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Components Service Life: From Field Test To Methodological Hypothesis

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Summary: **In order to constitute the implementation base for a calculation model of the external plaster Service Life, data regarding 100 sample-buildings are collected through extensive field test.**

The model represents a sample application of a general methodology, that estimate the component service life as a deviation from the standard value, modifying the factors referred to the influencing agents to be evaluated in advance for each building component.

The collected value, statistically elaborated, show low mid value dispersion, thus demonstrating the reliability of so-called "mid-normal" value. A software for managing the modification factors and quickly calculating the external plaster service life has been developed.

More recently, experimental tests have been started in order to relatively (not absolutely) assess the modifying factors, that at present are usually evaluated only through field tests. The results are assumed to be usable from middle year 2002.

Keywords. Service Life, Durability, Modifying factors, Influence agents.

1 INTRODUCTION - PRINCIPAL INSPIRATION OF THE METHOD

The method, raised from the results of a study which has been carried out during a long period of time (approximately 15 years, estimated to be sufficient to provide for a field-collected data), aims at offering, to people interested in programmed maintenance in the building sector, a suitable instrument to estimate the durability of the building components: in other words, a methodological criterion in order to identify the expiration terms to be inserted in *the planning* of the maintenance plan, which correspond to appropriate intervention.

To achieve this fixed aim, it seems suitable to refer to the "*in service*" behaviour of the building components, because a substantial data base could be available, and also to avoid all problems concerning data from laboratory tests or theoretical modelling.

Before the experimental assessment, a theoretical analysis has been carried out, basing on the results obtained by the international scientific community, that has allowed not only the implementation of the model but also some choices of a quantitative nature regarding the "scores" to be assigned in the first instance to the influencing agents taken into consideration.
All this considered possible to define "semi-prob" this methodology which compares the probilistic theory on the reliability and the objective data of the field tests, trying to obtain results which have the requirement to be available for the operators and of general validity, (whose lack in the past has often prevented from exporting valuable results - but obtained in restricted fields - also in other contexts, or at least it has left wide doubts on such possibility.

For what concerns the use of the laboratory data, a few observations can be done:

- the hypotheses formulated on the use of the results of the buildings sampling, executed for obtaining a database, seem to be confirmed from their insufficient dispersion. As a matter of fact, in general, the results - converging around to the assumed mid -value - seem to attest the reliability of a criterion aimed, at characterizing "mid-normal " situation;
- caution has been adopted in the use of the laboratory data, since they refer a few building components in context conditions, for which an uniformity of exercise could be supposed (not neglecting the same criterion for the connotations of technological and typological character of the buildings), and permitting ulterior appraisals in case of data dispersion;
- on the basis of observations made by some research workers, in the proposed model F_i factors, which trigger unrealiability of the experimental data, have been considered (besides of pathological states on the constructive

element). In fact, the experimental data often accumulate and statistically elaborate information related to non homogeneous situations, mainly due to the presence of some of F_i factors , not accounted for.

In the proposed methodology, have been overcome problems regarding the relationship between aging laboratory tests and in field tests, just through the consideration of the "influencing factors". These are the most influential agents on the durability of the building components, as "generators“ of modifying factors of an experimental data, collected in almost constant conditions concerning these agents, and then - in an equally decisive way - using data which haven't been derived from an experiment "*with techniques of natural exposure*" but considering the effective "in service” behavior.

The carried out methodology tries to consider two various requests:

- The use of the field-collected data, thanks to a sampling executed in the course of the years on buildings, materials and interventions;
- the possibility to generalize and therefore to export results otherwise referred for specific fields, through a criterion declared and aimed to adapt the model to the various contexts.

We assume is that the durability of building components can be estimated starting from base value, defined as "mid - normal", to which a performance level corresponds, corrected by weight factors. These factors measure the deviation between the assumed value and the case in examination, also on the basis of the criteria followed by other research workers.

It is said to have:

$$D_{pp} = D_{mn} \times \prod_{i}^{n} F_i$$

where:

D_{pp} the value of the "*most probable duration*", correspondent to the durability of the considered building components, in the assumed conditions (period in which the performances are above a predetermined value, because the probability it can assume lower values is less);

D_{mn} the value "*mid-normal*" of the "*duration*", that is the durability of the considered building components in the conditions assumed as "*mid-normal*"

F n the modifying factors of D_{mn} correspondents to many influencing agents or groups of influencing agents.

