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An Evaluation System to Optimize the Management of Interventions in the Historic Center of Florence World Heritage Site: From Building Preservation to Block Refurbishment

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Abstract: The goal of this paper is to present a methodology for setting priorities among interventions in the old city center of Florence, going from the conservation to the regeneration of its heritage. The proposed methodology is based on specific methods of analysis of degradation and parameters for the optimization of construction costs. The methodology can be considered an additional part of the Management Plan of the site of the Historic Center of Florence (adopted for the first time in 2016 and now updated with the inclusion of a buffer zone) that "represents an important tool for the conservation and enhancement of the Heritage and is also a source of address for the choices that the Administration is called to adopt regarding the use of the city and its spaces". The application of the method, in addition to being in harmony with some of the action projects of the second macro-area of the new Management Plan, also has points of contact with the provisions of the Municipal Operational Plan that provides for a reinterpretation of the existing building heritage. From the monitoring of individual buildings, aimed at their preservation, we will move to study the relationships that promote the creation of joint construction sites, thus optimizing costs.

Keywords: management plan; cultural heritage; Florence Historic Center; opportunity matrix; degradation index

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1. Introduction

The Historic Center of Florence has been on the World Heritage List since 1982. To further enhance its protection, UNESCO in 2004 recommended that all listed sites adopt a Management Plan while also making it better known, defended, and monitored.

After the first Management Plan in 2006 [1], the Municipality of Florence approved the second Management Plan in 2016 [2] as a tool for the conservation and enhancement of the World Heritage Site, and two years later introduced a monitoring plan [2].

This was a very important step both for the management of the World Heritage site and for the application of what UNESCO requires of World Heritage sites.

These objectives were achieved thanks to the collaboration between Tuscany Region and the University of Florence going so far as to create a joint laboratory (Here Lab—Heritage Research Lab) [3] with the Department of Architecture (DIDA), which was strongly involved in the definition of the Management Plan.

In order to monitor the progress achieved in the implementation of this plan, a monitoring exercise (Monitoring Plan) is carried out every two years involving the actors (public and private) of the projects selected within the management plan. There are thirty-three projects monitored, subdivided into five macro areas: (1) management of the tourism system; (2) conservation and knowledge of the monumental heritage; (3) mobility system; (4) Arno river and climate change; and (5) livability, commerce, and residence in the Historic Center.

Given the context, the paper presents the first result of research aimed at defining a decision support system (DSS) for the conservation and knowledge of buildings belonging to the monumental heritage of the historical center of Florence with reference to the technological elements that characterize their architectural (and artistic) identity, such as opaque vertical and horizontal structures (elevations and roofs).

Decision support systems (DSSs) have been identified as useful tools in a wide range of fields, including the context of the Management Plan for the conservation of the historical city center [4]. The DSS reduces costs and facilitates the identification of measures that make a process more efficient and productive, creating useful scenarios. Additionally, it allows reducing work time by helping users to plan efficiently and improve the level of customer engagement, thus saving time and money [5].

The research activity was initiated with the aim of investigating the relationship between costs, entities, and types of intervention, from conservation to re-functionalization of buildings in historic centers. The study of the relationships between the level of degradation and the interconnection of buildings, by means of a specifically defined method (Section 2.4), makes it possible to establish a priority order between interventions, making portions of the territory (blocks or groups of buildings) stand out. The proposed method is based on specific degradation analysis methods and parameters for the optimization of construction costs.

The proposed method is built according to an inductive approach on the basis of a specific case study, and a portion of the Historic Center of Florence can be configured as a DSS of wider use. It can be used in Italian and European contexts where, within a historical fabric, a plan for the conservation and/or regeneration of buildings must be prepared.

The method can be considered an implementation of the Management Plan of the Historic Center of Florence site (first adopted in 2016 and now updated with the inclusion of a buffer zone) that 'represents an important tool for the conservation and valorization of the Heritage and is also a source of guidance for the choices that the Administration is called upon to adopt regarding the use of the city and its spaces'. The application of the methodology and the results, in addition to being in tune with some of the action projects of the second macro-area of the new Management Plan, also has points of contact which can be used with the provisions of the Municipal Operational Plan, which foresees a reinterpretation of the existing building heritage. From the monitoring of individual buildings, aimed at their conservation, the study will focus on the relationships that favor the creation of common sites, thus optimizing management costs.

In particular, the DSS aims to improve the results achieved by the Heco Colors project [6] belonging to macro-area No. 2 of the Monitoring Plan. This project provides an integrated open data system of the architecture of the Historic Center based on the recognition of the color language of the architecture with references to the elevations of public and private buildings. The results provided by the Heco Colors project and applying the proposed DSS are intended to add quantitative information about elevations and roof degradation. The output of the DSS allows for defining the opportunity in operating the maintenance work between buildings belonging to the same block.

In Section 2, an analysis of the existing bibliography is proposed on cultural heritage urban development threats and cultural heritage assessment tools. Projects to safeguard the Historic Center of Florence, in which the method fits, are also illustrated. Finally, the proposed method is described. Section 3 describes the results of the experiment and Section 4 discusses the results and draws conclusions.

