EXPERIMENTAL EVALUATION OF PERFORMANCES OF DIFFERENT SOLUTIONS OF FINISHING FOR MASONRY BUILDINGS FOR DETERMINING DURABILITY

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Abstract

The components of the building envelopes have to provide performances of different types: it is supposed to resist to the weather agents, to have a good water vapor permeability in order to prevent some degradation phenomena, and to inhibit the capillary rising dampness. But it must also maintain all these features over the time, in other words it must have a high durability. The designers, when they have to choose finishing solutions, are put in front of very complex evaluations, with the aim of finding the most appropriate one, given the specific context stress factors.

To provide a useful guide for those frequent situations, two Departments of University of Naples Federico II conducted combined tests in the laboratories and on the field, on four types of finishing solutions (plaster + painting) for tuff masonry, which is typical of Southern Italy.

In the DICMAPI laboratory the specimens were subjected to tests of water absorption by capillarity, tests of water vapor permeability, tests of water absorption at a low pressure, and tests of accelerated aging in a QUV machine.

The field assessments were carried out on 500 sampled buildings in the city of Naples, over 10 years of monitoring, showing the different behavior of the four types of selected specimens: for example, the characteristics of the finishing solutions of macroporous plaster + silicate paint and cement plaster + quartz paint have remained almost the same, without significant performance decay. The results could represent a good starting point for the creation of a useful handbook for designers of recovery interventions.

Keywords: durability, performances, laboratory test, masonry, plasters, paints.

1. INTRODUCTION

The most part of materials and building components provide multiple performances: for example, finishing materials used for perimetral walls are mainly characterized by esthetical

needs, but also by necessities of protection towards the inside and, according to the latest laws about energy saving, often by needs of thermal insulation. Considering this multiplicity of performances they have to carry out, their context of stress is pretty various as well: sun, wind, dampness from different sources (rain, capillary rising dampness, condensation), and also mechanical stress, such as thermal variations, and phenomena of contraction.

Designers often find it hard to choose the products that suit the most a specific case, since the performances the components are needed for, may require totally opposite characteristics. In addition to this, the producers' data sheets usually refer to the reactions of the single components themselves, rather than to their behavior when they are used in a "system" of materials, for example wall + plaster + finishing + paint.

So, while it is easy to get information about the water vapor permeability of a painting product, it is much more difficult to get it for an ensemble made up by tuff + plaster + skimming mortar + paint. And there is also the necessity to gather information about the combined action of rain and wind, and the effects of UV rays, dampness condensation, etc.

Then, it seemed particularly useful to carry out an experimental research on the ensemble of a building envelope, that requires the evaluation of reciprocal influences that should be carefully examined for the analysis of the behavior of the whole system, rather than on the behavior of a single component used in the external façade, and on the stress context that can be predicted for it. Then, it ultimately seemed appropriate to inspect on the permanence of the characteristic performances during the time, through durability tests carried out with two different approaches:

- tests on the field, monitoring the real behavior of the components, during ten years, when used in buildings with finishing solutions that will be further explained;
- tests of accelerated aging in the laboratory with a QUV machine.

2. CRITERIA OF CHOICE OF SPECIMENS AND STRESS AGENTS

Choosing the typologies of specimens to use for the tests, it was decided to select the finishing solutions that are most used in the designing procedure of the recovering interventions, for buildings with tuff masonry, in the specific context of the city of Naples.

For this reason, we availed ourselves of the collaboration with the society S.I.Re.Na. – created by the City of Naples in order to promote the recovery of the historical center – that has collected of a database of more than 1200 interventions realized in the decade 2002-2012.

According to the statistical data, it resulted that the most used solutions were by far:

a. plaster made up with lime mortar + lime paint (hereinafter called "B");

b. plaster made up with "common" mortar (lime + plaster) + siloxane paint ("Gs");

In order to complete the extrapolation of the range of possibilities, two more solutions were chosen. These two appear to have opposite problems in relation to dampness:

c. plaster made up with cement mortar + quartz paint ("Gc");

d. macroporous plaster + breathable paint ("G").

The specimens were made up in the following modes:

- dimensions of yellow tuff specimens: 5 x 5 cm x (5+1) cm - 16,0 x 4,0 x 2,0 +/- 0,5 cm. only for the test in the QUV machine;

- finishing of the sides: plaster +paint on one side, bituminous liquid sheath on the other (fig. 1a).

