EXPERIMENTAL PROGRAM TO EVALUATE BUILDING ELEMENTS SERVICE LIFE : FIRST RESULTS ON BRICKWORK.

Evaluating service life on building elements

P.N. MAGGI, M.G. REJNA, B. DANIOTTI, F. RE CECCONI, T. POLI and G. RIGAMONTI
DISET, Polytechnic of Milan, Milan, Italy
A. JORNET, T. TERUZZI
Experimental Technical Laboratory (LTS), Department of Construction and Territory, Scuola Universitaria Professionale della Svizzera Italiana, CH-6952 Canobbio, Switzerland

Durability of Building Materials and Components 8. (1999) *Edited by M.A. Lacasse and D.J. Vanier*. Institute for Research in Construction, Ottawa ON, K1A 0R6, Canada, pp. 571-580.

Abstract

In this paper we report on preparatory work and results of an investigation performed in order to study experimentally the decay of the functional performances of some building elements by means of laboratory and outdoor aging. This experimental investigation is part of a larger on going research program agreed between DISET and LTS, whose goal is the development of a methodology for the prediction of building elements service life and for the modeling of degradation mechanisms. The aging tests have been performed on building elements belonging to the class of the external walls. The specimens are composed of perforated brickwork coated with render and of a protective layer consisting of an acrilical water painting. For comparison, the aging tests were also performed on a series of unprotected brickworks. The accelerated aging program, conducted within an environmental test chamber, develops on the iteration of a cycle consisting of four distinct phases in which are simulated the most significant climatic conditions and actions (rain, irradiance, freeze and thaw), to which the chosen building elements are generally exposed. The cycle has been calibrated so as to yield the right stressing load of the climatic agents on the basis of the time evolution of temperature and humidity measured during preliminary tests at different points inside the samples. Parallely to the laboratory aging program, outdoor aging will also be carried out. The decay of the functional performances of the specimens during the aging process has been recorded through the periodical measurement of some relevant material parameters by means of non-destructive and destructive testing methods. In a next and final phase, the experimentally collected data will be elaborated and interpreted in order to support and validate the proposed methodology for evaluating the service life of building elements

Keywords : service life prediction, durability, performance, brickwork.

1 Introduction

The experimental program to evaluate the durability of building elements presented in this paper is part of a wider research context dealing with the behavior of elements over time. The DISET department has been dealing with this issue for a number of years.

The lack of experimental data about changing of the performances and functional characteristics of the elements due to the action of stressing agents, induced us to set up an evaluation method for durability to be applied to building elements. This method was presented during a national meeting held at Turin Polytechnic in October 1996 (Maggi P.N., 1996).

In this method, the durability is expressed in terms of propensity and can be deduced from the response of the material to the stressing agents and more precisely, from the decay of the characteristics related to the supposed performance (functional characteristics) which can be assumed by the analysis of the structure of elements.

The experimental program, conducted by LTS, and its first results presented in this paper aim at verifying the reliability of this method.

2 Experimental program

2.1 The building elements and the start-up of the experimental phase

The experimental phase will allow to evaluate the durability of some building elements out of a catalogue of external walls, whose typology is the most frequently used in Italian constructions. The building element chosen to start the experimental program is a traditional cavity wall composed by: internal hollow bricks, thermal insulating layer and external perforated bricks coated with render and finished with a water painting. The test will tackle only the external part of the wall, so the samples (39 x 51 x 13 cm) will be only composed by the external brickwork, the render and the protective coat. The specimen will have two configurations : protected with water painting and not.

The comparison between the results of the unprotected specimens and those of the protected ones will show the protective performance of the coating over time.

2.2 General testing layout

In order to evaluate the durability of building elements, it was chosen to submit the samples to laboratory and outdoor accelerated aging, as well as to outdoor natural aging. The choice to resorting to a double method of evaluation allows to correlate the different scales, thus avoiding to produce unreliable results or, at least, some that are not traceable back to outdoor environmental stresses. As far as the outdoor exposure is concerned, two sites with similar climate (Milan and Lugano) but with different levels of pollution were chosen. The samples will be placed southern oriented, vertically and with an inclination of 45°. This latter position allows the exposure of the building elements to conditions of greater stresses than the ones to which a vertical external wall is normally subjected. Thus three types of aging can be distinguished: laboratory accelerated aging, outdoor accelerated aging(45°) and outdoor natural aging (90°).

The outdoor accelerated and natural aging will start in April 1999.