2. Materials and Methods

2.1. Cultural Heritage and Urban Development Threats

Articles 2 and 13 of the Convention on the Protection and Promotion of the Diversity of Cultural Expressions [7] emphasized the role of culture in sustainable development. Subsequently, the UN Conference on Sustainable Development "Rio + 20" [8] called for the integration of culture and sustainable development, which can play a significant role in facilitating the safeguarding of heritage values within the urbanization process. Furthermore, the conclusions on cultural heritage as a strategic resource for a sustainable Europe ([2], p. 2) emphasized the role of cultural heritage as a "powerful driving force for inclusive local and regional development". Given the significant role of cultural heritage in sustainable development, there are several indications for heritage protection within urban development policies and conventions. For example, the EU Key Action 'Cities of Tomorrow and Cultural Heritage' aims to 'improve the assessment of damage to cultural heritage, develop innovative conservation strategies, and promote the integration of cultural heritage in the urban context' [9]. The United Nations (UN), in its Agenda for Sustainable Development, Goal 11 Sustainable Cities and Communities, defines some objectives to "make cities and human settlements inclusive, safe, resilient and sustainable", and Goal 11.4 aims to "strengthen efforts to protect and safeguard the world's cultural and natural heritage" ([10], p.26). According to the State of Conservation Information System (SOC) reports compiled by UNESCO ([5], p.12), "between 1979 and 2013, 66% of reported [damaged] properties were cultural properties"; these properties are threatened by a list of factors affecting Outstanding Universal Value (Figure 1).

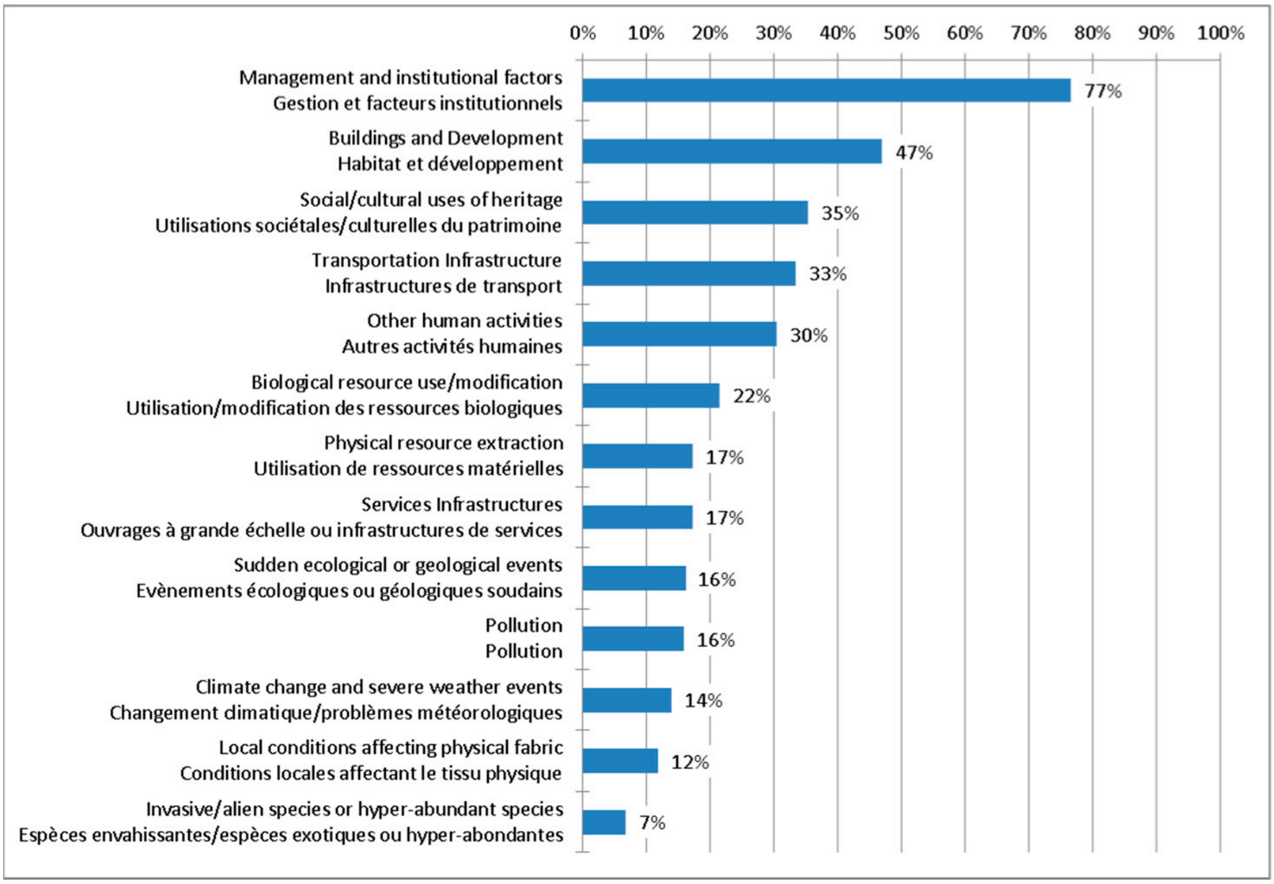


Figure 1. State of the Conservation Information System Report (UNESCO) [11].