Among the different performances that characterize the finishing of a tuff masonry, the following were mainly considered: (i) the faculty to resist decay because of the action of phenomena of capillary rising damp, (ii) the faculty of perspiration, (iii) the faculty to resist the action of rain, sun and condensation, (iv) the reaction of the material to these stress agents during the time.

So the following tests were prepared for the four different types of specimens: capillary water absorption, water vapor permeability, water absorption under low pressure, accelerated aging in a QUV machine, in addition to the monitoring on the field, executed on about 500 buildings with the aim of evaluating the in-use behavior for the four solutions.

3. EXPERIMENTAL

3.1 Capillary water absorption

The amount of absorbed water was measured according to the European Standard EN 15801 which specifies a method for determining the water absorption by capillarity of porous inorganic materials. The method may be applied to porous inorganic materials either untreated or subjected to any treatment or ageing. Three specimens for every typology, parallelepiped shaped, were dried in an oven at 40°C until to obtain a constant mass. Subsequently, the specimens were placed on a multilayer of 5 mm of filter paper, soaked in deionized water, maintaining the water level constant during the test (see figure 1b). Starting from the placement on the multilayer, the samples were weighed at fixed times and the amount of absorbed water (A) was calculated using the equation: $A = [(m_i-m_0)/S]*1000$, where m_i is the specimen weight (g) at time t_i ($\sqrt{s}$), m_0 is the dry specimen weight (g) and S is the specimen surface (cm^2) lying on the wet multilayer.

The capillary absorption coefficient (CA, expressed in $mg \cdot cm^{-2} \cdot s^{-1/2}$) was also calculated at the end of the test for all the samples, using the equation: $CA = (A_{30} - A_0)/(t_{30})^{1/2}$, where A_{30} is the amount of water absorbed by the specimen per area unit after 30 min, A_0 is the intercept of the straight line obtained in the linear graph with the y-axis and $\sqrt{t_{30}}$ is the square root of the time (s) after 30 minutes.

3.2 Water vapor permeability

The permeability to water vapor is defined as the amount of water vapor flowing in the time unit and in the surface unit through a porous sample. It is expressed as the ratio between the weight variation of the whole system in 24 h and the area of the sample surface, under a constant difference of the vapor pressure of water (expressed in $Kg/m^2 \cdot s \cdot Pa$ at 20°C), according to the European Standard EN 1015-19. The permeability test was carried out on three samples for each series, placed in Plexiglas vessels containing a saturated solution of potassium nitrate (KNO_3), capable of maintaining, at T = 20 ° C, a constant relative humidity H_R, equal to 93.2% (see figure 1c). Then the vessels were sealed and placed in a climatic chamber at T = 20 ° C and H_R = 50%. The steam flow through the samples was then evaluated by measuring, at time intervals of 24 h, the mass variation of the containers. The test may be considered completed when, by plotting the values of the mass as a function of time, three points are arranged on a straight line, that is, when the mass changes are constants for at least three successive weightings. The data so obtained allowed to calculate, in accordance with the European Standard mentioned above, the water vapor permeability (WVP).

3.3 Water absorption under low pressure (pipe method)

This test is useful to simulate the effect of water absorbed for rain and/or for moisture condensation on different types of finishing. The measurement of the absorbed water allows to evaluate surface modifications, to characterize the effect of a treatment of impregnation altering the surface permeability or to characterize the effect of a natural weathering.