During the work phase, that such methodology requires, should be reliably defined:

a) the performance level under which it is necessary an intervention, or - better - various decreasing performance levels to which different interventions of increasing intensity correspond, being in the building field non bi-stable components;

b) the value "mid-normal" of the non reliability;

c) the agents which influence the reliability, in other words the causes that can preside to the appearance of anomalies in respect to the physiological obsolescence of the building component;

d) the criterion of grouping of the mentioned agents;

e) the modifying factor to associate to the agents, each of a deliberate function of assigned weight, that is incidently shown in reality;

f) the criterion for the selection of the study cases;

g) the modalities of relief of the informations which have collected for the prechosen study cases;

h) the study cases correlated to D_{mn} in other words those thought in "mid-normal" situation;

i) the criterion of decomposition of the building organism in parts, refer to research.

j) the building components to adopt as a meaningful sample of starting, thinking opportune to begin from a sub - ensemble of the entire building organism;

k) the study cases that allow the proportion and the calibre of the factors F_i in a successive phase, during which it is necessary to determine the values of the single modifying factors, through the "earlier" reading of ulterior cases to select in different conditions with respect the "mid-normal"ones.

2 CHOICE OF THE BUILDING COMPONENTS OBJECT OF THE RESEARCH

It seemed suitable to start the study and to illustrate the proposed methodology on a limited sub - ensemble of building components, therefore to be able to easily finalize the research and to test the results.

To this aim the elements which constitute the external covering of the building have been selected, that is to say – according the UNI 8290 classification - elements pertaining to the following classes:

TECHNOLOGICAL UNIT CLASSES	2. CLOSURE
TECHNOLOGICAL UNITS	2.1 VERTICAL CLOSURE
TECHNICAL CLASSES OF ELEMENTS	2.1.1 vertical outside walls 2.1.1.1 Support 2.1.1.2 covering 2.1.2 external frame

TECHNOLOGICAL UNIT CLASSES	2. CLOSURE
TECHNOLOGICAL UNITS	2.4 SUPERIOR CLOSURE
TECHNICAL CLASSES OF ELEMENTS	2.4.1 Roofings 2.4.1.1 flat continuous roofing

In particular, on the basis of the ulterior decompositions which is possible to define in the inside of the technical elements classes, the following sub-classes of technical elements have been considered:

2.1.1.2 Coverings of facade

2.1.1.2.1 with natural stone / marble

2.1.1.2.2 with bonded materials (glass like, ceramic, etc.)

2.1.1.2.3 with external rended plaster / coloured

2.1.2.1 external frames in wood

2.1.2.2 external frames in iron

2.1.2.3 external frames in aluminum

2.1.2.4 external frames in PVC

2.4.1.1 flat continuous coverings

2.4.1.1.1 Practicable

2.4.1.1.1.1 covered with ceramic materials

2.4.1.1.2 Non practicable

2.4.1.1.2.1 covered with bituminous materials

The choice of the building components listed above derives from the following reasons:

- they are elements for which both the sampling and the observation of the process is easier;
- the life cycle in a generalized manner is not too long, and in any case allows to read and to interpret the results in reasonable time, at least regarding the fixed period of experimentation;
- previous research data concerning old sampling could be used;
- these are elements for which the influencing agents, tough numerous, have not been affected by other variables of a problematic valuation, and therefore they are very difficult to govern to which the ones used are suitable mainly to statistical elaboration.

Subsequently, it has been considered opportune to deepen the illustration on a single constructive element (external plaster), creating a software of management of necessary data and of duration calculation.

3 DEFINITION OF THE PERFORMANCE LEVELS

For each one of the 3 categories of building components the recurrent anomalies which affect the service life and the damage type, have been characterized.

It is best underlined and considered, in the present study, the anomalies consequent to errors made during the phase of planning and/or realization, referring to what happens in the course of a normal process of aging due to natural phenomena.

In order to identify the correspondent performance levels and to program the correspondents intervention: because, as exposed in the present chapter, it is pointless to consider the life cycle in absolute in the case of a maintenance program, being the mainly building components mostly bi-stable, it is important to report such concept also to intermediate stages as expression of lower performances then the initial, yet. In order to determine parameters such as reliabilities, durability, service life cycle it is necessary to prefix for every building component the performance levels under which it has to be considered in state of damage.