The high percentage of cultural heritage affected by urban development portrays the latter as a threat and source of conflict. Although "cities are increasingly seen as drivers of sustainable development, applying sustainability goals", urban development strategies and projects have remained a major threat to cultural heritage values. "One of the main negative effects of urban development, mentioned in the UNESCO State of Conservation (SOC) Report, is the impact on the visual integrity and aesthetic values of cultural heritage due to high-rise buildings" [5,12]. Recently, the visual impact has been considered as an additional and important factor to be considered in environmental impact assessments (EIAs) in order to protect cultural heritage [13,14]. For example, Directive 2014/52/EU [15] of the European Parliament and the Council on the assessment of the effects of certain public and private projects on the environment (2014) indicates that 'in order to better preserve the cultural and historical heritage and landscape, it is important to address the visual impact of projects, i.e., the change in the appearance or view of the built or natural landscape and urban areas, in environmental impact assessments'. The increasing number of cultural assets that have been visually affected by high-rise buildings and incompatible new construction in urban areas (e.g., Dresden, Liverpool, London, Seville, and Vienna) underlines this challenge [16].

2.2. Cultural Heritage Assessment Tools

While urban characteristics have changed and developed constantly with population growth, cultural heritage as an integral part of urban areas has continued to express the historical evolution of cities. Indeed, the protection and sustainable development of cultural heritage as a source of identity has a key role in maintaining the link between the past and the future [17].

The management of World Heritage properties in urban areas requires an appropriate assessment tool to mitigate the potential impacts of new construction. Recognizing this challenge, in 2011, ICOMOS published the Guidance on Heritage Impact Assessments for Cultural World Heritage Properties [18] to guide the impact assessment of cultural heritage sites. Heritage impact assessment (HIA) is a new assessment tool to identify and analyze the potential impacts of new projects on World Heritage cultural properties. The HIA is a version of the environmental impact assessment (EIA), which is specifically designed for the cultural and heritage sector, focusing on the expression of outstanding universal value (OUV) and its preservation. The HIA is particularly suitable for those sites characterized by dynamic urban contexts; thus, cities of art represent the most favorable field of application. In many countries, including Italy, as a result of the study conducted by Ashrafi et al. [19], these issues, as well as the awareness of the depth analysis necessary for the conservation of sites exist, but the operationalization and full understanding of the HIA is lacking [20].

The analyses making up the HIA can be complex requiring the contribution of a professional team and operators with expertise related to the specific project or site. Many HIAs require the storage of numerous data and the use of tools, such as a geographic information system (GIS), promoting a systematic and rational approach [21,22].

Cultural heritage projects and, generally, urban and territorial transformations, can be considered as processes producing direct effects on the physical environmental system of a given area and indirect effects on the social and economic system. According to the legislative framework, these kinds of projects are made the object of specific evaluation procedures such as, among others, feasibility studies, cost–benefit analyses, and strategic environmental assessments [23].

As pointed out by Savieri et al. [24], in the past, traditional cultural heritage conservation practice focused primarily (or sometimes exclusively) on the city's architectural monuments or, rather, on its valuable assets. Nowadays, however, there is widespread recognition that a more inclusive and integrated approach is needed to identify and understand urban values which underpin the identity and character of the city [13].

The concept of integrated conservation is now widely recognized worldwide and is closely related to its enhancement [25].

Conservation is, therefore, integrated, as it deals with the integrated heritage of the historic city made up of the tangible and intangible assets of each community [26].

The model proposed by Sesana et al. [27] incorporates and evaluates the multidimensional aspects linked to the characteristics of historic buildings aiming at ensuring its integrated conservation. The aspects detected are expressed through the use of mixed scales, i.e., through qualitative and quantitative data depending on the aspects investigated. It makes it possible to carry out both assessments of individual aspects of degradation (assessment of technological or environmental degradation of the building, etc.) and assessments of global degradation.

An assessment procedure concerning the integrated conservation of historic heritage is developed by Etxano et al. [28] and is implemented through two phases: the first one is a direct survey of the building under evaluation. The degradation found on the connotating components is obtained through a score on an appropriate scale verifying the presence and intensity of the connotating factors of the various degradation categories. To carry out the second phase, the data collected is first processed using the Evamix multi-criteria technique [29,30]. The results obtained are processed to obtain both a partial score for the individual deterioration category and a score for the overall deterioration of the building analyzed [31].

Another approach is proposed by Francioni et al. [32], who defines a methodology integrating urban surveying with the City Information Modeling paradigm to support the assessment of the vulnerability of historic heritage buildings, adopting a dispatchable approach. This approach is based on the use of geo-data (generally in the possession of public administrations or available in open data) as an indirect source, structuring an informed and responsive city model [33,34]. Furthermore, a procedural modeling strategy based on the knowledge of building types is introduced to implement basic information and to obtain initial rough assessments. This approach guarantees the economic sustainability of the initial intervention postponing to a later time the digital survey operations necessary for an accurate knowledge and geometric description of the building units, but it is burdensome both in terms of cost and energy.

Rossitti et al. [17] proposed a methodological framework that is grounded on the recognition of cultural properties' values and their possible integration into the local economic system and assesses the reuse of projects' financial sustainability. This methodology's application is discussed through a case study allowing us to discuss the role of the proposed evaluation framework in supporting and promoting cultural heritage reuse and its possible room for improvement.