The water absorption was measured with the pipe method according to the RILEM II.4 standard and using the apparatus illustrated in figure 1d. The test is performed by applying a water column on the material under examination and measuring every 5 minutes the volume of water absorbed (directly by reading on the graduated glass tube), for a total time of 60 minutes. Based on the data collected during the test, it is possible to calculate the degree of absorption of water at low pressure (WLP), obtained from the ratio between the difference of the water volume (ml) absorbed at the final time (Q_{tf}) and at 5 minutes (Q_{t5}), and the surface area (cm^2) of contact of the cell (S), as follows: WLP = (Q_{tf} – Q_{t5})/S.
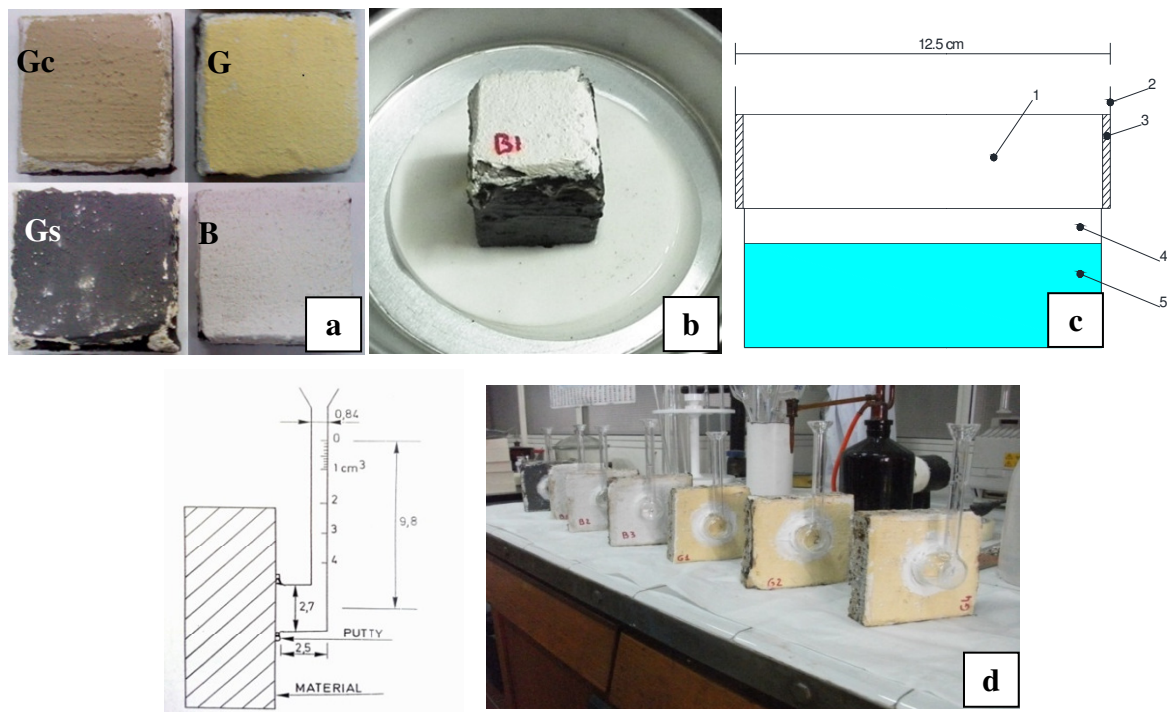

Figure 1 -(a) four typologies of manufactured specimens; (b) capillary water absorption of a specimens placed on a wet multilayer;(c) scheme of apparatus for water vapor permeability test: (1) sample,(2) test vessel rectangular shaped, (3) putty, (4) air interspace (≈ 10 mm), (5) saturated solution of potassium nitrate (KNO_3); (d) apparatus of water absorbed at low pressures (dimensions in cm).

3.4 Accelerated aging in a QUV machine

The enrollment of the test and the elaboration of the results were carried out taking account of the following standard: UNI 9922, UNI EN ISO 4628-1, UNI EN ISO 4618-2, UNI EN ISO 4628-1, using a machine with fluorescent QUV lamps. The QUV accelerated weathering tester reproduces the damage caused by sunlight, rain and dew. In a few days, the QUV tester can reproduce the damage that occurs over years outdoors. Differently from xenon arc test

chambers, it doesn't reproduce the whole sun radiation, but only its damaging effects with a wavelength between 300 nm and 400 nm. It is based on the principle that the long-lasting materials are mainly affected by UV rays with short waves when used outdoors, and this is the primary cause of their atmospheric aging. To simulate outdoor weathering, the QUV tester exposes materials to alternating cycles of UV light and moisture at controlled, elevated temperatures. It simulates the effects of sunlight using special fluorescent UV lamps, and simulates dew and rain with condensing humidity and/or water spray. Before subjecting the specimens to the accelerated aging test, a chromatic characterization was carried out, realizing a number of color measurements between 5 and 7, thanks to the use of a spectrophotometer, which were then elaborated with the software Spectramatic NX. The testing cycle (see figure 2) was repeated for 32 times, exposing the specimens to 128 hours of radiation and 128 of condensation, for a total of 256 of exposition, and it was structured in a pattern described in tab.1. At the end of the testing cycles, the evaluation of the decay of the surface was realized using three tables, according to the UNI EN ISO 4628-1 standard. It classifies the number and dimension of defects found, and the intensity of variations, as shown in tab 2. Concerning the intensity of the chromatic variation, it was evaluated by comparing (using the spectrophotometer) the colorimetric surveys (L^*, u^*, v^*) of the stressed specimens with those of the unstressed ones. The color difference, in fact, can be calculated using the Euclidean distance of the (L^*, u^*, v^*) co-ordinates. In colorimetry, the CIE 1976 (L^*, u^*, v^*) color space, commonly known as CIELUV, is a color space adopted by the International Commission on Illumination (CIE) in 1976, as a simple-to-compute transformation of the 1931 CIE XYZ color space, but which attempted to a greater perceptual uniformity.

