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Multicriteria analysis for choosing maintenance strategies

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Abstract

The life cycle of building components can be managed according to different maintenance strategies, which mainly differ in performance and economic terms.
What is the most convenient one among the possible scenarios? It has been shown in the past that the typology of maintenance interventions and the consequent periodicity are closely related to performance decay, and can lead to choices that, however, generally concern the purely economic sphere.
In this sense, it seems interesting to know the modalities of the performance decay, which may allow – even though for many components the "measurement" of its values is problematic - the construction of performance / time curves. This result was possible, in other experiments conducted in the past, for one of the components to be considered most critical for the whole building (the plaster), thanks to a study that sampled 53 masonry buildings with homogeneous characteristics (both from the technological point of view and from the era of realization), observed within 20 years.
This paper highlights that the only economic evaluation is not enough to identify the ideal solution, because – inter alia - there is a more suitable solution depending on the context framework in which the decision maker is operating. Commitment, budget, component typology, time span to consider, are the main factors influencing the choice, not ignoring design issues.
A TOPSIS multi-criteria analysis is proposed, the results of which are an interesting starting point for defining maintenance plans characterized by greater reliability, not only technical but also economic.

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1. Introduction

A building is a dynamic system. Over time, all of its parts are subjected to a progressive change which results in the worsening of its characteristics, of its technical qualities, that is to say to performance decay.

Dealing with this process offers a huge variety of choices of action, included between two extremes: restoring the performance or witnessing its deterioration.

All the possibilities toward the performance decay make up the maintenance activity. While performing this choice, a designer has first to consider several aspects of maintenance interventions, each characterized by a cost, a periodicity, a duration and much more.

The issue of maintenance activity, which must be taken into account during the whole life of a building, is in fact what probably epitomizes best the complexity of a building product, mainly because of two reasons:

- the huge number of factors affects performance decay, together with the little knowledge about its laws of variation;
- the interaction of various professional and human roles, each with their needs and characteristics influencing the decisions on the matter.

The knowledge of the performance variation of components over time is essential in relation to the redaction of a maintenance plan following a maintenance strategy. A maintenance strategy consists in fact in the decision of the typologies of interventions, of the levels of performance in correspondence of which they have to be executed and of the levels of performance to be achieved. This means that, in order to enact a maintenance strategy, the times at which such levels of performance will be reached, has to be acknowledged.

In first place it is necessary to define the levels of performance and the typologies of interventions, and literature has already made it this far. The levels of performance associated to the levels of decay can be identified with the *performance degrees* indicated in ISO 15686-7 code, in the table reported below. [1]

Table 1. Performance degrees in ISO 15686-7

Performance degree 0	No symptoms
Performance degree 1	Slight symptoms
Performance degree 2	Medium
Performance degree 3	Strong symptoms
Performance degree 4	Totally unacceptable, including collapse and malfunction

On the other hand, Nicolella [2] lists the different typologies of intervention, sorted by a crescent order of entity. He individuates the following:

- Monitoring / Inspection;
- Cleaning / Superficial intervention;
- Reparation;
- Substitution / Integration;
- Total substitution.

It is then necessary to associate performance degrees to in-use conditions for each component, and to know the times, during the service life of the component, at which such in-use conditions occur. That is to say, performance-time curves have to be built for each component.

So, basing on a previous experimentation which led to the construction of a performance-time curve for plaster coverings, which provides the information that are needed for hypothesizing reliable maintenance strategies, this research performs an exploration of a multi-criteria decision analysis method to take into account all of the variables that insist in the maintenance process. The objective is to select the optimal maintenance strategy by evaluating the benefits and risks in relation to such variables.

2. The starting point

In Naples, Italy, an experimentation had been carried out by a team of researchers on 100 sample buildings from 1988 to 2000, according to the guidelines of the abovementioned ISO 15686-7 code, consisting in:

- in-depth observation of the initial conditions at the beginning of the experimentation, in some cases by visual inspection, and in other with the support of a thermographic camera;
- documentation of the maintenance activities executed during the early years;
- observation of the evolution of the conditions of conservation in the following period, with inspections mainly carried out via thermographic camera.