2.3. Projects to Safeguard the Historic Center of Florence

During the Sixth Session of the UNESCO World Heritage Committee, held in Paris at the headquarters of the United Nations Educational, Scientific and Cultural Organization (December 1982), the Historic Center of Florence was inscribed on the World Heritage List. Article 11 of the Convention established an Intergovernmental Committee for the Protection of the World Cultural and Natural Heritage at UNESCO [35]. Each participating state, on the basis of the data provided, is responsible for preparing, updating, and disseminating a list of World Heritage properties considered to be of outstanding universal value. In addition, it must draw up a list of the World Heritage sites in danger, indicating the properties to be protected, the interventions and maintenance work required, and the international assistance required [36]. The international community, national communities, and, above all, local communities, understood in the widest and most varied sense of the term, are called upon to defend the outstanding universal value of a site, with the knowledge that its decay is a very serious loss for the whole of humanity. The issue of how to respond to management consistent with the values of inscription never entered the national and local political agenda until the early 2000s, thanks to a strong call by UNESCO to promote new candidacies with Management Plans and an explicit invitation to Member States to equip even old sites with a Management Plan. In Italy, there was an abrupt acceleration on this issue in 2005, when a process started a few years earlier by the Ministry of Cultural Heritage and Activities and the managers of World Heritage sites was implemented. In the peripheral state administrations and in the municipality, there was minimal awareness that Florence, or rather its Historic Center, was on the World Heritage List. There was no official document, regulation, or spatial planning instrument mentioning this unique feature [37].

The need to draw up a document for the preservation and enhancement of the site and the obligation to comply with the provisions of the World Heritage Convention gave rise to the need on the part of the Municipality of Florence, the body responsible for the site, to set up a special office that would be dedicated primarily to the sustainable management of the Historic Center and the drafting and monitoring of the relevant Management Plan. With a provision of the Department of Culture of the Municipality of Florence in 2005, a special structure was created within the Municipality of Florence, called the 'UNESCO Office' of the Municipality of Florence, with the task of dealing with the following functions:

- Drafting and monitoring the Management Plan required by the World Heritage Convention in order to promote the conservation, enhancement, and sustainable Management of the Historic Center of Florence;
- Activation and coordination of effective links between public and private actors and stakeholders operating in the Historic Center of Florence;
- Concerted identification of guidelines and joint action projects to be included in the Management Plan and verification of their progress; co-ordination of the management of the funding allocated to the Management Plan and the related Action Plan;
- Periodic reporting on the state of conservation of the Historic Center and changes to the Management Plan and Action Plan;
- Organization of cultural initiatives and celebrations of centenaries related to the historical identity of the city of Florence;
- Promotion, realization, and coordination of studies and research on the history of the city, the territory, and the monumental heritage;
- Implementation and monitoring of projects financed by Law No. 77 of 20 February 2006 'Special measures for the protection and enjoyment of Italian sites of cultural, landscape and environmental interest included in the "World Heritage List", under the protection of UNESCO;
- Consolidation, through specific projects, of transnational cooperation and collaborations between the UNESCO World Heritage Sites and the sister cities of Florence;
- Collaboration in projects aimed at strengthening the management skills of public bodies and associations in the management of World Heritage List sites.

After the first Management Plan in 2006, Florence approved the second Management Plan in 2016 [1] as an instrument for the conservation and enhancement of the World Heritage Site and, two years later, presented a monitoring plan. This is a very important step for the management of the World Heritage site and for the application of what UNESCO requires of the World Heritage sites; the achievement of these objectives took place thanks to the direct collaboration between the Region of Tuscany, or the peripheral state administrations, and the University of Florence in particular, arriving at the creation of a joint laboratory (Here Lab—Heritage Research Lab) with the Department of Architecture (DIDA), which was strongly involved in much of the research applied to the Management Plan which was verified through its monitoring plan [38,39].

A monitoring system is indeed essential to ensure the effective implementation of a Management Plan and is used to assess the current situation and to plan for change, as it provides the information needed to review and update the Management Plan [40].

It presents what is happening at the World Heritage site and what has been achieved in the planned program. In other words, monitoring is the true test of the effectiveness of the management of a World Heritage site, as it measures the implementation of the Management Plan in both quantitative and qualitative terms, and thus whether and to what extent the outstanding universal value of the site is being preserved [41].

Regarding the Management Plan for the Historic Center of Florence, the monitoring process is divided into two phases:

1. Verification of the coherence of the project, both with respect to the mission of the site and with respect to the maintenance of its OUV (verification carried out during the selection phase of strategic projects);
2. Checks the progress of projects, establishes monitoring indicators, and verifies whether the project objectives are achieved on time.

