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Cost-benefit analysis of the means of access used in maintenance actions

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Abstract. The efficiency of the inspection and maintenance of the buildings' envelope is strongly linked to the means of access available to carry out these interventions. The adoption of adequate means of access facilitates the maintenance works, considering the constraints of each building. The means of access, besides having a fundamental role on the quality of the maintenance interventions on facades, represent a very significant part of the cost of repair of these elements. Therefore, the assessment of the cost variation between the different means of access available is fundamental to optimize costs and resources. In façades, there is a variety of solutions in terms of means of access. The selection of the most appropriate solution must be made according to the characteristics (e.g. architecture, height) and constraints (e.g. users, surrounding space) of each building, the needs for maintaining the façade, and the time and funds available for the intervention. In this study, a comparative analysis of the cost of the means of access in the maintenance plans developed for the different types of façade cladding (ceramic tiling systems, natural stone claddings, rendered façades, painted surfaces, ETICS, and architectural concrete façades) is carried out. The results show that the means of access costs influence the cumulative average maintenance costs and, in the long-term, there are advantages in planning permanent means of access at the design phase of the building.

1 Introduction

To maintain their performance over time, all building components require regular inspections and maintenance interventions [1]. Some components are easily accessible, while others require special means of access to carry out maintenance works [2]. Many of the external façades are not designed to provide adequate safety access for the maintenance staff. Consequently, temporary means of access are used to perform the maintenance works when required, which is usually translated into higher costs during maintenance interventions, since extraordinary measures need to be taken to mitigate this limitation [3].

In the literature, there are no research studies that quantify the economic impact of temporary means of access during the service life of buildings' envelope elements. In addition, the studies that address maintenance costs [4], the cost of the different types of

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inspections/maintenance of buildings [5], or the difference between what is planned and what is spent [6] are very scarce. Concerning accessibility, the studies only suggest that this impact is real and significant to put into practice maintenance strategies during the life cycle. According to the Construction Industry Institute (CII) [7], temporary facilities for access are one of the main categories that influence the indirect construction costs. El-Haram and Horner [8] refer that, to reduce the maintenance costs, the number and/or the duration of the maintenance activities must be reduced, being the accessibility and planning maintenance resources the way to reduce the duration of the maintenance activities. Ferreira et al. [9] refer that the means of access have a strong influence on the maintenance strategies since they correspond to a considerable percentage of the total costs of the maintenance activities, this can be particularly true for natural stone claddings. When this research is extended to the safety field, it is understood that permanent solutions are more expensive than temporary solutions [10]. However, in [10], the exploration stage is not considered. However, from the findings of this study, it is assumed that, when maintenance is really implemented in buildings during the life cycle, there are advantages in choosing the permanent solutions. Its cost is amortized over the years since there are non-predicted expenses with temporary solutions.

In this sense, to optimize the maintenance activities, in this paper, a comparative analysis of the cost of the different temporary means of access in the maintenance plans developed for the different types of façade cladding is carried out. In this study, six temporary means of access are analysed: supported and suspended scaffolds, aerial work platforms (articulated booms, telescopic booms, and scissors lifts), and rope access. In terms of façade claddings, six types are also considered: ceramic tiling systems (CTS), natural stone claddings (NSC), rendered façades (RF), painted surfaces (PS), externa thermal insulation composite systems (ETICS), and architectural concrete façades (ACF). Furthermore, the analysis performed, in this study, is only carried out in terms of cumulative average costs of the maintenance plans. It is assumed that both the impact of the different maintenance activities in the degradation condition, and the time intervals between inspections, are not influenced by the means of access selected. Furthermore, it should be mentioned that this research is valid for current buildings (for both offices and housing buildings) more than one story high.

2 Different means of access

Generically, the means of access can be divided in two types [11]: permanent and temporary access systems. The permanent access systems are usually planned during the design stage and implemented at the construction stage [11]. The main function of these systems is aiding the periodic maintenance of the buildings. In all other situations, temporary access systems are used. Generally, this type of means of access is installed before inspections or maintenance interventions take place and are removed after completion of the actions. The selection of the most appropriate access system should be made according to the characteristics (architecture, height, among others) and constraints of each building (users, surrounding space, among others), the maintenance needs of the façade, and the time and funds available for the intervention. In this study, the means of access most often used in maintenance activities in current buildings are analysed, such as supported and suspended scaffolds, rope access, and aerial work platforms (articulated booms, telescopic booms, and scissors lifts). In the following sections, these means of access are described in more detail.