Table 1 - Chart of the accelerated aging cycle in a QUV machine

SUB-CYCLES	DURATION	TEMPERATURE	SUNLIGHT RADIATION	CONDENSATION
SUNLIGHT RADIATION	4 hrs.	60°C	Yes	No
CONDENSATION	4 hrs.	50°C	No	Yes

Table 2 - Chart of classification to indicate the defects and to measure the variations

| Class.	Number of defects	Dimension of defects	Intensity of variations
0	none, that is to say no detectable	not visible at a 10x zoom	unchanged, no detectable variations
1	very few, a small, scarcely significant number of defects	only visible at a 10x zoom	very slight, a barely detectable variation
2	few, a small but significant number	barely visible at common sight	slight, a clearly detectable variation
3	moderate number of defects	clearly visible at common sight (to 0.5 mm)	moderate, a variation that can be detected very clearly
4	considerable number of defects	from 0.5 mm to 5 mm	considerable, a determined variation
5	dense disposition of defects	bigger than 5 mm	greatly marked variation
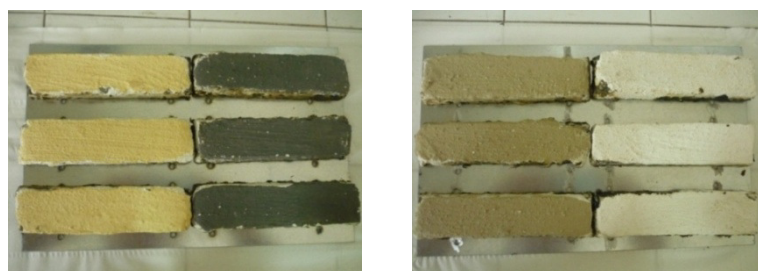
Figure 2 - The specimens subjected to accelerated aging in a QUV machine.

4. RESULTS AND DISCUSSION

Figure 3 shows a comparison between the 4 types of capillary absorption curves (each curve represents an average value of three experimental tests carried out for each type of specimen), together with a table which reports the average values of capillary absorption coefficients CA, calculated taking into account the linear portion of the curves.