In general, the monitoring plan, drawn up in 2018 and now being updated (Preliminary Document to the 2022 Management Plan), monitors thirty-three projects, divided into five macro-areas. The 2022 Management Plan was recently drafted, updating the previous 2016 version. The methodology proposed in this work focuses on "Conservation and knowledge of the monumental heritage" and has as one of its objectives to extend and implement the results of the Heco Colors project, which is part of the second macro-area of the monitoring plan: HECO Colors [6] financed by the MiBACT funds of Law 77/2006 "Special measures for the protection and enjoyment of Italian sites of cultural, landscape and environmental interest, included in the 'World Heritage List', under the protection of UNESCO" is an integrated open data system of the architecture of the Historic Center. It is based on the recognition of the color language of architecture and aims to develop guidelines to be used in urban prevention and maintenance [42,43]. The project is useful in several areas:

- Maintenance and prevention: the monitoring of interventions carried out on the architectural heritage makes it possible to schedule future inspections or interventions, setting alarms when the maximum time between one inspection and the next is exceeded;
- Management of cities of art: it is possible to know the economic needs for maintenance and restoration work on building facades;
- Planning: it is possible to know and visualize intervention priorities in order to consciously plan maintenance actions;
- Urban decoration: the chromatic survey of backgrounds, cornices, and plinths makes it possible to develop appropriate methodologies for the conservation and enhancement of building façades with the identification of color matrices and palettes, and textural prototypes.

2.4. About the Method

The developed procedure systematically integrates several methods defining an evaluation process in which both quantitative and qualitative data are collected and analyzed. Generally, these types of evaluation are mainly adopted when:

- The answer to each question has more than one component requiring different evaluation methods;
- An attempt is made to increase the accuracy and consistency of the results;
- There are several steps in the evaluation process and the results obtained by one method are useful for the next steps.

It is evident that more methods can capture a wider range of perspectives.

Specifically, an experimental evaluation based on two phases is used in this work:

1. Definition of a degradation index (DID) specific for elevations and roofs, referring to each building as a stand-alone;
2. Creation of an opportunity matrix (DMO) that relates possible interventions on the elevations and roofs of the buildings constituting a block.

These methods thus constitute the structure of the DSS and are discussed in detail below.

1. Definition of the degradation index for elevations and roofs (DID)—referring to individual buildings.

To assess the state of conservation of elevations and roofs, a numerical indicator of the level of degradation has been defined. Specifically, this numerical indicator hereinafter referred to as Id_{tot} is equal to:

$$Id_{tot} = \Sigma(Id_p + Id_r) * r_{life} \quad (1)$$

i.e., the sum of the degradation index both referring to roofs *Idr* and to prospect *Idp*. Two levels of risk to human life were considered: high (r_{life} = 2), when the building has prospect(s) on a public street (possible detachment/collapse of an element of the prospect and/or roof may entail) and low (r_{life} = 1), when the building has front(s) exclusively on streets accessible only to residents, such as private streets.

The calculation of the degradation index *Idp*, it is expressed as:

$$Id_p = \frac{A_d}{A_t} K_d K_c \tag{2}$$

where

$\frac{A_d}{A_t}$ is the ratio of the degradation area (*Ad*), quantified as the amount of material missing from the surface to the total area of the elevation (*At*).

K_d is the factor that takes into account the type of degradation. Its range value goes from 1 to 4 (slight, medium, severe, extreme) depending on the damage it may cause to the material in terms of loss of historical and cultural value, and risks to human life.

K_c is the weight factor considering the importance of degradation in the sense of the complexity of restoration/maintenance operations and the related intervention cost. Its value is the ratio between the costs of ordinary maintenance (cleaning operations), material consolidation costs (material recovery), and the costs of complete material replacement (restoration of missing or no longer recoverable parts).

The degradation index refers to roofs Id_c has the same structure as that defined for elevations, with the difference being that the ratio $\frac{A_d}{A_t}$ is referred to as the area of degradation quantified as the amount of material missing from the roof and the total area of the latter.

The degradation index Id_{tot}, therefore, makes it possible to establish the state of conservation of elevations and roofs according to its value. There were four levels of Id_{tot} defined according to the maximum value that this index can reach (i.e., 16), as shown in Table 1.

Table 1. Degradation index values Id_{tot}.

$Id_{tot} = 0$	Level 0	No degradation
$0 < Id_{tot} \leq 4$	Level 1	Good condition
$4 < Id_{tot} \leq 8$	Level 2	Light degradation
$8 < Id_{tot} \leq 12$	Level 3	Moderate degradation
$12 < Id_{tot} \leq 16$	Level 4	Widespread degradation

The calculation of *Idtot* and its value can be implemented within the database of the Heco project which instead considers the degradation index only as a function of the level of elevation chromatic alteration.

The aim is to assess the overall state of conservation of the building's external envelope improving the suggestions regarding the management interventions.