2.1 Supported scaffolds

Scaffolding is one of the most used means of access in building maintenance [3]. In a simple way, this mean of access consists of a set of platforms at different levels in parallel to the façade and linked by ladders. The main disadvantages include: the possible damage of the surface if the façade does not meet the conditions to place anchorage points that connect the scaffolding to the building structure, to guarantee the safety of the temporary structure [3]; the need of space and suitable ground surrounding the façade to be installed [3]; and a significant impact on the labour cost and construction schedule [12].

2.2 Suspended scaffolds

Suspended scaffolds consist of a platform, rigging to suspend the platform, a hoist to move it up and down, and an anchor for the suspension ropes [13]. The selection of this mean of access should consider the weather conditions, namely the action of the wind, and the geometry of the roof. Compared to scaffolding, this equipment has shorter assembly and disassembly times, enabling access to facades where there are restrictions at the soil level. It has a good carrying capacity for people and materials needed for maintenance, but it has access limitations due to complex architectures and saliences [2].

2.3 Rope access

The rope access allows easy access to all points of the façade, as well as quick installation, using little equipment compared to other means of access [3, 14]. Additionally, the technique has a reduced visual impact on the building and does not need to damage the cladding to work on the façade [14]. Regarding the disadvantages, the adoption of this technique requires specific training of the worker [14] and it is uncomfortable for long-term work [2]. Good weather conditions should be assured during the intervention on the façade. This technique is mainly used for light maintenance actions and surveying [3].

2.4 Aerial work platforms

There is a wide variety of aerial work platforms, but the most common are: articulating booms; telescopic booms; and scissor lifts. These means of access are normally used in occasional and short-term works and are only adequate to maintenance operations in low-medium-height buildings, since the reach of the aerial work platforms is reduced when compared with the other means of access (approximately, 20 m to articulating and telescopic booms, and 10 m to scissor lifts).

3 Comparative analysis

In this study, a comparative analysis of the cumulative average maintenance costs of different means of access, for different façade claddings (CTS, NSC, RF, PS, ETICS, and ACF) and maintenance strategies, is carried out. These six cladding systems correspond to the most current types of claddings [15, 16]. The costs of materials, equipment, and labour for maintenance activities (cleaning operations, minor interventions, and total replacement) are the same. In this study, four maintenance strategies are analysed:

- MS1 - includes only the total replacement of the façade. It is applied to the six claddings;
- MS2 - combination of total replacement and minor interventions. It is only applied to five claddings. It is assumed that MS2 is not applied to PS;
- MS3 - combination of total replacement, minor interventions, and cleaning actions. It is only applied to five claddings. It is assumed that MS3 is not applied to PS;
- MS4 - combination of total replacement and cleaning actions. It is only applied to PS.

Since the maintenance of buildings' envelope elements is not fully implemented in society, MS1 represents the maintenance strategy most frequently practiced by stakeholders [17]. The consideration of minor interventions in MS2 intends to illustrate that small repair works can increase the performance and durability of the building elements [18]. The purpose of the cleaning operations in MS3 is to analyse the impact of the most popular maintenance action (easier and more economical) in building elements [19]. MS4 is a particular case of MS3 since minor interventions are not carried out in PS [20].

For CTS, NSC, RF, ETICS, and ACF, the following means of access are analysed: supported and suspended scaffolds, aerial work platforms (articulating booms, telescopic booms, and scissors lifts), rope access, and, finally, the situation in which maintenance activities can be carried out safely without the need for additional means of access is also analysed. Regarding the maintenance strategies, four situations are analysed: MS1, MS2, MS3 and MS3*. In other words, in MS3, cleaning operations, minor interventions, and replacement are carried out using the same type of means of access; in MS3*, it is assumed that cleaning operations are always carried out by rope access and that, for the remaining interventions, the type of means of access used varies. For these façade claddings, it is assumed that rope access is only suitable for cleaning operations. Unlike the other façade claddings, for PS, only two maintenance strategies are analysed: MS1 and MS4. For this type of façade cladding, the rope access, in addition to being suitable for cleaning operations, is also suitable for the replacement of the cladding.