The trend of the curves shows that in a first period (about 30-40 min) water absorption is substantially constant, while varying significantly when the rising water begins to affect the finishing layers, characterized by porosity (and hence absorption of water) very different from each other. Figure 4 reports a comparison between the 4 typologies of water vapor permeability curves (each curve represents an average value of three experimental tests carried out for each type of specimen), together with a table in which are reported the average values of the water vapor permeability (W_{VP}) and the resistance to the steam diffusion (μ), together with some porosimetric characteristics of the four different finishing(porosity and average pore diameter).The trend of these curves shows that there are two different behaviors, closely related to the different slopes of the lines: "Gc" and "Gs" specimens exhibit a lower slope than "B" and "G" specimens, meaning that they present a lower W_{VP} and therefore a greater diffusion resistance μ. These results are strongly correlated to the porosimetric data. In fact "Gc" and "Gs" specimens are manufactured with cement-based plasters, very compact, with as much compact paintings, while "B" and "G" are both manufactured with plaster and paintings characterized by higher porosity. Finally, figure 5 shows the curves related to the water absorption at low pressures (each curve represents an average value of three experimental tests carried out for each type of specimen), together with a table which summarizes the values of the W_{LP}. The behavior of these curves is substantially determined by the type of painting, more or less impermeable to water. Among the paints used in the present work, the lime paint (specimens "B") is definitely the most permeable to water, and this leads to W_{LP} values about 4 times higher than other materials. On the contrary, the small differences between the other three samples are related to the different substrates. It is interesting to note that, among the solutions evaluated in the present work, the typology "G" shows the higher water vapor permeability (μ = 6.40) coupled with a low permeability to rainwater (W_{LP} = 0.56).
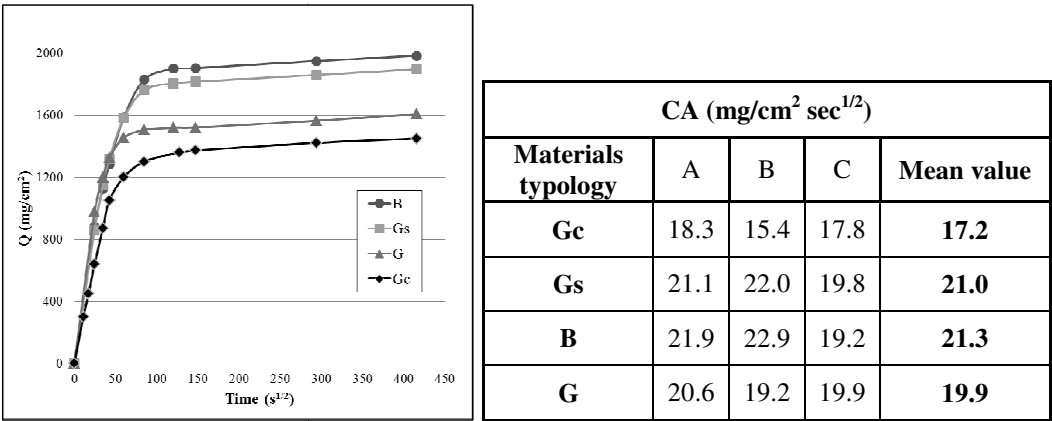
CA (mg/cm^2 sec$^{1/2}$)				
Materials typology	A	B	C	Mean value
Gc	18.3	15.4	17.8	**17.2**
Gs	21.1	22.0	19.8	**21.0**
B	21.9	22.9	19.2	**21.3**
G	20.6	19.2	19.9	**19.9**

Figure 3 - Capillary water absorption curves of the manufactured specimens

Materials typology	Porosity (%)	D_m (µm)	W_{vp} (Kg/m·s·Pa)	µ
Gc	28.5	0.33	1.59E-11	12.19
Gs	28.6	0.63	1.96E-11	9.91
B	33.7	0.80	2.70E-11	7.19
G	47.9	8.22	3.04E-11	6.40
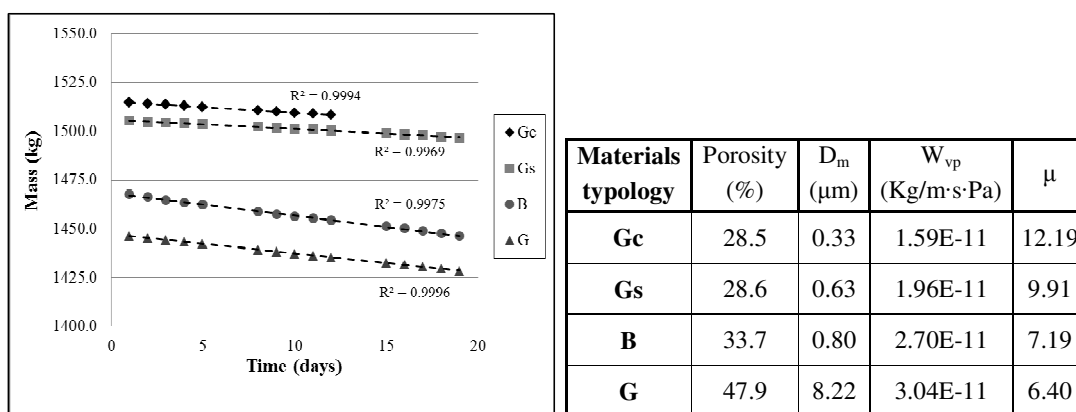
Figure 4 - Water vapor permeability curves of the manufactured specimens