The aim was that of evaluating the value of service life for plaster coverings, which was totally fulfilled, and the Nick Method for the evaluation of service life of plaster coverings, included in UNI 11156-3:2006, code is its result. The results have also been published and presented in other works. [3] [4] [5] [6]

Then, following this first step, the research continued until 2016, finalized to assess the life cycle of plaster covering by creating performance-time curves with an extension of 30 years for 53 of the initial 100 samples buildings, ultimately leading to the obtainment of the performance-time curve for the plaster covering as the envelopment of the single curves. [7]

In order to put into practice the possibilities of use of this curve, four different maintenance strategies were hypothesized:

- I – Consumption of the performance during its life cycle, with absence of maintenance interventions;
- II – Partial reconstructions and finishing works on the whole surface;
- III – Defense of plaster from atmospheric agents, by renovating the finishing layers with partial reconstructions;
- IV – Frequent removal of anomalies, with superficial interventions until the necessity of a partial reconstruction.

In order to apply the maintenance strategies to plaster covering, the maintenance interventions from the list were specified for this component, linked to the in-use conditions for plaster coverings corresponding to the performance degrees from Table 1.

Table 2. In-use conditions and maintenance interventions for plaster coverings

PERFORMANCE DEGREE	IN-USE CONDITIONS FOR PLASTER COVERINGS	MAINTENANCE INTERVENTIONS
0	No performance decay	None
1	Incipient exfoliations and air bubbles – evident chromatic alterations	Partial grouting + painting (I_1)
2	Accentuated exfoliations and air bubbles – microcracks or incipient detachment extended to less than 30% of the surface	Smoothing + painting (I_2)
3	Accentuated exfoliations and air bubbles – microcracks or incipient detachment extended to more than 30% of the surface	Partial makeover of the plaster + smoothing + painting (I_3)
4	Partial/total collapse	Total makeover of the plaster + smoothing + painting (I_4)

The execution of the maintenance strategies described above was planned for a period of 30 years, as detailed below.

Table 3. Detail of the execution of the maintenance interventions according to the four strategies

	5	10	15	20	25	30
Strategy I						
Strategy II			I_3			I_3
Strategy III				I_2		I_3
Strategy IV		I_1		I_1		I_3

This scenario offers the rare possibility to evaluate objectively which one is the most convenient maintenance strategy, among the ones than can be chosen by the designer. In fact, as it was mentioned before, one of the reasons behind the complexity of maintenance activity is the uncertainty about performance decay, which normally leads to a large use of condition-based and preventive maintenance, in which the times of interventions cannot of course be predicted at the beginning, making the comparisons of convenience of course less reliable.

Therefore, the second difficulty has now to be faced, that is to say the necessity to consider a significant number of factors in the evaluation, due to the presence of a significant number of interacting elements. To achieve this, it is necessary to make use of a method that is able to take them into consideration, a multi-criteria decision analysis method (MCDM).

3. State of the art and methodology of the research

3.1. State of the art

Multi-criteria decision analysis methods are a common tool to evaluate the optimal decision in various contexts, by giving to each alternative scores based on the criteria chosen, and then comparing them. Several methods have been developed in this field, and some of these have already been used in the field of the evaluation of optimal maintenance strategies.

The father of the idea behind this application was Triantaphyllou [8], who suggested the criteria to adopt to implement this evaluation, individuating them in cost, repairability, reliability and availability. He also showed an application of the use of AHP (Analytical Hierarchy Process) for this choice. Then, a lot of authors explored the use on this theme of combinations between different methods: among the others, Bevilacqua [9] implemented the AHP by integrating goal programming to determine the optimal maintenance policy in an oil refinery; Ilangkumaran [10] proposed a combination of fuzzy AHP with TOPSIS, in order to select the optimal maintenance policy for textile industry. Ghosh [11] introduced an integration of AHP, goal programming with fuzzy logic; Chen [12] tried using AHP, TOPSIS and grey relational analysis to evaluate the performance and decided the optimal maintenance policies that suited semiconductor company in a more effective and accurate manner.