2.3 Laboratory accelerated aging program

The first preliminary phase (May and June 1998) has consisted in verifying the stressing loads at different locations inside the sample through the continuous monitoring of temperatures and humidity. After this preliminary calibration phase of the cycle was ended, the laboratory accelerated aging program was started for the unprotected samples. To this purpose 14 samples were prepared.

At this date two samples have already concluded their stay inside the environmental test chamber: sample 10.1, with 7 weeks of aging test (148 cycles), and sample 8.1, with 13 weeks of aging test (285 cycles). The complete laboratory accelerated aging program will take about 8 more months.

3 The laboratory test cycle

In order to determine duration and structure of a complex test cycle able of reproducing the right environmental conditions, we first identified the outdoor agents affecting service life of the chosen building elements. Stressing agents were defined on the basis of both national and international standards (UNI and ICITE, ISO/TC 59/SC 3/ N 296, CEN, ASTM E 632, ASTM G 26, AFNOR - NF T 30-049).

The definitive aging cycle has a total duration of 6 hours and 25 minutes and is composed as follows:

1. *Rain*. In this first phase, whose duration is 60’, the samples are sprayed with water at a temperature of about 20°C. The air inside the environmental test chamber is kept at a constant temperature of 20°C and at a relative humidity higher than 95% ; T_{12}=Transition time: 5’;
2. *Freeze*. The wet samples are subsequently exposed to an ambient temperature of -20°C for 90’; T_{23}=Transition time: 80’;
3. *High temperature and high humidity conditions*. The ambient temperature is kept constant at 55°C and the relative air humidity is maintained above 95% for a duration of 60’; T_{34}=Transition time: 5’.
4. *High temperature and low humidity conditions with UV radiation.* During this phase the ambient temperature is lowered to 30°C and the relative air humidity is held at about 40%. The samples are irradiated by means of a Xenon lamp for a duration of 80’. The temperature at the surface of the samples is about 60°C; T_{41}=Transition time: 5’.

4 Characterization tests

The characteristics affecting the performances of the exterior walls under investigation were determined using the functional analysis method (Maggi P.N., 1998). This method allows to easily highlight the characteristics which influence the performances of the wall directly, the so called *functional characteristics*, and the characteristics which affect performances indirectly, the so called *related characteristics*.

In order to find out changes in functional or related characteristic, each specimen is analyzed before entering the environmental test chamber, as well as during and at the end of its stay inside the chamber. These characteristics are determined by means of both non-destructive and destructive tests, as shown in the Table 1.

Table 1: Characteristics measured on each specimen

Non-destructive tests	Destructive tests	Reference Standards
Weight measurement		
Weight loss measurement		
	Water vapor permeability	DIN 52615
	Water absorption	DIN 52617
	Porosity	SIA 162/1, test no. 5
	Elastic modulus	
	Bond strength	

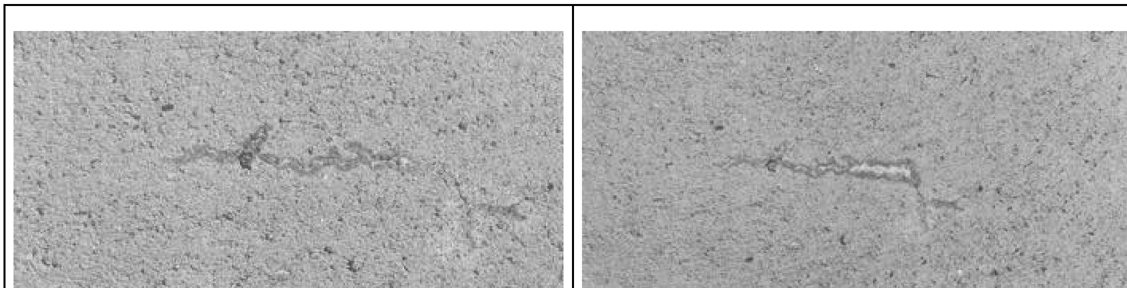
On a weekly base, each specimen is photographed and weighted, and the amount of lost material is determined. The lost material is collected using fine meshes placed under each specimen.

Destructive tests are performed at the end of the planned exposure times of the specimens. The state of the render is characterized by the determination of its vapor permeability, water absorption, porosity and elastic modulus. The elastic modulus test will be determined according to the test method presented by Prim et al. (Prim, P., 1990).