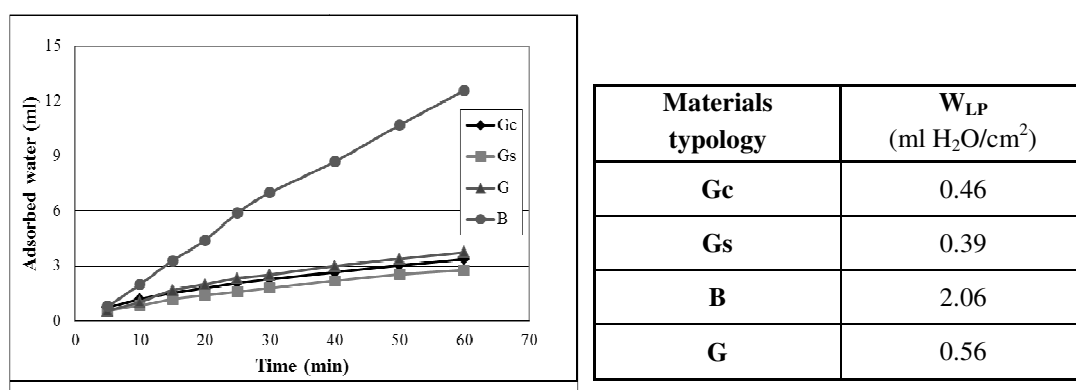| Materials typology	W_{LP} (ml H_2O/cm^2)
Gc	0.46
Gs	0.39
B	2.06
G	0.56

Figure 5 – Low-pressure water absorption curves of the manufactured specimens.

Concerning the QUV tests, "G" and the "Gc" specimens were characterized by a general lack of decay, showing a good resistance to the accelerated aging cycles that were carried over. The "B" specimens have shown a slight superficial decay in the shape of a very thin fading, and of just visible cracks, and for this reason this decay involves both the paint, and the plaster. Finally, the "Gs" specimens show a significant decay, mainly characterized by a slight fading of the pictorical layer, and in particular by chalking, and clearly visible cracks.

The color difference, in the last column of the following table 4 (referred only to one of the series of specimens), is obtained with the formula $\Delta E = (\Delta L^2 + \Delta u^2 + \Delta v^2)^{1/2}$.

Table 4 - Influence of the accelerated aging test on the color variation.

SERIES	PLASTER	PAINT	n° of samples	ΔE	Mean ΔE	Colour fading rating
B	Lime	Lime	1	2.09	1.85	COLOUR FADING 1
			2	0.82		
			3	2.64		
G	Macroporous	Breathable	1	0.90	0.86	COLOUR FADING 0
			2	0.74		
			3	0.93		
G_C	Cement	Quartz	1	1.68	1.25	COLOUR FADING 0
			2	1.33		
			3	0.73		
G_S	Lime - cement	Siloxan	1	1.54	2.21	COLOUR FADING 2
			2	1.53		
			3	3.55		

On the field, as shown in figures 6 and 7, the buildings covered with lime plaster + lime paint and those with "common" mortar + siloxane paint, have been subject to more consequences than the others, because of rising dampness, micro-cracks, temperature variations. For what concerns performances of adhesion of the plasters on masonry, there have not been significant differences in ten years of monitoring. A previous project verified that the lack of adhesion begins from the 15th year.

Figure 6-7: micro-cracks and rising dampness in a building with "Gs" solution

5. CONCLUSIONS

The tests have shown some important evidences:

- the "G" specimens are characterized by good results both in water vapor permeability and in water absorption at a low pressure tests: this is not a well-known information, and it is particularly useful for the designers of recovery interventions;
- also QUV tests show that "G" specimens have, over the time, only a little decay of initial characteristics;
- the behavior of "Gs", the most used solution in the recovery interventions in the last 10 years in the city of Naples, is the worst among the selected specimens;
- all the results that have just been exposed, actually, find a direct correspondence in what it was possible to observe in all the tested buildings of the centre of Naples;
- during the first ten years of monitoring, the tests on the field effectively showed that the finishing solutions of macroporous plaster + silicate paint and cement plaster + quartz paint have a higher attitude to last during the time for the respective characteristics, with the condition that the designers choose the most fitting solution, not considering the real context of the stress agents;
- the conducted tests seem to confirm the importance of knowing the real performances of the whole system rather than of a single component, especially in relation to a predetermined stressing context;
- the goal is the creation of a handbook for designers, in order to lead to a choice of more appropriate and durable building components.

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