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Sustainable façade rehabilitation protocol for residential buildings in historic districts: The Spanish Quarter of Naples, Italy

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Abstract

European historic centers are home to many residential buildings that reflect the history, culture, and construction traditions of their respective countries, forming a valuable architectural heritage to preserve for future generations. However, their private nature often leads to negligent maintenance, resulting in advanced states of degradation, causing the ruin and demolition of some structures. This article highlights the need to establish sustainable rehabilitation master plans aimed at preserving these buildings and ensuring the quality of life for citizens, in line with the principles of the New European Bauhaus. A façade recovery protocol is developed to restore their urban dignity, which includes a technical data sheet model, applied in a case study: the Spanish Quarter of Naples. The analysis enables a diagnosis of the entire building complex, identifying common damages across different construction systems and materials. An extensive bibliographic study provides a range of sustainable, traditional, and innovative therapeutic interventions with proven effectiveness. This protocol serves as a reference manual for technicians involved in rehabilitation projects, not only for the Spanish Quarter but also for other similar cases.

Keywords: Rehabilitation, Residential heritage, Historic buildings, Protected façades, Sustainable rehabilitation, New European Bauhaus (NEB)

1. Introduction

The city centers of European capitals are the best reflection of their extensive historical and cultural legacy. They preserve not only the ancient urban fabric but also much of the architectural heritage that adds value to the Old Continent, making it one of its main attractions. Today, they have become one of the key economic drivers, reflecting the level of development of the various countries and the urban and social awareness of their municipalities [1] [2].

Many of these cities have been designated as World Heritage Cities by UNESCO. The list continues to grow each year, currently exceeding 450 cities and historical sites considered as part of the cultural heritage of humanity within Europe [3].

In the historic centers of these cities, we find not only the principal public and religious buildings but also numerous examples of residential architecture, which become a valuable source of information regarding the history, culture, and construction traditions and materials of the area. Many of these buildings are subject to varying degrees of protection, primarily affecting their vertical building envelopes, most of which share a common past and similar architectural features, both compositional and material.

However, it is important to highlight that many of these residential buildings suffer from advanced states of deterioration, leading to serious issues of habitability and functionality that affect the quality of life of their inhabitants. This results in a gradual abandonment of the buildings by the residents and the inevitable decay and deterioration of the neighborhood [4].

In the case of Naples, where the area examined in the present study is located, the General Regulatory Plan (PRG) [5] and the Municipal Urban Planning Plan (PUC) (a new plan currently under development whose approval will replace and reorganize the General Regulatory Plan) [6] establish that the historic center (Zone A), where the Spanish Quarter is situated, should direct its interventions toward the conservation and rehabilitation of its buildings, ensuring the typological and morphological compatibility of the urban fabric. In addition, the PUC introduces new strategies for urban regeneration and the improvement of livability.

The administration typically does not allocate budgetary funds to conserve these buildings, despite their recognized heritage value. The Spanish Quarter, included in Zone A of the PRG, received international recognition from UNESCO as a World Heritage Site [7]. National legislation ensures the protection of this heritage by imposing on property owners the obligation to conserve, safeguard, and maintain these buildings. Nevertheless, the private ownership and co-ownership nature of these buildings, the aging population of residents, and the high levels of immigration make it difficult for community members to reach consensus on undertaking maintenance and rehabilitation actions. The issue becomes even more challenging when considering joint initiatives to encompass the entire neighborhood, establishing a master plan for the recovery of the historic ensemble, as would be desirable.

Available resources, which are always insufficient, are instead directed towards preserving other public properties, which are generally of greater significance and historical or artistic value. Within this paradigm, the comprehensive rehabilitation of historic centers, including these residential buildings, plays a fundamental role in fostering a change that reverses the deterioration and abandonment of this invaluable architectural heritage. The renewal of the urban image of these constructions, particularly their façades, is the first step in restoring their dignity and ensuring the preservation of these neighborhoods.

At this point, it is important to highlight the risk that these interventions may be more focused on achieving economic profitability rather than recovering the architectural, artistic, and cultural value of the neighborhood. This issue has affected many European historic centers since the second half of the 20th century [8] [9]. Gentrification, unfortunately, is a phenomenon associated with the urban transformations in many of these neighborhoods [10] [11]. It often entails negative aspects, such as the increase in property sale and rental prices, which must be borne by the residents [12]. It is also true, however, that it attracts a younger population, typically families with children, who revitalize and rejuvenate the neighborhood, ensuring its prosperity [13].