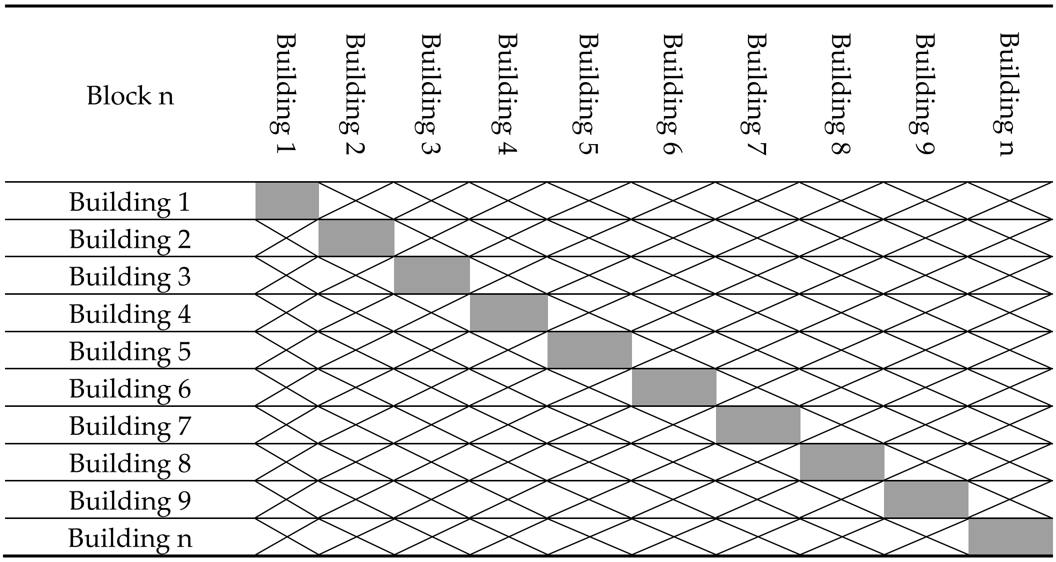
2. Definition of the opportunity matrix (DMO)—consider the set of buildings related to each other.

Usually, an intervention is considered necessary following a building-by-building analysis without considering the state of conservation of the surrounding area. The setting up of an opportunity matrix makes it possible to verify the common characteristics that would make an intervention on several buildings more convenient and advisable.

By linking buildings together, costs are optimized and restoration and reuse activities are concentrated according to economies of size and scale. When speaking of maintenance work both at a technical or management level, it must be considered that each technical element of a building is connected to other elements. This connection can be technological and operational.

The matrix is made up of rows and columns in which the buildings making up the block under consideration are inserted.

Each quadrant resulting from the row–column intersection is divided into four parts forming four small triangles that refer to the operational/technological connections. An example of an opportunity matrix:



Considering the specific case, the operational connection was assessed by comparing the Id tot value obtained from each of the two buildings under examination.

The scale of operational connection is described as follows:

 No operational connection—Id_{tot} buildings between levels 0 and 1.

 Weak operational connection—Id_{tot} buildings between levels 1 and 2.

 Medium operational connection—Id_{tot} buildings between levels 2 and 3.

 Strong operational connection—Id_{tot} buildings between levels 3 and 4.

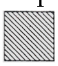
The technological connection, on the other hand, was evaluated, as the convenience of associating interventions on two buildings was linked to reasons of structural and executive nature, i.e., the structural connection between the buildings and the presence of a construction site area[1].

The scale of structural connections is described as follows:

 No technological connection—no structural connection between buildings.

 Weak technological connection—a structural connection between buildings but no presence of a site area.

 Medium technological connection—a structural connection between buildings and the presence of a site area only available on public property (i.e., public street sidewalk).

 Strong connection—a structural connection between buildings and the presence of a site area.

Once the matrix is compiled, the final output of the DSS is obtained, i.e., the highlight of the buildings on each block where there occurs an opportunity for joint intervention. This result is obtained by assessing both the structural connection between the two buildings and their level of degradation of elevations and roofs. In conclusion, when two buildings have a strong technological and operational connection, there occurs a strong opportunity for joint intervention.

3. Results

The procedure described in the section above was applied experimentally to the group of blocks belonging to the Historical Center of Florence and specifically to the Laddarno area. This study area was chosen to enable the integration of results with those already existing and obtained by the Heco project.

Having defined the general area (Figure 2), i.e., the Historical Center of Florence (red line Figure 2) and the Laddarno area (red area Figure 2), three blocks were studied (Figure 3) between the crossroads formed by Lungarno Gucciardini, Via Santo Spirito, Via dei Serragli, and Via Maggio.

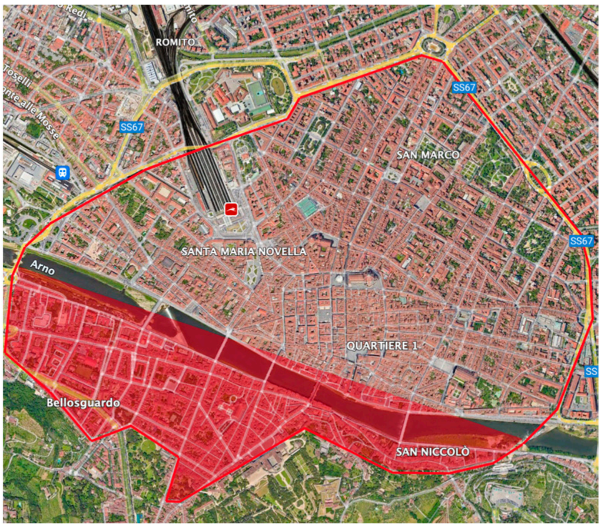


Figure 2. Laddarno area.

Figure 3. Blocks under investigation.

Each block has been numbered in order to be easily recognizable, and the constituent buildings have also been numbered.

For each building belonging to the block, a study was conducted to define the state of conservation of the prospect and roof and, in particular, the degradation affecting them. This is one of the most important parts of the process to obtain reliable results (Id tot value). It is necessary to apply the right method for assessing the condition of the technical elements considered. Inspections often cause excessive costs if they are not organized efficiently and must be planned considering the characteristics of the property. So, the first step was documenting and recording the current state of the heritage under investigation.