The methodology suggested here is structured as a TOPSIS method, but differentiates itself from the fuzzy TOPSIS in the choice of the weights of the *m* criteria, which is obtained through the use of a *m* x *m* comparison matrix rather than by simple attribution, like in AHP. Another difference lies in the determination of the scores of the alternatives, which is not performed by the assignment of 1-10 scores by decision makers. Each value in the matrix derives in fact from an accurate study, as it will be shown in the following.

3.2. Fuzzy TOPSIS

The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is a multi-criteria decision analysis method, which was originally developed by Hwang and Yoon in 1981 with further developments by Yoon in 1987, and Hwang, Lai and Liu in 1993. TOPSIS is based on the concept that the chosen alternative should have the shortest geometric distance from the positive ideal solution and the longest geometric distance from the negative ideal solution. It is a method of compensatory aggregation that compares a set of alternatives by identifying weights for each criterion, normalising scores for each criterion and calculating the geometric distance between each alternative and the ideal alternative, which is the best score in each criterion. All the criteria have then to be monotonically increasing or decreasing.

In its application, the first step is to define the alternatives (A_i, $i = 1, 2, \ldots, n$) and the criteria (C_j, $j = 1, 2, \ldots, n$) according to which the alternatives will be evaluated. Then a weight (W_j, $j = 1, 2, \ldots, m$) has to be attributed to each of the criteria. In an original formal addition suggested here, the weight is positive if the criterion is beneficial, and negative if the criterion is not beneficial.

Once the scores for each alternative according to each of the criteria have been given, usually in the form of 1-10 scores assigned by a number of decision makers, the related D matrix, with n lines and m columns, can be created.

$$D = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & \ddots & \cdots & x_{2n} \\ \vdots & \cdots & \ddots & \vdots \\ x_{m1} & \cdots & \cdots & x_{mn} \end{bmatrix} \tag{1}$$

In the D matrix, called the fuzzy decision matrix, x_{ij} represents the score assigned to the i-th alternative according to the j-th criterion.

Then, the x_{ij} values in the matrix have to be normalized to r_{ij} values, by applying the equation:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}, i = 1, 2, \ldots, m \tag{2}$$

The result is the normalized fuzzy decision matrix.

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & \ddots & \cdots & r_{2n} \\ \vdots & \cdots & \ddots & \vdots \\ r_{m1} & \cdots & \cdots & r_{mn} \end{bmatrix} \tag{3}$$

Then, the W_j weights that were established at the beginning for the criteria have to be applied to the matrix, by multiplying each of the r_{ij} values to the related w_j weight, obtained for each criterion through the equation:

$$w_j = \frac{W_j}{\sum_{j=1}^{n} |W_j|} \tag{4}$$

So, the t_{ij} values of the weighted normalized fuzzy decision matrix will be obtained as:

$$t_{ij} = r_{ij} \cdot |w_j|, i = 1, 2, \ldots, m; j = 1, 2, \ldots, n \tag{5}$$

The T matrix, made up by the t_{ij} values, can finally be realized.

At this point, in order to perform the evaluation, the worst alternative (A_w) and the best alternative (A_b) have to be determined as shown here:

$$A_w = \{t_{wj} = \langle min(t_{ij}|i = 1, 2, \dots, m|j: w_j > 0)\rangle, \langle max(t_{ij}|i = 1, 2, \dots, m|j: w_j < 0)\rangle\} \quad (6)$$

$$A_b = \{t_{bj} = \langle max(t_{ij}|i = 1, 2, \dots, m|j: w_j > 0)\rangle, \langle min(t_{ij}|i = 1, 2, \dots, m|j: w_j < 0)\rangle\} \quad (7)$$

Then, for each of the alternatives, the distances from A_w and A_b can be calculated, in the form of d_{iw} and d_{ib}, respectively. Of course, the former is a positive parameter, while the latter is a negative one.