However, these interventions should be aimed at rehabilitating the neighborhood, restoring and enhancing its urban image in a sustainable way, improving the quality of life for all citizens, both residents and visitors, while ensuring the inclusion of all stakeholder groups in the process. Ultimately, the goal is to promote actions within the framework of the New European Bauhaus (NEB), adhering to its three core principles: beautiful, sustainable, inclusive [14].

Therefore, the following proposes a sustainable rehabilitation protocol for the façades of residential buildings in historic neighborhoods. This protocol applies a dual methodology: a field study to assess the conservation state of the properties, with the proposal of a form to systematize the data collection of the damages present in the buildings, which is both efficient and user-friendly; and a deductive methodology that, based on the literature and documented examples of previous interventions, provides a comprehensive set of proven solutions for repairing the detected damages. These include both traditional construction techniques and more innovative methods that use new-generation materials, some of which are more natural and sustainable, capable of improving the energy efficiency of the building envelope.

This protocol is applied to a specific case study, the Spanish Quarter of Naples, a perfect example of the outlined issues, setting the guidelines for the sustainable rehabilitation of residential buildings in this picturesque Italian enclave. It can serve as a reference when intervening in other European historic places and sites with similar architectural characteristics.

2. The Spanish Quarter of Naples

The Spanish Quarter, located in the heart of the historic center of Naples, was founded in the mid-16th century as a settlement for the Spanish militia under Don Pedro Álvarez de Toledo y Zúñiga (Figure 1, A). The viceroy, who arrived in the city in 1532 and ruled for 20 years, promoted the transformation of Naples, providing it with a proper urban planning framework [15].

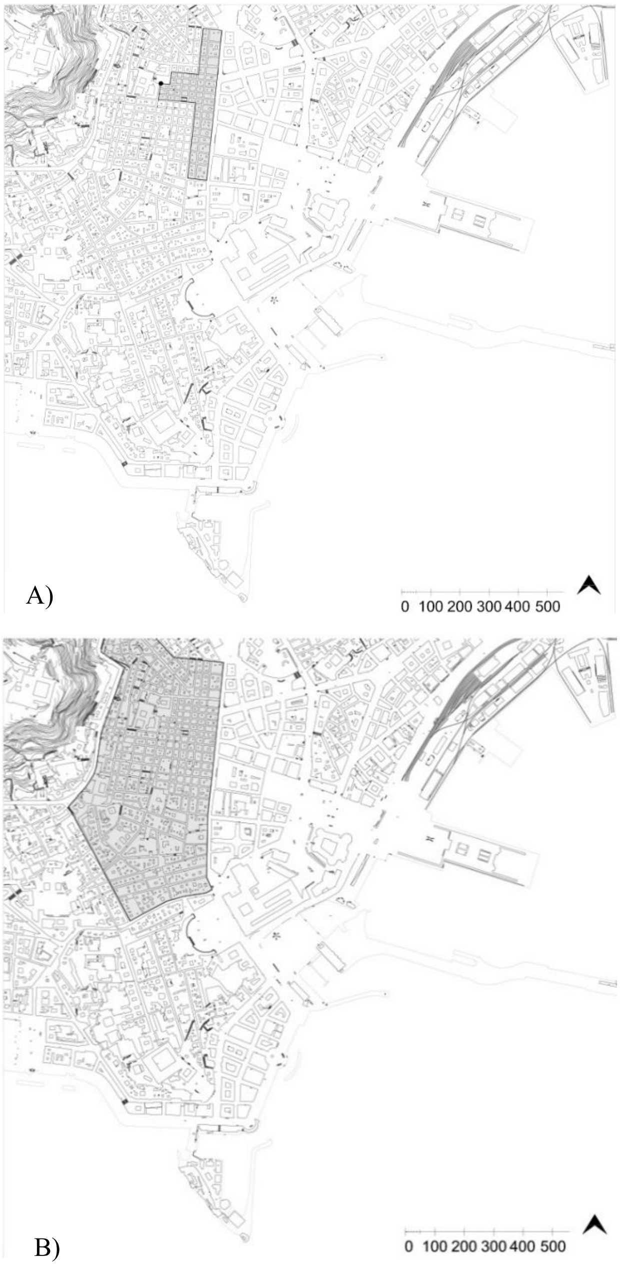

Figure 1. A) Spanish Quarter of Naples; B) Perimeter of the study area

The Quarter, which covers an area of nearly 80 hectares, was originally designed with an orthogonal layout, featuring perpendicular streets that create predominantly square city blocks, each about 20 meters per side (Figure 1, B). These blocks were occupied by two-story buildings, separated by courtyards and gardens, with a well-balanced street section that ensured adequate sunlight and ventilation.