The cumulative maintenance costs of a building component, *C*, over time are given by Equation (1), and correspond to the sum of the costs related with inspections, $\sum C_{inspection,t}$, and other maintenance activities, $\sum C_{maintenance,t}$. Since the maintenance needs of building components of the same type are different due to the variability of the degradation process, the maintenance costs are presented in terms of cumulative average costs. In this study, a time horizon, t_h, of 150 years is considered. A long-term horizon is used in order to guarantee that a considerable percentage of the Monte Carlo simulation samples reach the end of the service life, in the more durable cladding systems, allowing decreasing the uncertainty of the analysis. To contemplate future investments, Equations (2) and (3) are used to compute the net present value of the inspection and maintenance activities [21].

$$C = \sum C_{inspection,t} + \sum C_{maintenance,t} \quad (1)$$

$$C_{inspection,t} = \sum [\, C_{inspection} / (1 + \upsilon)^t] \quad (2)$$

$$C_{maintenance,t} = \sum [\, C_{maintenance} / (1 + \upsilon)^t] \quad (3)$$

where $C_{inspection}$ and $C_{maintenance}$ are the inspection and maintenance activity costs (Tables 1 and 2), respectively, and υ the real discount rate (a real discount rate of 6% is adopted [22]).

The costs of different maintenance activities (Table 1) are adapted from the literature [23]. Since the cost of the maintenance activities varies according to the materials applied, the following assumptions are adopted: CTS - sandstone tiles; NSC - *Alpinina* stone; RF - current cementitious-based render; PS - paint based on acrylic polymers; ETICS - expanded polystyrene boards as thermal insulation material and acrylic-based coat as finishing material; and ACF - façade cast in situ with thickness of 25 cm and a smooth texture without paint. The costs of the different means of access analysed (Table 2) are the average costs in Portugal, which were obtained through consultation with companies in this area of expertise from May to July 2020. As a case study, it was assumed that the equipment would be needed to intervene in a 250 m^2 façade cladding.

Table 1. Costs of the inspection and maintenance activities without the costs of the means of access.

Costs (€/m^2)	CTS	NSC	RF	PS	ETICS	ACF
Inspection	1.03					
Cleaning operations	17.28	21.17	16.68	16.68	16.68	16.98
Minor interventions	55.57	58.60	24.48	-	47.93	74.55
Total replacement	58.65	139.31	26.48	20.18	85.78	96.28

Table 2. Costs of the different means of access

Means of access	Supported scaffolds	Aerial work platform			Suspended scaffolds	Rope access
		Articulating booms	Telescopic booms	Scissor lifts		
Costs (€/m^2)	10.20	8.13	11.84	10.58	4.68	2.12

In Figs. 1-5, the cumulative average maintenance costs (including inspection costs) for CTS, NSC, RF, ETICS and ACF, respectively, related to year 0, obtained for the four situations and for the different means of access are compared. For a 150-year time horizon and a real discount rate of 6%, the cost associated with the inspection are 5.39 €/m^2 (time interval between inspections of 3 years) for RF and ETICS, 3.92 €/m^2 (time interval between inspections of 4 years) for CTS and ACF, and 3.04 €/m^2 (time interval between inspections of 5 years) for NSC. Still, in Figs 1-5, for both MS3 and MS3*, the cumulative average maintenance costs, for the situation without means of access, is the same, since specific access equipment are not needed.

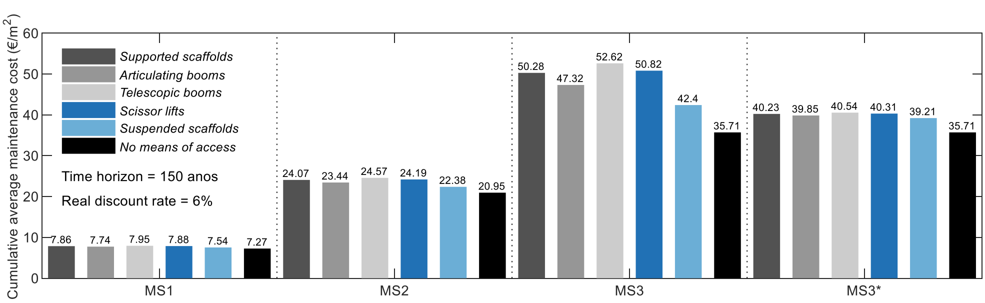

Fig. 1. Comparison of the cumulative average maintenance costs (including the inspection costs) for CTS, for different maintenance strategies and means of access, for a time horizon of 150 years.