$$d_{iw} = \sqrt{\sum_{j=1}^{n}(t_{ij} - t_{wj})^2}, i = 1, 2, \dots, m \quad (8)$$

$$d_{ib} = \sqrt{\sum_{j=1}^{n}(t_{ij} - t_{bj})^2}, i = 1, 2, \dots, m \quad (9)$$

The discriminative parameter of the multi-criteria analysis can finally be evaluated, in the form of the similarity to the best condition, s_{ib}. The decision with the highest value will be the best one among the m alternatives, or more in general the alternatives can be ranked according to this parameter in crescent order.

$$s_{ib} = \frac{d_{iw}}{d_{iw}+d_{ib}} \quad (10)$$

3.3. AHP enhancement

The analytic hierarchy process (AHP) is a structured technique for organizing and analysing complex decisions, based on mathematics and psychology. It was developed by Thomas L. Saaty in the 1970s and has been extensively studied and refined since then.

The way weights are attributed to criteria in AHP seemed to be more transparent and reliable than in TOPSIS, so that part was included in the methodology. In AHP method, a W matrix is built, with the n criteria both on the lines and on the columns. So, every value in the matrix is a c_{kl} that reflects the relative importance of $k = 1, 2, \dots, n$ criterion compared to $l = 1, 2, \dots, n$ criterion, higher if k is more important than l. In the central diagonal of the matrix, where each criterion is compared to itself, of course all the values will be 1.

$$W = \begin{bmatrix} c_{11} & c_{12} & \dots & c_{1n} \\ c_{21} & \ddots & \dots & c_{2n} \\ \vdots & \dots & \ddots & \vdots \\ c_{n1} & \cdots & \dots & c_{nn} \end{bmatrix} \quad (11)$$

Then, for each k-th criterion, the W_k weight, from which w_k can be obtained as in TOPSIS, is calculated as:

$$W_k = \sqrt[n]{\sum_{l=1}^{n} c_{kl}} \quad (12)$$

Before accepting the results, a consistency check has to be done. As explained in the equations below, λ_{max} and CI, the Consistency Index have to be calculated, then RI, the Random Index has to be obtained from Saaty's table [13] in relation to the number of criteria n.

$$\lambda_{max} = \frac{\sum_{k=1}^{n} \frac{\sum_{l=1}^{n} c_{kl} \cdot w_l}{w_k}}{n} \quad (13)$$

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (14)$$

Table 4. Saaty's table for the Random Index in function of the number of criteria

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0,00	0,00	0,58	0,90	1,12	1,24	1,32	1,41	1,45	1,49	1,51	1,48	1,56	1,57	1,59

Finally, the consistency check will be successful if the consistency ratio CR, equal to the ratio between CI and RI, is greater than 0,1. Otherwise, different c_{ij} have to be assigned until the check results verified.

Then, the positive or negative sign, depending on whether the criteria are beneficial or not, can be attributed to the values.

4. A proposal of application of MCDM to the choice of maintenance strategies

Through the methodology of AHP-enhanced TOPSIS, the optimal maintenance strategy for plaster coverings will be unveiled. The maintenance strategies that will be submitted to the evaluation are those previously listed, from now on indicated respectively as A_1, A_2, A_3 and A_4, while the chosen criteria are the following:

- Cost (C_1);
- Safety (C_2);
- Availability (C_3);
- Sustainability (C_4).

As anticipated previously, the scores for each criterion will not be in the form of 1-10 scores. Rather, each score will be obtained with a specific process.

4.1. Cost

Cost is probably the element that influences the most the choice of maintenance strategies, because of the hardly revisable budget in the availability of the commitment. The cost of each maintenance strategy of course depends on the cost of the single interventions. So, the total cost of a maintenance strategy is here calculated by multiplying the unitary cost of each intervention, found in the Price List of Campania Region of 2016, for a surface of 2000 m^2, which is a mean value for buildings like those sampled from 1988 to 2016. The costs are then capitalized to the 30^{th} year according to the time schedule of the interventions.