Actually, in the building process for the reasons already underlined :

- on the one hand, it isn't easy to fix objective a measurable or codifycable performance level;
- on the other hand, at least for most building components, the bi-stability does not demand the definition also of intermediate performance level between the initial one and the prefixed minimum one to associate progressive intensities of interventions, as indicated in figure 1.

DEGRADATION		PERFORMANCE		INTERVENTION TYPOLOGY
State 1	®	Level 1	®	Monitoring / inspection
State 2	®	Level 2	®	Cleaning / repair of surface
State 3	®	Level 3	®	Repair / restoration
State 4	®	Level 4	®	Partial substitution / integration
State 5	®	Level 5	®	Total substitution

Fig. 1: to any condition of conservation and therefore of degradation a performance level corresponds, which cause a type of maintenance operation, of gradually increasing intensity, in the timing of the general program

As far as the five indicated typologies of interventions, it is possible to propose the following definitions:

- *Monitoring /inspection*

It is finalized both to control the congruence between plan forecasts and effective in service behaviour and to the sub - condition maintenance strategy. In both cases it is aimed at defining the location of anomalies which can cause imminent compromission of emergency, hygiene, general feasibility.

- *Cleaning / repair of surface*

Epidermic intervention, either because realized on finishing parts or regarding the most superficial layers of no finishing elements; they are non-invasive and to lowest or null technological involvement of other parts;

- *Repair:*

participation aimed at eliminating the anomalies in respect of the initial conditions of the restoration, also when the achieved performances aren't the required ones (however higher than the prefixed minimal level), to execute for extending the average life of the part until the total substitution.

- *Partial substitution / integration*

Intervention in which a part of the element, the subsystem or the system, is removed or replaced because insufficient or superficial repair, in other words when it isn't efficient to eliminate the damage without adding new parts or however by modifying the subsystem or the system.

- *Total substitution:*

It coincides with the "death" of the component and therefore it identifies its life cycle: its total substitution starts a new programming, which will consider the *mid*-life.

The articulated unity of characteristics to be estimated could render in many cases, if lead by sophisticated and complex techniques, extremely complex and onerous the activity of monitoring and diagnosis, above all because of a strong specialized character.

It appears to be necessary to institute a biunivocal correspondence type between the numerical performance data (when it is possible) and their visible manifestations, to interpret as lessening of the value, by causing a noticeable anomaly without particular diagnostic equipments.

In brief, the managerial phase of a maintenance program should be rendered more accessible for the present force-job on the market, with the possibility to characterize the most appropriate intervention to resolve any unplanned situations that are unexpected and undesired.

A solution can be represented by methodologies like the M.E.R. that offers the possibility to execute a diagnosis on the base of

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detailed descriptions.

This opportunity is possible for some building components (for example, these assumed in the present study), and not for others as some structural elements can be subject to performance failure surveyed by instrumental investigation.

With reference to figure 1, in which 5 "states" are codified that correspondent to as many situations of degradation, for example, it reports a sort of manual for the determination, in phase of planning, of the technology and the chronology of the operations to program, and in managerial phase, for the guide of the designer towards the location of situations to being able to face in the most appropriated way. For each of the assumed building component there are descriptions conceived not to be influenced from the detector. For each one of the "defined states" therefore it will be necessary to characterize the most probable recurrence, to plan the temporary planning, that doesn't account for the mutual ties of technological nature and operating nature between the various parts in which the building organism has subdivided itself.

2.1.1.2 Coverings of facade

2.1.1.2.1 with natural stone /marble

state 1 initial similar conditions, absence of anomalies and superficial patina

state 2 presence of superficial patina that alters the chromatism

state 3 incipient flaws and/or separations that interest limited zones (< 10%)

state 4 in action flaws and/or separations that interest limited zones (< 30%)

state 5 in action flaws and/or separations that interest widespread zones (> 30%)

2.1.1.2.2 with bonded materials (grass like, ceramic, etc.)

state 1 initial similar conditions, absence of anomalies and superficial patina

state 2 presence of superficial patina that alters the chromatism

state 3 incipient flaws and/or separations that interest limited zones (< 10%)

state 4 in action flaws and/or separations that interest limited zones (< 30%)

state 5 in action flaws and/or separations that interest widespread zones (> 30%)

2.1.1.2.3 with rended plaster / coloured

state 1 absence of considered alterations

state 2 soot presence

state 3 incipient flaws and/or separations that interest limited zones (< 10%)

state 4 in action flaws and/or separations that interest limited zones (< 30%)

state 5 in action flaws and/or separations that interest widespread zones (> 30%)