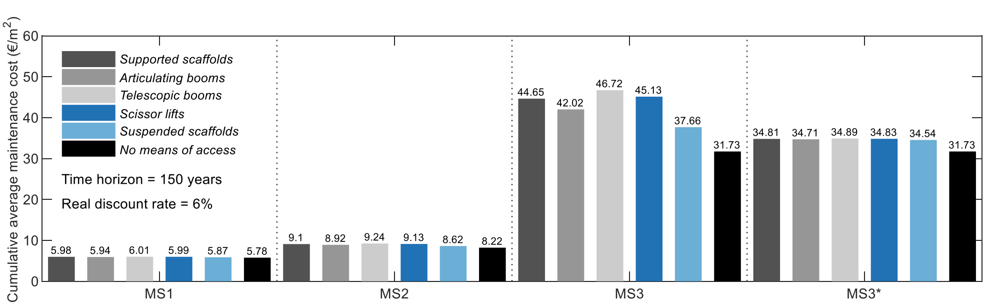

Fig. 2. Comparison of the cumulative average maintenance costs (including the inspection costs) for NSC, for different maintenance strategies and means of access, for a time horizon of 150 years.

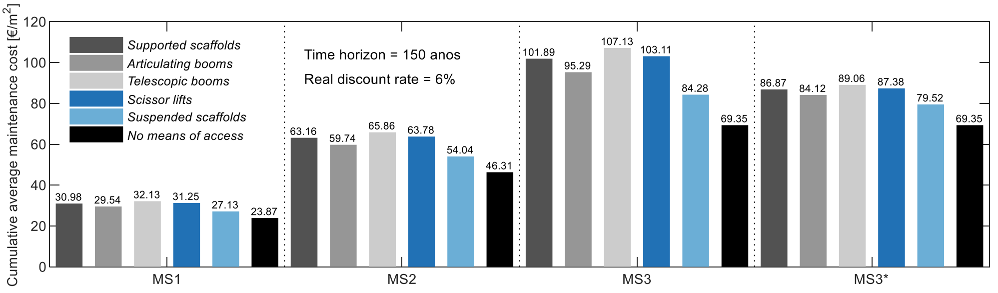

Fig. 3. Comparison of the cumulative average maintenance costs (including the inspection costs) for RF, for different maintenance strategies and means of access, for a time horizon of 150 years.

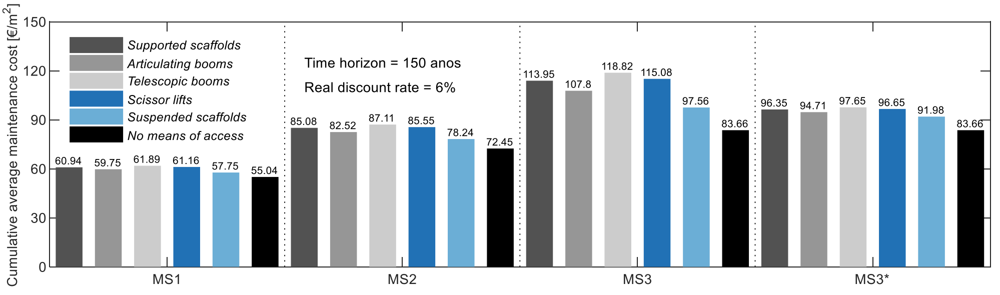

Fig. 4. Comparison of the cumulative average maintenance costs (including the inspection costs) for ETICS, for different maintenance strategies and means of access, for a time horizon of 150 years.

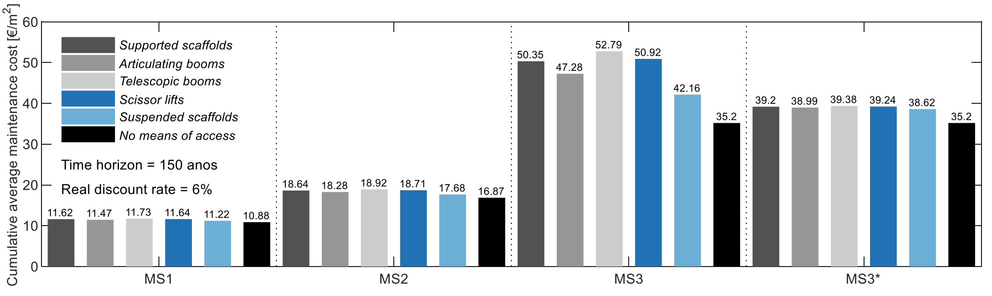

Fig. 5. Comparison of the cumulative average maintenance costs (including the inspection costs) for ACF, for different maintenance strategies and means of access, for a time horizon of 150 years.