However, almost from the outset, the original buildings began to undergo chaotic and uncontrolled modifications and extensions. New additions occupied the former courtyards and gardens, raising the height of the buildings to five or six stories (Figure 2). This vast new volume altered the balance of the street sections as they originally existed, leading to congestion and physical and environmental degradation of the Quarter (Figure 3).

Figure 2. Height of the buildings in the study area

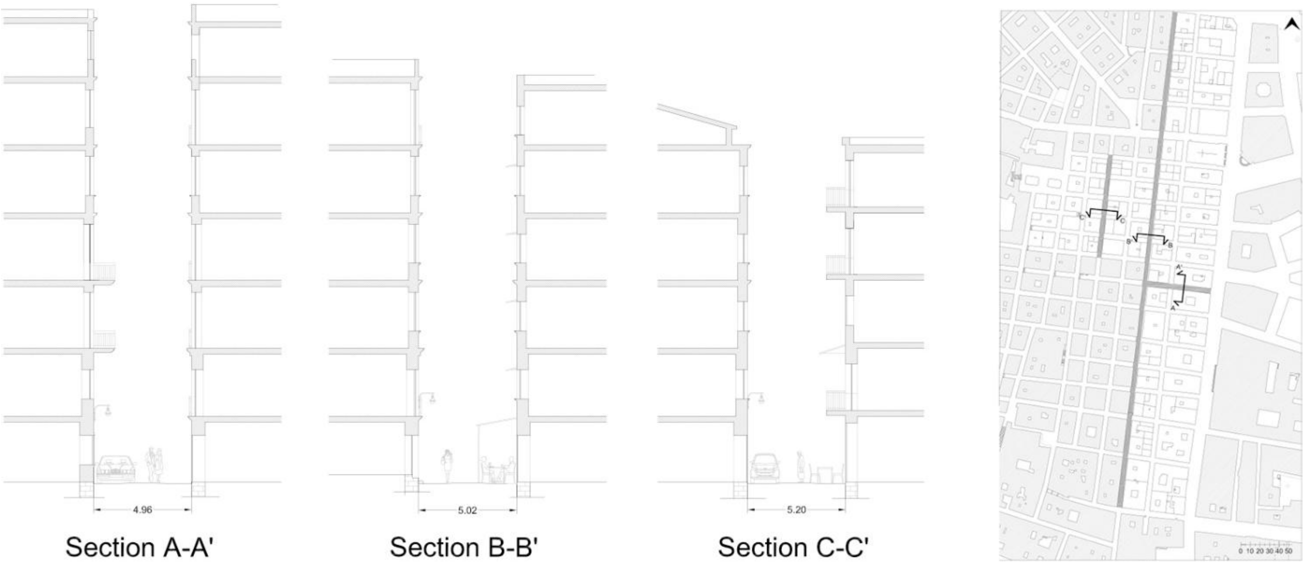

Figure 3. Typical street section: A) Via San Sepolcro; B) Vico Tre Regine; C) Via Speranzella

Material deterioration translated into social decay, with a high percentage of immigrants and low-income residents, further exacerbating the decay of the buildings due to the lack of maintenance resources. Although some buildings have been rehabilitated sporadically, others have even been demolished, resulting in the loss of part of this architectural heritage (Table 1).

Table 1. Residential and demographic indicators (2023)

Indicator*	Montecalvario	Study area
Resident population	23.510	1.451
Residential dwellings**	11.770	727
Unoccupied dwellings	1.669	103
Occupied dwellings ***	10.101	624
Owner-occupied dwellings	~4.939	~305
Rented dwellings	~4.313	~266
Other tenure arrangements	~849	~53

* The Spanish Quarter does not constitute an official statistical unit; data are available only for the administrative district of Montecalvario. Therefore, an area-weighted estimation has been carried out. The data on population, households, and dwellings are drawn from the Municipal Strategic Document of Montecalvario (2023) [16]. Tenure shares (ownership/rental/other) are derived from indicator ND6 – Comune di Napoli [17].
**Residential dwellings are divided into Unoccupied dwellings/ Occupied dwellings.
*** Occupied dwellings are divided into Owner-occupied dwellings/Rented dwellings/Other tenure arrangements.