2.1.2.1 external frame in wood/steal

state 1 absence of considered alterations

state 2 varnish degraded in some points

state 3 varnish degraded on the greater part of the surface; some elements are damage but the frame has still good wear to the air and the water

state 4 the frame is difficult to maneuver, the packings are deteriorated like the varnish and some elements; the wear to the air and the water is partial

state 5 the frame doesn't have wear to the air and the water

2.1.2.3 external frame in aluminum /PVC

state 1 absence of anomalies

state 3 frame difficult to maneuver; deteriotated packings

state 5 the frame does not have wear to the air and the water

2.4.1.1 plane continuous covers

state 1 absence of discontinuity and infiltrations in below areas

state 2 limited problems of stagnation; degradation of the protecting varnish state 3 deficiency of liquid mortar in the floor bindings if present; limited discontinuities in the impermeable mantle; sporadic breakaway of the folds

state 4 widespread discontinuity and breakaway with problems of infiltrations in below zone; floor elements (if present) not well fixed and/or unconnected

state 5 widespread water infiltrations in below areas.

4 MID-NORMAL VALUE AND CASE-STUDY

The mid-normal value D_{mn} of the "duration" of a building component is the statistic value surveyed for some sample buildings.

For this reason, it is preliminarily necessary to characterize these buildings, according to the following criteria:

- quality and quantity of the available information: year of construction, constructive technologies, execute operations, anomalies found during the years, etc;
- possibility to carry out activity of monitoring, to characterize the meaningful variations in terms of performances of the building components;
- characteristic of execute operations: possibility of comparison, degree of innovation, etc;
- homogeneity of the influence agents, whose values constitute those correlated to the mid value, that is those to whose recurrence is from associating value 1;
- possibility to have a variability for single groups of influence agents, in order to be able to estimate correctly the weighting.

For obvious reasons of convenience, we have taken into consideration building-samples of the city of Naples, in reference to two precise constructive typologies:

- buildings with carrying structure in tuff masonry, constructed in the period between the end of the 800 and first decades of the ' 900, known as "class 1";

- buildings with carrying structure in reinforced-concrete constructed in years ' 50/' 60, known as "class 2".

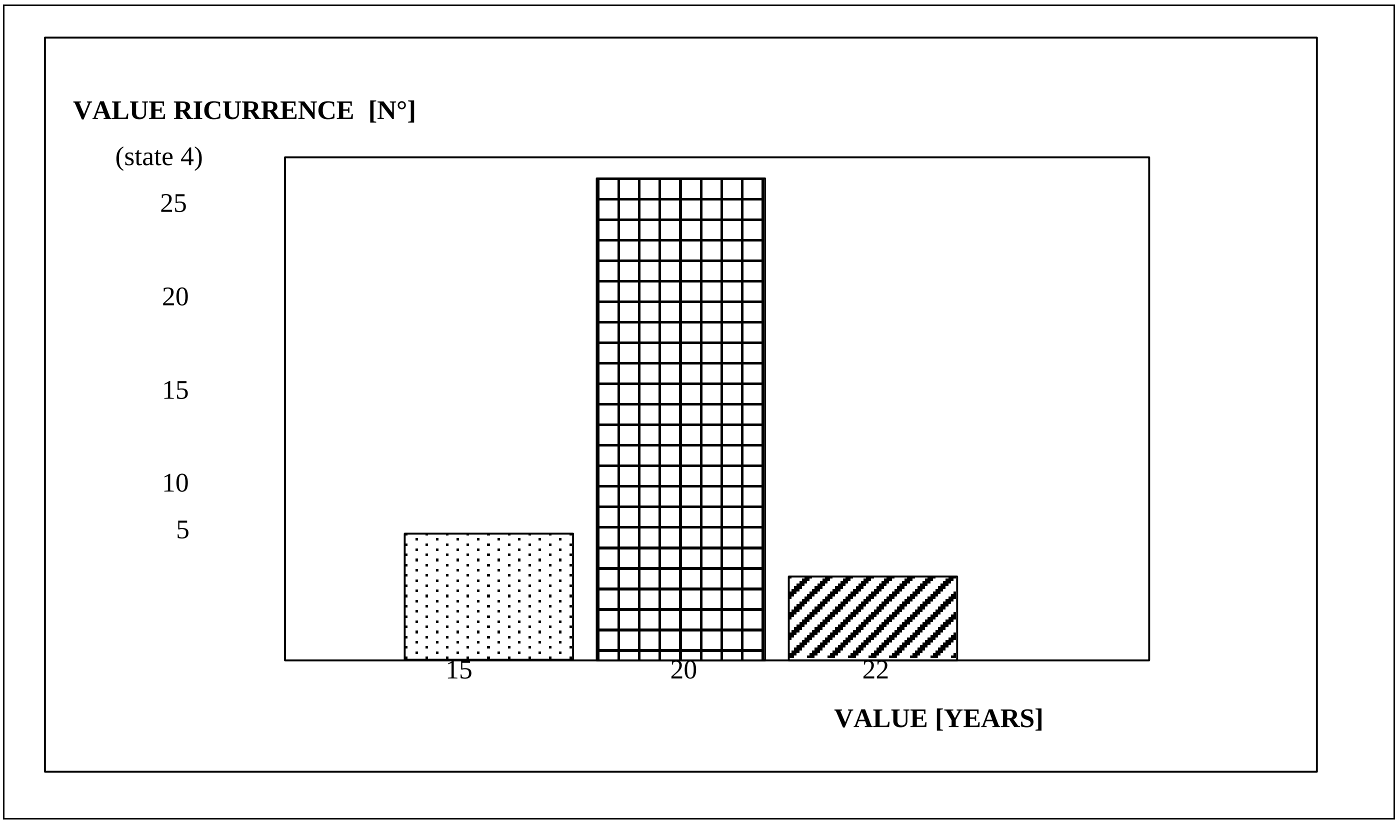
In particular, the articulation of the proposed model suggested the choice of a sub-ensemble of reference for every building in relation to the technological unit "vertical closing", as prospected.