For PS, the cumulative average maintenance costs (including inspection costs) for the different means of access are presented in Fig. 6. For a 150-year time horizon and a real discount rate of 6%, the cost associated with the inspection is 8.33 €/m^2 (time interval between inspections of 2 years).

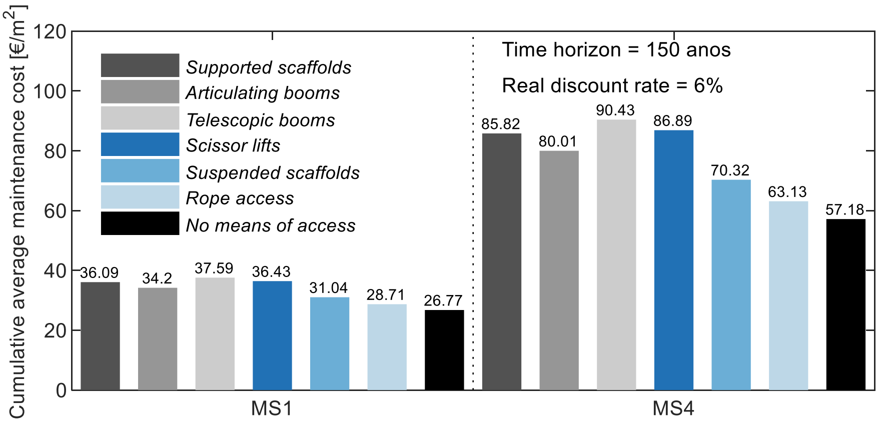

Fig. 6. Comparison of the cumulative average maintenance costs (including the inspection costs) for PS, for different maintenance strategies and means of access, for a time horizon of 150 years

In global terms, there is a direct relationship between cumulative average maintenance costs and the unit cost of the means of access (Table 2). In relation to other means of access, in the situation where maintenance actions can be carried out without the use of specific access equipment, the cumulative average maintenance cost shows a reduction from 10% (for NSC) to 26% (for PS). Crossing these results with the service life and the number of interventions [24], as expected, there is a direct relationship between the cumulative average maintenance cost and the number of interventions that the cladding is subjected to over the time horizon. In other words, the reduction in the cumulative average maintenance cost in MS3 is higher than in MS2 or MS1. It is also found that the use of rope access to carry out cleaning operations leads to an average reduction of 20% in cumulative average maintenance costs for CTS, NSC and ACF and 15% for RF and ETICS.

4 Conclusions

Ensuring the performance of inspections, maintenance and/or repair works requires time and effort. Therefore, when necessary, the selection of the adequate mean of access is fundamental to reduce both the time and effort required for those tasks. The costs of means of access vary between 2.12 €/m^2 (rope access) to 11.84 €/m^2 (telescopic boom) and, from the analysis, it appears that, for any means of access, there is an increase in the cumulative average maintenance cost with the increase in the complexity of maintenance strategies. In addition, it is observed, as expected, that the lowest cumulative average maintenance costs occur for the most economical means of access, leading to an average reduction of 10% to 26% of cumulative average maintenance costs when compared to other means of access (compared to supported scaffolds, leads to an average reduction of 11% to 32%). For the situations where the use of means of access is essential, the results suggest that rope access (in the case of cleaning operations and replacement of the coating by painting) and/or suspended scaffolds (for other types of maintenance work) are the best alternatives (compared to supported scaffolds, they lead to an average reduction of 5% to 21%). The use of rope access to carry out cleaning operations has a significant impact on cumulative average maintenance costs. For the 150-year time horizon, there is an average reduction of 15% to 20%. For the other means of access, compared to supported scaffolds, the articulating booms leads to an average reduction of 2% to 6%, the telescopic booms to an average increase of 2% to 5% and the scissor lifts at an average increase of 1%. This study was carried out for a fixed discount rate and time horizon. The variation in these two variables has little influence in the results. In other words, the cumulative average maintenance costs will be different, but the conclusion will be the same. The results obtained in this study are relevant for the state-of-the-art in maintenance of buildings' envelope elements. The maintenance of buildings' envelope elements is often neglected because it is considered an expensive and non-priority activity. These results reveal that with some planning the maintenance costs can be reduced. Furthermore, it also shows the need for research in this field.

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