5 Results

5.1 Non-destructive tests

The two photographs of Figure 1 show the same crack shortly after its appearance on the surface of one of the samples (left) and after 285 aging cycles (right). A deposit within the crack can clearly be observed. This deposit is probably due to soluble silica transported and released at the sample's surface during the dry phase of the aging cycle. The crack acts as a preferential path for water movement.



Sample 7.1. after 148 cycles

Sample 7.1. after 285 cycles

Fig. 1: Photograph showing a detail of the same sample after two different aging times

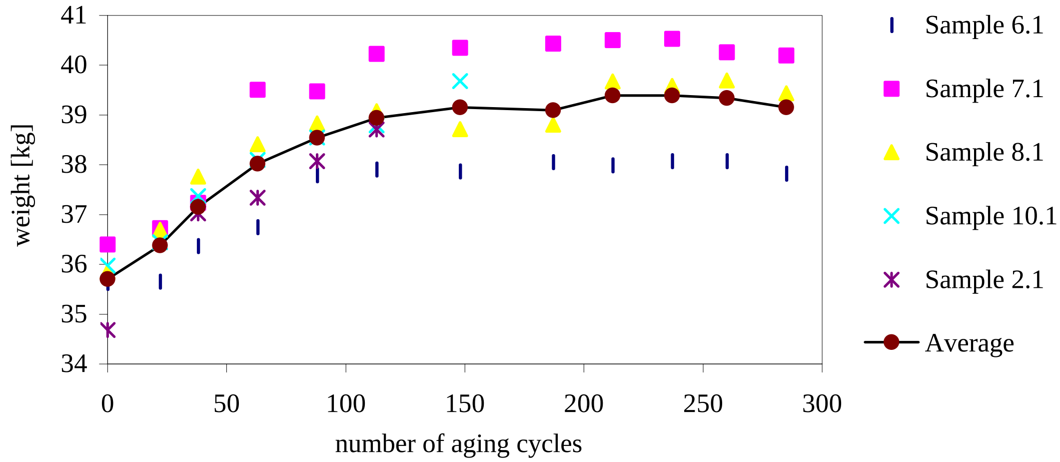


Fig. 2: Weight of the samples as a function of the numbers of aging cycles

In Figure 2 the weight of the samples is shown as a function of the number of aging cycles. There are two important facts to highlight: on the one hand each specimen absorbs a considerable amount of water during the test. In fact, the weight of the specimens increases from 7% to 12%. On the second hand, for all specimens the weight seems to reach its saturation value after about 150-200 aging cycles.

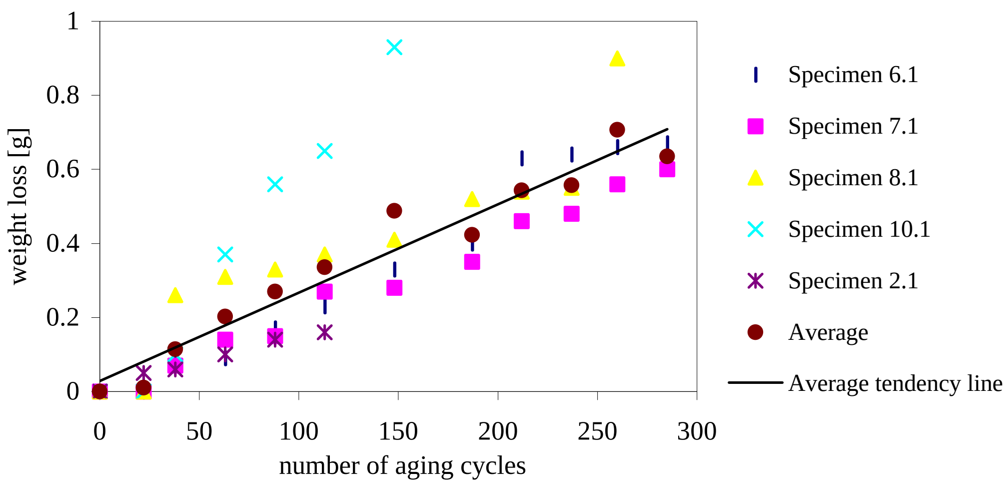


Fig. 3: Weight loss as a function of the number of aging cycles

The action of water, both in combination with freeze and thaw cycles and alone as washing away water, on the sample can be clearly seen on Figure 3. This figure shows the amount of mass loss due to the aging cycles as a function of the number of cycles. The tendency line computed on the average of the mass loss of each sample points out a linear trend.