Therefore, following access to the library, public archives and photo collections in situ were collected, stored, and processed, and the available information about buildings was useful to determine their current state of conservation (degradation or pathologies).

To standardize the process, we used an electronic checklist (SM1) that many researchers have developed and used to develop their studies. Figures 4 and 5 show some of the photos collected and attached to the checklist.

Figure 4. (From left to right)—An example of prospect and roof degradation recognition (orange area: discoloration; purple area: rising front).

Figure 5. An example of the prospect and roof degradation recognition—blue area: differential degradation.

In the next section, the results obtained from the application of the method are specifically described.

3.1. Step 1—Calculation of Roof and Elevation Degradation Index

3.1.1. Kd Factor

A review and comparison of the literature classified the degradation of stone and wood material (Figure 6).

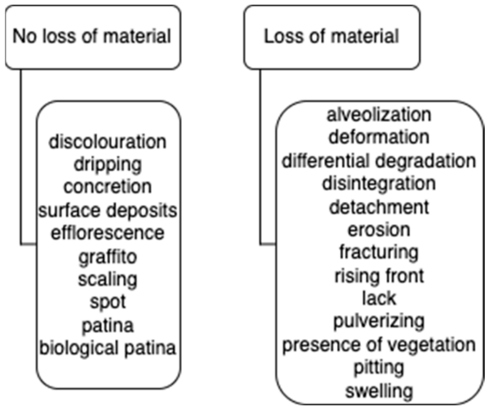


Figure 6. Degradation classification of stone and wood materials.

These two macro-categories have been divided into two further sub-categories that take into account the danger of each degradation generating further degradation (Table 2).

Table 2. Assessing the level of severity and value to degradation.

Light	Medium	Severe	Extremely Severe
1	**2**	**3**	**4**
Discoloration Dripping Graffito Spot Patina	Biological patina Surface deposit Efflorescence Scaling Concretion	Alveolization Differential degradation Disintegration Erosion Fracturing Rising front Pulverizing	Deformation Detachment Exfoliation Swelling
1, 2: no loss of material		3, 4: loss of material	

The first two levels (light and medium) consist of degradations that do not involve any loss of material. A "Light" degradation level means that only cleaning actions (with water or low-pressure air) are needed to restore the original color altered by time; degradations falling in the medium level have a formation of by-products due to chemical reactions that require removal with specific tools (e.g., sponges and scalpels) that require more time and care in execution.

The last two levels (severe and extremely severe) consist of degradations that entail a loss of material and thus require consolidation treatments. Degradations falling into the "severe" level are degradations that occur with a loss of material over a long time, mostly in the form of pulverization; the "extremely severe" level includes degradations whose characteristics entail actual detachment of materials from the support, even of large dimensions. The *Kd* value represents the multiplier factor of the anomalies that varies from 1 to 4 depending on the type of degradation. The values associated with them were used for the calculation of *Kd* referring to roofs and elevations.

Using the indications provided by the UNI 11182:2006 standard (alteration and deterioration of stone materials) and the UNI 11130:2004 standard (deterioration of wooden artifacts), the types of deterioration described above were classified for each prospect and roof of the buildings belonging to the blocks under examination; thus, that *Kd* value was then assigned.

3.1.2. Calculation Factor *Kc*

The second factor that has been taken into account is *Kc.*

The cost estimation of intervention considers the most frequent maintenance/restoration operations in the area of valuable materials, such as stone and wooden materials, within cultural assets.

The following price lists were used to estimate costs:
Price list Regione Toscana 2022 (January/July).
Price list for the restoration of artistic heritage DEI 2022.
Price list for recovery, renovation, and maintenance DEI 2022.

Since we are dealing with buildings in the Historic Center and often of high historical/artistic value, (where necessary) price analyses are prepared for estimating maintenance costs that take into account labor costs, material costs, the cost of hiring equipment and mechanical means, overhead, and company profits.

Table 3 shows the most common intervention procedures that can be performed on stone and wood materials depending on the type of degradation they are subject to.

Table 3. Intervention procedure and costs (stone and wood materials).

Degradation	Loss of Material	Intervention Category	Intervention Procedure for Stone Materials	Intervention Costs for Stone Materials	Intervention Procedure for Wood Materials	Intervention Cost for Wood Materials
Discoloration, Dripping, Graffito, Spot, Patina	No	Simple cleaning	Cleaning with low-pressure deionized water	EUR 58.98/mq	Cleaning for loose dirt	EUR 57.98/mq
Concretion, Scaling, Surface deposit, Efflorescence, Biological Patina	No	Complex cleaning	Cleaning with compresses and tools	EUR 61.98/mq	Cleaning with a tool	EUR 64.84/mq
Alveolization, Differential Degradation, Disintegration, Erosion, Fracturing, Rising front, Pulverizing	Yes	Integration	1. Removal of non-compatible parts 2. Surface cleaning 3. Stone element grouting 4. Finishing	EUR 215,35/mq	Integrations of wooden parts without inlays or decoration	EUR 53.67/mq
Deformation, Detachment, Exfoliation, Swelling	Yes	Consolidation		EUR 480,88/mq	Consolidation of an unpainted wooden structure	EUR 139.75/mq

The weighting of the different types of degradation was carried out according to their maintenance/restoration complexity and their relative costs. This concept is supported by research showing that in the decision-making process, the cost factor is of greater importance than the useful life (durability) of building components. This means that maintenance activities, if cost-effective, will be carried out even for those technical elements with no real need for maintenance.