Then, it has to be considered that different maintenance strategies result in different residual service life of the component. Values of residual service life at the end of the period of the maintenance strategy that are lower than the mean value of the service life of the component produce an economic loss, as some methods from the fields of estimation, such as the *depreciation cost approach*, point out. This economic loss can be evaluated as future expense related the cost of total reconstruction (I_4 from Table 2), which is needed to restore the original service life of the component after P_{min} is reached, discounted for a number of years equal to residual service life.

This value is finally summed to the capitalization of the costs of the single interventions of the strategy. Of course the assessment of residual service life, which depends not only on the number of years passed of the component, but also on the interventions that have been executed on it, is preliminary to the obtainment of this value.

The four values of residual service life have been obtained from the performance-time curve for plaster coverings, adapted to each maintenance strategies in Fig.1, where performance is in blue, in order to find the t_{min} time at which the lowest acceptable performance P_{min}, represented as a red line, is reached.

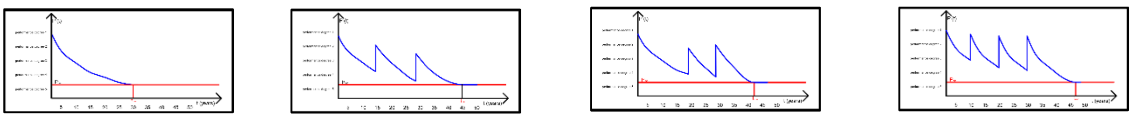

Fig. 1. Performance-time curves of the four strategies for plaster coverings

Table 5. Detail of the calculation of cost for each maintenance strategy

	COST OF SINGLE INTERVENTIONS	CAPITALIZED COST	ESTIMATED FINAL RESIDUAL LIFE	FUTURE EXPENSE	TOTAL COST
A_1	0 €	0 €	0 years	141.880 €	141.880 €
A_2	113.880 € 113.880 €	258.370 €	15 years	105.420 €	363.800 €
A_3	85.920 € 113.880 €	211.650 €	12 years	114.540 €	326.180 €
A_4	77.120 € 77.120 € 113.880 €	314.000 €	16 years	98.610 €	412.610 €

4.2. Safety

Plaster coverings, being located on the external wall of the building, may represent one of the most dangerous elements of a building both for those who live in it, and for those who do not. This has been shown in events like the one occurred two years ago, when a 14-year-old boy lost his life, in the city of Naples, because of the fall of a big piece of plaster from the facade of a historical building, as important as poorly maintained. Though this kind of events is presumably avoided by executing interventions in the first 30th years of life, there is still a chance of failure, due to the probabilistic concept of service life.

Then of course safety, intended here as a value that is inversely proportional to the probability of failure over the period of duration of the maintenance strategies, deriving from the probabilistic nature of performance decay, is relevant as a criterion of choice. The probability of failure is evaluated by using the performance-time curves that have already been realized to assess residual service life. Considering that past experimentations have shown that, for plaster coverings, critical condition are present:

- after 15 years in the 9,4% if cases;
- after 20 years in the 47,1% of cases;
- after 22 years in the 52,8% of cases.

So, it seems correct to multiply these percentage of likeliness, to which the risk of failure is of course strictly related, for the value of the area between the curve and the horizontal line where $P = P_{min}$, calculated separately for each time interval defined by the years listed above. The final value, constituted by the sum of products between graph area and probability, is in a raw scale, but this is irrelevant as TOPSIS normalizes the values for each parameter.

