 years; according to the information of CSA S478-95-R2001 Canadian technical norm (CSA, 2001) and information equivalent to ISO 15686 norm the Canadian version of LEED® on design and durability in buildings (Green Building Council, 2004).

Estimated Service Life for h1

We have:

$$ESL_{h1} = 60_{h1} \prod_{n=1}^{7} F_{n,h1}$$

ESL_{h1}= 57.3697 years

ESLh1= 57.3697 years

Let us notice that service life for h1 is below the reference service life; this way, the project will have to be re-designed in order to correct factors F5 and F1, which were the lowest values in the factor analysis.

Service life estimation for h2

We have:

$$ESL_{h2} = 60_{h2} \prod_{n=1}^{7} F_{n,h2}$$

ESL_{h2}= 69.3632 years

ESLh2= 69.3632 years

Let us notice that for h2, the estimated service life surpasses reference service life; hence, re-design is not necessary as it meets the conditions pointed out in figure 1.

Finally, the fifth step is to compare the projects

According to the values obtained from the analysis of service life, we have:

ESL_{h1}= 57.3697 years,

ESL_{h2}= 69.3632 years

The comparison shows:

House h2, due to its characteristics and factors, is the most durable and the one with the longest service life; in this case, there is no need to re-design the project and after the design phase, construction can immediately begin; on the contrary, house h1 with an ESL lower than RSL has to be re-designed paying attention now to factors F5 and F1 to improve durability by design and move on to construction.

In column 3, table 1, observations and durability aspects, one can see the criteria of durability by design for the house that needs to be redesigned, particularly in points F5 and F1. (NB: table 1 refers to house h1 but the points referring to observations and durability aspects are the same to take into account for both houses in case of re-design).

Conclusions

In the process of architectural design, a value in years is required to determine the service life of the building from a reference point and to be able to carry out predictions about service life.

- There are many variables that can affect the durability and service life of a building, so these shall be the possible factors that deteriorate the components of buildings.
- This work proposes a methodology to estimate the service life of a building, constructive components or sets of buildings using both quantitative and qualitative information for the calculation of an estimated service life that approximates as much as possible to the design service life from the standpoint of architectural requirements.
- Obtaining the service life of each building will depend on each factor and the sort of information (qualitative, quantitative or mixed); this is affected by a variable in view of adjusting reliability in weighing the projects with the realest conditions of the comparison between two or more sorts of scenarios.
- For the valuing of the factors, the lowest values for each project shall be identified and then propose the specific durability points in which the projects have to be re-designed.
- In the case of the example of application of the method, it is concluded that house h2, because of its characteristics and related factors, is the most durable and with the longest service life; in this case, h2 does not need re-design and from the design phase, the project can go on to be built. On the contrary, for h1, since ESL is smaller than RSL it has to be re-designed and go back to design phase and then pay attention to factors F5 and F1 to improve durability by design and build the project.
- This method is recommended for a possible use in processes of sustainable certification and carbon footprint, as well as in

the certification processes and permits of habitability granted by some municipalities.

Supplementary material

Table 1. (html)

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