5.2 Destructive tests

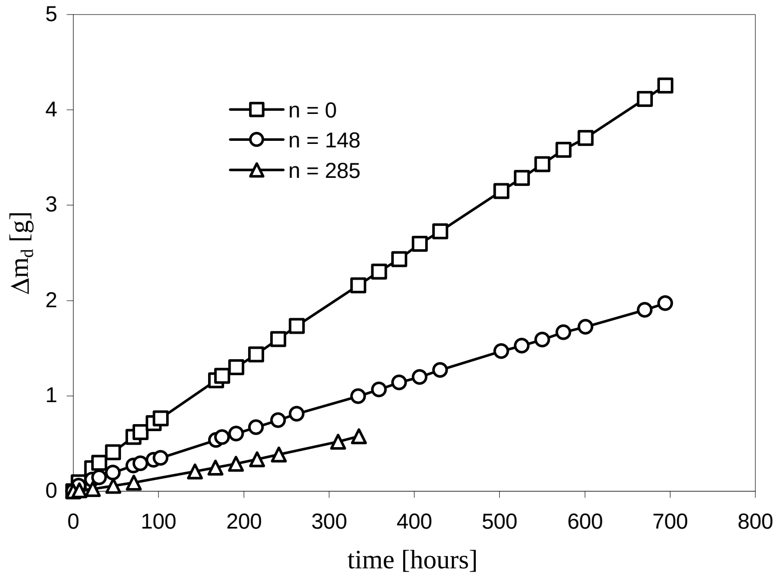


Fig. 4: Amount of water vapor which diffuses through the render as a function of time

In Figure 4, the amount of water vapor Δm_d, which diffuses through the render during the test of water vapor permeability conducted after exposure of the sample to n= 0, 148 and 285 aging cycles is plotted as a function of time. The test has been performed in accordance with the German standard DIN 52615 (1987) and at the following testing conditions: temperature 23°C, relative air humidity 0% vs. 50%. From the slope of the three linear curves plotted in the graph, it can be observed that the water vapor permeability of the render decreases for increasing number of aging cycles.

Table 2: Vapor diffusion resistance factor

	n = 0	**n = 148**	**n = 285**
μ	63,1	142,6	167,5
s_d (m)	0,8	2,2	2,6

In Table 2 the coefficient of water vapor diffusion μ and the thickness s_d of the diffusion-equivalent air layer, as derived from the curves plotted in Figure 2, are listed. The data show that the permeability of the render to water vapor decreases at least by a factor of two.

Figure 5 displays the amount of water Δm_a absorbed per capillarity by the render as a function of time after exposure of the sample to n = 0, 148 and 285 aging cycles. From the curves plotted in the figure it can be seen that both the rate of water absorption and the total amount of water absorbed until saturation decrease with increasing number of aging cycles. This behavior is also indicated quantitatively by the results listed in Table 3, where the values of the average absorption rate within the first six hours of testing (w_6) and of the total amount of water absorbed by the samples

(ΔW) are given. The test has been performed in accordance with the German standard DIN 52617 (1987) and pursued until total saturation by capillarity.

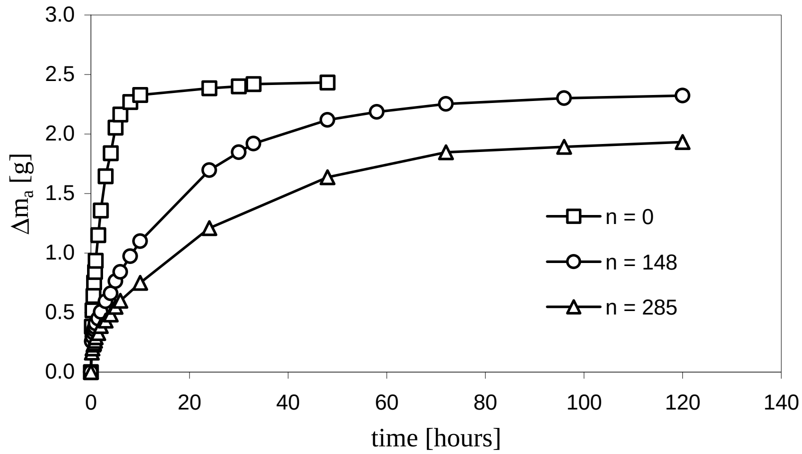


Fig. 5: Amount of water absorbed per capillarity as a function of time.