Once the degradations have been subdivided according to the categories of intervention (simple cleaning, complex cleaning, material integration, material consolidation, and material replacement), the *Kc* factor is calculated as the ratio between the costs referring to each category of intervention and the costs of complete replacement. These costs refer to the current historical period and are estimated based on the average of regional cultural heritage price lists (Table 4).

Table 4. Kc values.

Intervention Category	Stone	Wood
No intervention	0	0
Simple cleaning	0.18	0.48
Complex cleaning	0.22	0.54
Material integration	0.76	0.45
Material consolidation	1.71	1.16
Material replacement	1 (280.81 €/mq)	1 (119.98 €/mq)

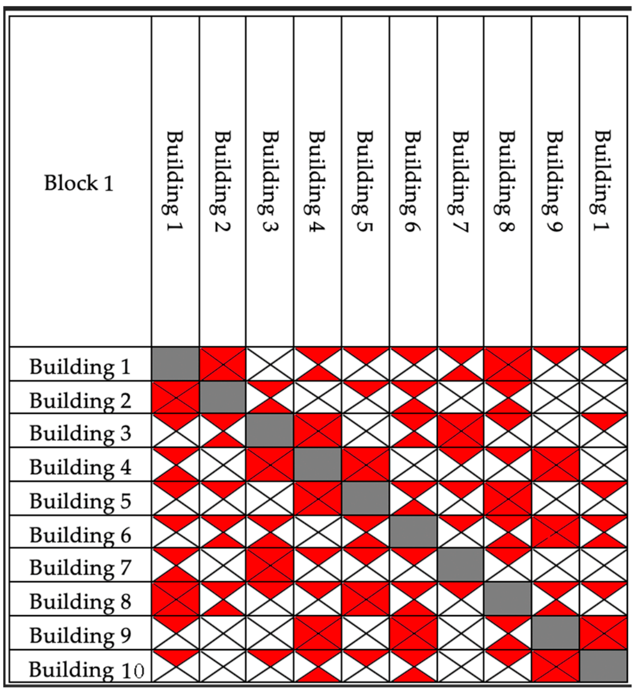
3.1.3. Idtot Calculation

The degradation index calculated for elevations and roofs provides an initial indication of the degradation of each technical element. It gives an overview of the elements having priority for intervention.

The index also refers to the individual buildings that make up the blocks under consideration, and the calculation sheets of an example block (block 1) are given below (SM2).

3.1.4. Definition of the Operational Connection Matrix

While maintenance activities are carried out, it often happens that the opportunity arises to carry out several maintenances together even if they are not foreseen in the MOP. These maintenances are called opportunity maintenances and are to be assessed on a case-by-case basis depending on the budget available. Below is the matrix of operational connections between buildings belonging to block 1:



4. Discussion and Conclusions

The maintenance of historic buildings can be seen as a complex decision-making problem due to the limited availability of economic resources. In decision-making processes, it is important to have a method that follows standard procedures that support technicians and managers.

Generally, heritage regeneration interventions concern single portions of buildings (e.g., their shell). Through the application of the proposed DSS, the aim is instead to consider a broader perspective, which takes into account not only the external shell of buildings but also the entire infrastructure serving them, so as to ensure a deep refurbishment action. The DSS defined makes use of a series of assessments involving the calculation of a degradation index and the definition of a matrix of opportunities for intervention. Thus, methodologies based on both quantitative data (e.g., the calculation of a degradation index) and qualitative data (e.g., the definition of an intervention opportunity matrix) are alternated.

Although, in the experimental phase, the method is easily exportable to other systems (e.g., different technical elements constituting the building), given the flexibility and generality of the individual methods.

One of the main advantages of the proposed DSS is that it disregards the analysis of the ownership of the buildings that characterize the block. In fact, the buildings that make up a block are naturally either publicly or privately owned, or the same building may frequently have both types of ownership. Once the output is received from the DSS, if there are two or more buildings with different ownerships, a strong operational connection is established, and it is possible to assess the possibility/willingness of the parties (owners) to intervene with maintenance. Another advantage is the possibility of cost optimization through the evaluation of the operational connection between buildings in the same block.

Indeed, as stated by several scholars, including Battisti et al. [44], performing a joint maintenance activity is more economical than performing individual maintenance activities. This notion is called "positive economic dependency" and occurs due to the economies of scale of performing group maintenance activities [45].

The latest is of relevance, as the application of DSS can help optimize limited budgets reserved for building maintenance whether it is publicly or privately owned.

The future development of the research is based on the experimentation/application of the method to the reference context after the selection of buildings in the historic center of Florence and its buffer zone. Following this experimentation, it will eventually be possible to define any points or phases of the method that need further implementation.

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Notes

[1] Area where the storage of construction materials and means of construction must take place. It must be located within the construction site in open areas allowing easy access for the means of unloading materials and must not be in the way of other work on the construction site. It must also be a common area and connected to both buildings being worked on.

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