Table 6. Evaluation of safety for each maintenance strategy

	GRAPH AREA IN 15-20 YEARS	GRAPH AREA IN 20-22 YEARS	GRAPH AREA IN 22-30 YEARS	SAFETY ASSESSMENT
A_1	17	5	6	7,13
A_2	53	15	29	27,4
A_3	17	20	36	30,1
A_4	33	28	60	48,0

4.3. Availability

Availability is the capability of equipment functioning well during a definite period or even beyond it. Then, it is only necessary to calculate, for each strategy, the mean value of duration of the maintenance interventions (MTTR, Mean Time To Repair), and the mean time between interventions (MTBF, Mean Time Between Failures), in order to apply the well-known formula:

$$Availability = \frac{MTBF}{MTBF+MTTR} \tag{15}$$

Table 7. Evaluation of availability for each maintenance strategy

	PERIODS BETWEEN INTERVENTIONS	MTBF (years)	DURATION OF INTERVENTIONS	MTTR (years)	AVAILABILITY
A_1	29, 55 years	29,55	5,4 months	0,453	0,985
A_2	14,7 years 14,7 years	14,7	3,6 months 3,6 months	0,297	0,980
A_3	19,8 years 9,7 years	14,75	2,25 months 3,56 months	0,242	0,984
A_4	9,9 years 9,9 years 9,7 years	9,85	0,8 months 0,8 months 3,56 months	0,144	0,986

The duration of interventions was obtained by multiplying the h/m^2 value reported in the Time List of Campania Region or, if not present, by extrapolating the work details from the Price List of Campania Region – 2016 Edition, for a surface of 2000 m^2, considered to be a mean value, as in the evaluation of costs.

The very high values of availability for all the strategies that appear in Table 7 surely stand as a proof of one of the main benefits of programmed maintenance, that is to say its possibility to reduce the frequency of interventions by executing in a single year as many interventions as possible.

4.4. Sustainability

In the evaluation of sustainability, it would be redundant to take into account *economic sustainability*, as this theme already influences the cost parameter. Then, only environmental sustainability will be considered for the attribution of the scores according to this criterion.

It is a common knowledge that buildings are one of the major causes of pollution, both in their construction, in the users' energetic needs when satisfied by non-renewable energy sources and in the activities of maintenance. Therefore, it seems significantly important to reduce the negative impact on environment of maintenance interventions.

The materials which production affects the most the environment is certainly the cement. Its environmental impact can be assessed in function of the energy that is released during its production, by considering that the ratio between the energy and the mass of cement is 4,882 MJ/kg[11] and by adopting a density value of 1.360 kg/m^3 for cement. The energy consumption caused by an intervention of total reconstruction on a surface of 2000 m^2 is then 166.600 MJ, while interventions of partial reconstruction, considered to occur on the 50% of the surface, dissipate 83.300 MJ. The value of sustainability will then be evaluated as inversely proportional to the energy consumption.

Table 8. Evaluation of sustainability for each maintenance strategy by calculation of VOCs released

	NUMBER OF PLASTER RECONSTRUCTIONS	ENERGY CONSUMPTION	SUSTAINABILITY
A_1	1	166.600 MJ	2
A_2	2	333.200 MJ	1
A_3	1,5	249.900 MJ	1,5
A_4	1,5	249.900 MJ	1,5

4.5. Weight comparison matrix

The last step, before the actual application of TOPSIS, is to establish the weights for each criterion, by defining the relative importance of the criteria in the weight comparison matrix, and performing the consistency check.

$$W = \begin{bmatrix} 1 & 1/4 & 3 & 1/2 \\ 4 & 1 & 6 & 3 \\ 1/3 & 1/6 & 1 & 1/4 \\ 2 & 1/3 & 4 & 1 \end{bmatrix} \tag{17}$$

The consistency check is satisfied. In fact, λ_{max} = 5,61 > 4; CI is equal to 0,537 and RI, according to Saaty's table, is 0,9. Then, CR = 0,596 > 0,1.

Of course, C_1 is the only non-beneficial criterion , while C_2, C_3, and C_4 are all beneficial. So, the value of the weights are W_1 = -1,48, W_2 = 1,93, W_3 = 1,15, W_4 = 1,64 and the respective normalised weights are w_1 = -0,238, w_2 = 0,312, w_3 = 0,185 and w_4 = 0,265.