Table 3: Water absorption parameters.

	n = 0	**n = 148**	**n = 285**
w_6 [kg/m^{2}h$^{-1/2}$]	0,47	0,18	0,13
ΔW [g]	2,43	2,32	1,93

In Figure 6 the bond strength between render and brickwork is shown as a function of the number of aging cycles. The bond is measured in terms of the tensile stress required to detach from the underlying brickwork or cause failure of a core taken from the sample. From the data shown in Figure 6, it can be seen that the bond of the render increases for increasing number of aging cycles. After 285 cycles the bond overcomes the tensile strength of the render, as indicated by the different location of the broken surface (see Table 4).

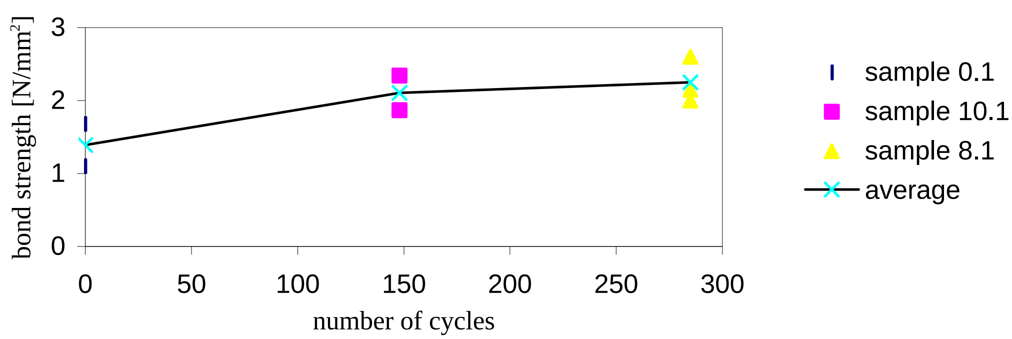


Fig. 6: Bond strength as a function of the number of aging cycles

Table 4: Bond strength

specimen id	nr. of aging cycles	σ [N/mm^2]	location of fracture	σ_m [N/mm^2]
0.1	0	1,10 1,68	render-brick interface	1,39
10.1	148	1,87 2,34	render-brick interface	2,10
8.1	285	2,60 2,15 2,00	render	2,25

5.3 Destructive tests on prisms

Prisms of render 4 cm wide, 4 cm high and 16 cm long were made when building the samples and were aged in the same environmental chamber were the samples were placed. The aging agents affecting the prisms are the ones affecting wall samples except for the UV radiation. Figure 7 shows a great increase of elastic modulus of the prisms over time (sample 15 and sample 16 are reference prisms).

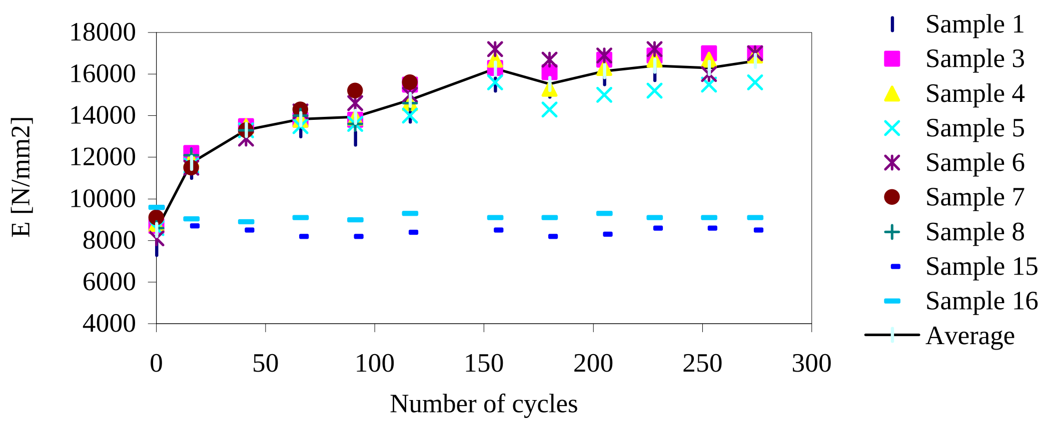


Fig. 7: Elastic modulus of the prisms

Table 5 lists the values of flexural and compressive strength of prisms of render as a function of the number of aging cycles. For comparison, the evolution with time of the same mechanical properties is reported also for prisms which have not been exposed to any aging cycle. It can be observed, on the one hand, that exposure of the prisms to the aging cycles results in an increment of both their flexural and their compressive strength, which become, respectively, two- and three-times larger. The strengths of the unexposed samples, on the other hand, remain unchanged, as it happens for the elastic modulus.