So the prospect to consider mid-normal has the following characteristics:

- exposure to south-west;
- aggressive area;
- free facade (d>>H);
- disposition on the road to intense/fast traffic;
- smooth surface;
- plane vertical surface;
- presence of openings;
- external polish frame (windows);
- vertical external frame;
- practicable and not continuous flat covers with medium slope < 5%;
- practicable and not continuous flat covers with expansion joints;
- practicable continuous flat covers with discontinuity to the extrados;
- common mortar plaster painted with light color;
- prospects of the ancient buildings with cornice, stringcourse, small overhangs and with openings;
- external vertical closings of the ancient buildings in tuff masonry;
- prospects of the modern buildings with cornice, large overhangs and with openings;
- external vertical closings of the modern buildings in brick masonry;
- external frame of the ancient buildings in painted wood;

- external frame of the modern buildings in aluminum;
- practicable continuous flat covers with natural covering;
- practicable continuous flat covers with antifreeze covering;
- practicable continuous flat covers with covering put down without the grout;
- not practicable continuous flat covers covered with bituminous girdle armed with polyester with flexibility to cold > -5 °C;
- not practicable continuous flat covers covered with bituminous girdle armed with polyester with flexibility to cold > -5 °C protect with acrylic varnish;
- not practicable continuous flat covers covered with bituminous girdle armed with polyester with flexibility to cold > -5 °C put down on old asphalt.

Following is the histogram of the main collected values. We can see that for 28 times, the value <<<22o years" has appeared (and so it is assumed then effectively which D_{mn}) on the 48 cases of study regarding the buildings of class 1, while – in any case – the other values are very near to the most recurrent one.



5 CHOICE AND DETERMINATION OF THE AGENTS AND OF THE MODIFYING FACTORS.

The choice of the agents and consequently of the relative modifying factors should comply two types of requirements:
- to take in consideration in a systematic way all the agents that influence the reliability of a building component in service, to not commit conceptual errors in the base hypotheses;

- to have a user-friendly instrument, that is able to neglect the influence agents of little significance, tough present.
The criterion to select a set of agents for single type of considered building component, rather than attempt of generalization of the groups of agents, was adopted.

For each of these, subgroups are taken into consuideration which corresponds to a factor; not to render too long and complex the calculation of the product of the mid-normal value for the various factors.
For example, the factors for the external plaster are organized in four groups:

1. CLIMATIC AGENTS
2. ENVIRONMENTAL AGENTS
3. CONFIGURATION AGENTS
4. TECHNOLOGICAL AGENTS

each one sub-divided and later specified in detail.