4.6. Results

The TOPSIS methodology is now implemented as detailed in paragraph 3.

$$D = \begin{bmatrix} 141880 & 7{,}13 & 0{,}985 & 2 \\ 303610 & 27{,}4 & 0{,}980 & 1 \\ 266010 & 30{,}1 & 0{,}984 & 1{,}5 \\ 352450 & 48{,}1 & 0{,}986 & 1{,}5 \end{bmatrix} \quad (18)$$

$$R = \begin{bmatrix} 0{,}256 & 0{,}112 & 0{,}501 & 0{,}649 \\ 0{,}548 & 0{,}432 & 0{,}498 & 0{,}324 \\ 0{,}480 & 0{,}475 & 0{,}500 & 0{,}487 \\ 0{,}636 & 0{,}758 & 0{,}501 & 0{,}487 \end{bmatrix} \quad (19)$$

$$T = \begin{bmatrix} 0{,}061 & 0{,}035 & 0{,}093 & 0{,}17 \\ 0{,}13 & 0{,}13 & 0{,}092 & 0{,}09 \\ 0{,}11 & 0{,}15 & 0{,}093 & 0{,}13 \\ 0{,}15 & 0{,}24 & 0{,}093 & 0{,}13 \end{bmatrix} \quad (20)$$

The PIS is (0,051; 0,236; 0,093; 0,17), while the NIS is (0,15; 0,035; 0,092; 0,086). Then, the d_{iw} and d_{ib} vectors, and finally the s_{iw} vector, can be calculated.

d_{iw} = (0,13; 0,10; 0,12; 0,21)

d_{ib} = (0,20; 0,16; 0,12; 0,11)

s_{iw} = (0,39; 0,40; 0,52; 0,66)

The s_{iw} shows that the optimal maintenance strategy is the fourth one, the one characterised by a higher number of interventions.

5. Discussion and conclusions

The result of the TOPSIS methodology, which shows that the 4th maintenance scenario constitutes the optimal maintenance strategy, is highly influenced by the weight that was arbitrarily given to the criteria. In particular, it causes a total change of result for the 1st strategy, based on the absence of interventions. In fact, while strategies with no interventions are characterized by high benefits in all the other 3 parameters, in relation to safety it shows a high risk: this makes them the worst strategy according to the TOPSIS method. This is a perfect example of the importance of taking into account all the variables in play in order to make reliable decisions in the field of maintenance.

Yet, the secondary purpose of this result is not obvious. In fact, the premise suggested that one of the most peculiar traits of building engineering is the necessity to fulfill the needs of a high number of figures, who interact between themselves and are variously characterized; despite that, TOPSIS method, as presented here, only offered a deep analysis of how maintenance strategies differ between themselves under many lights.

Then, while it would be easy to conclude that A_4 can be considered to be the best choice for plaster coverings, it cannot be so: an incredible variety of situations can occur in engineering practice, and none of the four criteria takes this into account. Actually, the solution to this puzzle simply lies in the definition of the weights of the criteria. In fact, while here they have been attributed according to a logic of ordinary nature, they can be changed to suit best the specific situations. For example, a case where the budget is particularly low can be represented by a higher value for the parameter of weight. This inference undoubtedly widens the use of this method template for designers.

The interesting results of this experimentation also encourage further research in the field of durability, as the performance-time curve for plaster coverings was the only starting point for the numerical evaluation of the criteria. This means that the creation of reliable performance-time curves for other building components can offer the possibility to realize templates for multi-criteria analysis like this one on them as well.

One last note has to be made regarding the construction of the performance-time curves that include the increases of performance related to maintenance interventions, which have been used to evaluate cost and safety. In this case, speculation played a significant role in constructing them, as not enough data are present at the moment to perform an accurate evaluation of how the laws of performance decay change after the execution of a maintenance intervention. If codified maintenance strategies like the four that have been analyzed here were executed more often, and a continuous monitoring was performed on the buildings subjected to them, there would be a significant database that could help to build more accurate performance-time curves related to maintenance strategies, generating a circular process of development of multi-criteria analysis for the choice of optimal maintenance strategies.

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