Table 5: Flexural and compressive strength

nr. aging cycles	age [days]	flexural strength (*) [N/mm^2]	compressive strength [N/mm^2]
0	7	1,9	7,3
0	7	1,8	7,5
0	28	1,8	7,6
0	28	1,8	6,8
0	120	2,0	7,4
0	120	2,0	7,6
148	105	2,5	18,6
148	105	2,4	17,9
285	120	4,5	21,4
285	120	4,8	21,1

(*) determined using simple beam with center-point loading

6 Future development of the research

The results obtained so far do not show a significant decay of the functional characteristics of the materials used. In fact, after 285 cycles, although in some samples little cracks have appeared, water vapor diffusion and water absorption by capillarity have decreased and the bond strength between render and brickwork has increased, thus indicating a reduction of permeability and an improvement of the mechanical properties. The same trend has been observed for flexural and compressive strength and modulus of elasticity measured on the prisms submitted to the accelerated aging. These results are in agreement with other unpublished data obtained at the LTS and also with results published by other authors (Bernsdorf et al., 1988, Künzel, 1994).

In the next months the aging tests on the unprotected samples will continue until a decay in the functional characteristics is obtained: for each characteristic it will be defined a critical level, under which the service life can be considered finished.

The first result we'll obtain is to estimate the experimental service life of the building component and of the constituting materials under accelerated aging testing.

A second result will consist in the comparison between the time behavior of the protected samples and the unprotected ones: this will give information about the degree of protection during time obtained by acrilical painting.

Outdoor aging testing on the same type of samples will be conducted in Italy and Switzerland to find out time re-scaling and this to obtain the real service life of the components for two different climates and pollution conditions.

The flapdoor of the aging chamber will be substituted by a section of the real building component and the aging cycles repeated to simulate its behavior between the outdoor environment (aging chamber) and indoor environment (laboratory at controlled conditions).

Once validated the experimental layout on this first reference component the aging program will be adopted for the building components of the catalogue of external walls, most used in Italy, to evaluate service life and to compare different products and components.

All this experimental data will be useful to support the original analytical material sensitivity evaluation method and to define a final durability and service life evaluation method.

7 Acknowledgments

Our thanks are due to the staff of the LTS, without whose assistance the results reported here would not have been possible, and to M. Melzi for its valuable cooperation in connection with the protective paint coatings.

8 References

Bernsdorf, P., Jeran, A., Grimm, H., Scherb, R., Siebel, V., (1988), *Putzmörtel – Mechanische Kennwerte*, Bautenschutz und Bausanierung , Heft 2, Rudolf Müller, Köln, Germany.

Daniotti, B., Maggi, P.N., (1993), *Valutazione della qualità tecnologica caratteristica dei prodotti complessi per l'edilizia*, Quaderno n° 2 DISET- Politecnico di Milano, Progetto Leonardo, Ed. Esculapio, Bologna, Italy.

Daniotti, B., Poli, T., Re Cecconi, F., Rigamonti, G., (1998), *Methodology and experimental program to evaluate building components service life*, CIB World Building Congress 1998, Symposium A Materials and Technologies for Sustainable Construction, Gavle , Sweden.

Künzel, H. (1994), *Schäden an Fassadenputzen*, Schadenfreies Bauen, Band 9, IRB Verlag, Stuttgart, Germany.

ISO, (1999), *Buildings – Service Life planning – Part 2: Service Life Prediction Principles, ISO, Geneva*, *ISO/DIS 15686-2.*

Maggi, P.N., Rejna, M., Daniotti, B., Poli, T., Ravetta, F., Re Cecconi, F., (1996), *Progettazione e qualità utile*, Ministry of scientific and technological university and research, Politecnico di Torino, Italy.

Maggi, P.N., Rejna, M., Ravetta, F.,(1998), *Functional analysis as a method of designing new building components*, CIB World Building Congress 1998, Symposium A Materials and Technologies for Sustainable Construction, Gavle, Sweden.

Prim, P., Wittmann, F.H., (1985), *Méthode de mesure de l'effet consolidant de produits de traitement de la pierre*, Vth International Congress on Deterioration and Conservation of Stone, Lausanne, Switzerland.