This situation has intensified the divide between the Quarter and neighboring areas, reducing it to a true urban enclave, both due to the devaluation of its residential function and the level of environmental degradation [18]. This situation is further exacerbated in the case of ground-floor spaces, a considerable number of which also have residential use (Figure 4).

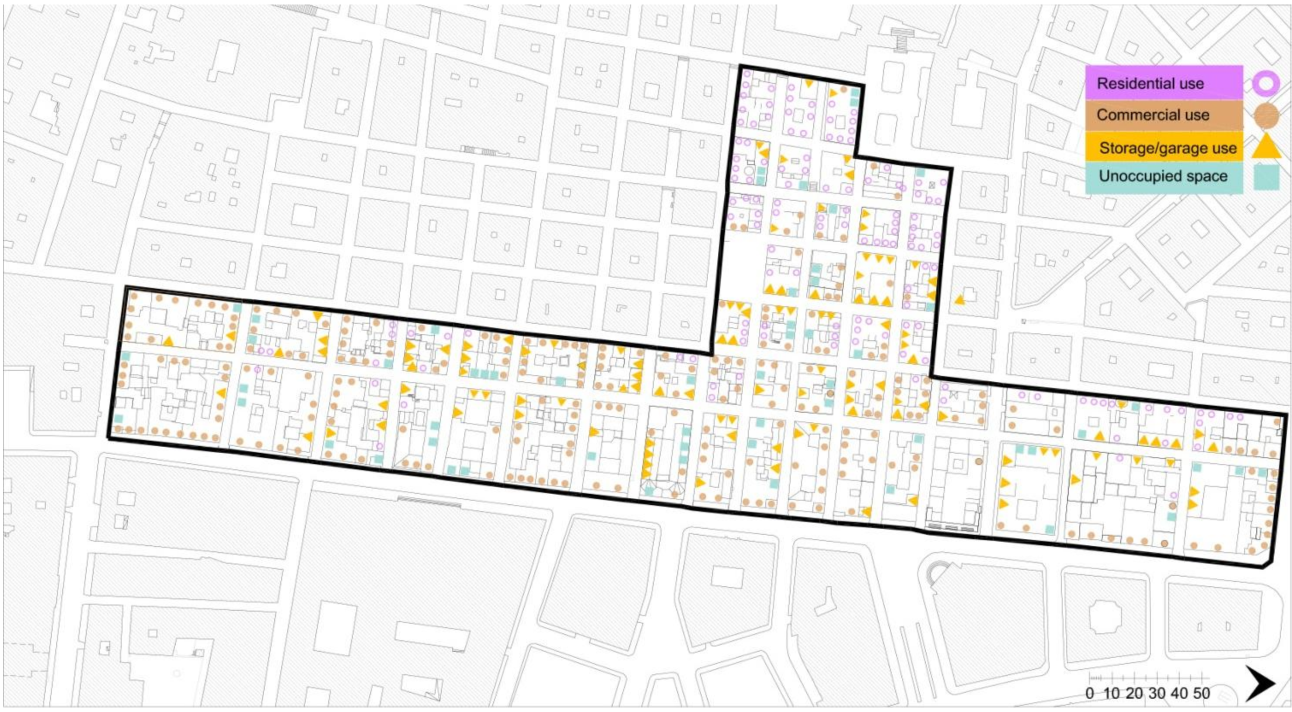

Figure 4. Uses of ground-floor spaces

3. Sustainable rehabilitation protocol for the façades of historic buildings

3.1. Delimitation of the intervention area

The first step to be carried out is the demarcation and identification of the buildings to be studied, in this case, those of the Spanish Quarter of Naples (Figure 1).