6 ARTICULATION OF THE PROPOSED METHODOLOGY

The hypotheses formulated in the arrangement proposal of the methodology are the following:

a) the 4 groups of agents define 4 modifying factors, which have different weights according to the following proportions:

Climatic 4;

Environmental 4;

Configuration 1;

Technological 2.

b) the exposed values correspond to *the range* of values that the four groups can assume, as a function of their weight in the reliability of the assumed building components:

Climatic:	$0.675 \leq F_1 \leq 1.075$
Environmental:	$0.735 \leq F_2 \leq 1.135$
Configuration:	$0.92 \leq F_3 \leq 1.02$ for the coverings
	$0.95 \leq F_3 \leq 1.05$ for the fixtures
	$0.97 \leq F_3 \leq 1.07$ for the covers
Technological:	$0.85 \leq F_4 \leq 1.05$ for the coverings in the buildings of class 1
	$0.875 \leq F_4 \leq 1.075$ for the coverings in the buildings of class 2
	$1 \leq F_4 \leq 1.2$ for the frame in the buildings of class 1
	$0.8 \leq F_4 \leq 1$ for the frame in the buildings of class 2
	$0.87 \leq F_4 \leq 1.07$ for the practicable covers
	$0.87 \leq F_4 \leq 1.07$ for the non practicable covers

c) So the formula for the calculation of D_{pp} assumes the following form:

$D_{pp} = D_{mn} \times F_{CL} \times F_{To} \times F_C \times F_T$

being, respective:

F_{CL} the modifying factor by the climatic agents;

F_{To} the modifying factor by the environmental agents;

F_C the modifying factor by the configuration agents;

F_T the modifying factor by the technological agents;

d) For the calculation of single Fi the following procedure is adopted. On the base of the determined scores (that are inversely proportional to the ability to produce situations of reliability), every 4 group of factors has *a range* of possible values between the minimum and the maximum. Inside this *range* there is the mid-normal value (than can't be in the center of the range) to which corresponds modifying factor 1; the values comprised between this value and the minimum will assume values smaller than the unit (they provoke lessening of the reliability), those comprised between this value and the maximum (they correspondent to better conditions for the reliability) will have values greater than the unit.

e) To determine the value of the factor for a group of agents, it is possible to operate as follows:

- defined ΔF the refuse of factor (point b);

- defined ΔP the refuse between the maximum score and minimum;

- defined P_{mn} the value of the total score correspondent to the situation defined as mid-normal (factor 1);

- defined P_{max} and P_{min} the scores maximum and minimum;

the value of V to adopt will be comprised between the following values:

$V_{min} = 1 - [\Delta F / \Delta P \times (P_{mn} - P_{min})]$

$V_{max} = 1 + [\Delta F / \Delta P \times (P_{max} - P_{mn})]$

generically:

$V = 1 + [\Delta F / \Delta P \times |P_{mn} - P|]$

7 INFLUENCE AGENTS FOR THE EXTERNAL PLASTER.

The groups of influence agents for the assumed component are the following:

1. *CLIMATIC*

1.1 TEMPERATURE
1.2 DAILY ΔT TEMPERATURE
1.3 WIND AND RAIN
1.4 SNOW
1.5 MOISTURE

2. *ENVIRONMENTAL*

2.1 POINTS CARDINALS
2.2 SEA
2.3 POLLUTION
2.4 VIBRATIONS
2.5 OTHER BUILDINGS FACING

3. *CONFIGURATION*

3.1 SUPERFICIAL ASPECT
3.2 LYING
3.3 SHAPE/NUMBERS OF ANGLES
3.4 EXTENSION

4. *TECHNOLOGICAL*

4.1 PROTECTIVE ELEMENTS
4.2 CRITICAL POINTS
4.3 COLOR
4.4 KIND OF STRINGING AND NATURE OF THE SUPPORT

8 TREND OF THE RESEARCH

The developed software manages numerical data from the experimentation executed on the field.

Better examined in other paper [1] a laboratory experiment is now starting, in which the data of tests will be backed up in order to equal the modifying factor.

In this sense, there won't be any problems of correlation between experimental data and test data or any problems of re-scaling, because the laboratory will provide reliable assessment of the relative incidence of the Fi, and not on absolute incidence, that would give problems for the comparison with results from experimentation executed on the field.

In parallel, another research has started. This research is aimed at exporting to other building components the study based on the external plaster: for example, the EBR FRP (*Fiber Reinforced Plastics Externally Bonded Reinforcement)* [2] .

Another phase of test is developing regarding the model already implemented, through a reading and a verification of back data collected for external plaster in others and various areas of the Italian territory.

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