Figure 5. Perimeter of the study area of the Spanish Quarter of Naples

As mentioned, the Quarter has a grid layout formed by square city blocks, approximately 20 meters per side, except for those adjacent to Via Toledo, which are twice the size in the direction perpendicular to this perimeter street [19]. The area to be assessed, with a T-shaped plan, is located in the heart of the Quarter, adjacent to its right flank, and is delimited as follows: to the east by Via Toledo; to the west by Via Speranzella, Vico Secondo Montecalvario, and Vico Lungo Montecalvario; to the north by Via Giuseppe Simonelli, Vico Santa Maria delle Grazie a Toledo, and Piazza Montecalvario; and to the south by Via Portacarrese a Montecalvario and Vico d'Afflitto. It includes 16 perpendicular streets and 6 parallel streets to Via Toledo (Figure 5).

It includes a group of 63 buildings, some of which occupy entire city blocks. Although they feature varied compositional schemes and materials, they share characteristics that define and reflect their common historical and architectural past (Figure 6).

Figure 6. Via Toledo, Spanish Quarter of Naples

3.2. Evaluation of the conservation status of the buildings

Next, it is necessary to understand the typological, compositional, constructive, and material characteristics of each of the buildings, as well as their conservation status, which may vary widely given the private residential nature of these properties.

3.2.1. Preparation of a technical form for data collection

It is necessary to systematize the data collection process, so technical forms are prepared that include all the dimensions to be covered by the study:

- The type A form includes the identification data of the property: address, cadastral reference, location plan, general image of the property, general description, construction date, number of floors and their uses, and the number of façades and their orientation, along with images of the façades.
- The type B form includes the compositional description (identifying architectural styles, ornaments, etc.) and the materials of the various building sections.
- The type C form includes the description of the conservation status of the structure, the façade, and the roof.
- The type D form describes the material damages, including: description, location, and illustrative images.
- Finally, the type E form includes records of other types of damage, which may be material or of a different nature, such as the presence of distorting elements, among others.

3.2.2. Fieldwork

The next step is to carry out the fieldwork, during which data will be collected for all the buildings included in the study, recorded in the corresponding technical forms. In this particular case study, a total of 63 forms have been prepared, corresponding to each of the existing buildings in the delimited area of the Spanish Quarter of Naples (Figure 7).

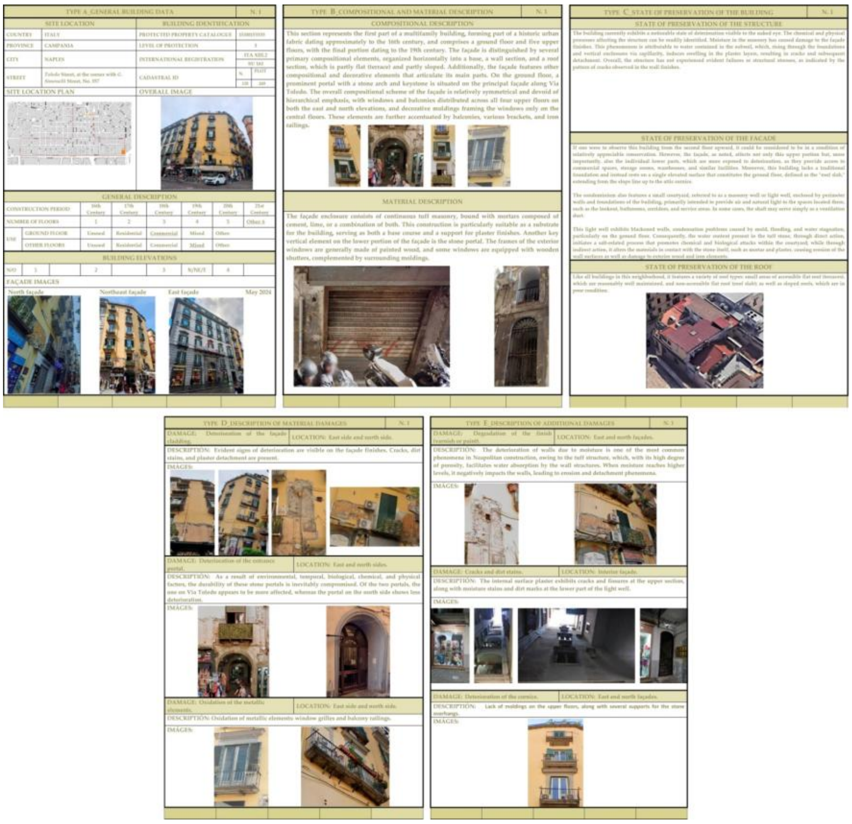

Figure 7. Example of a technical form completed during the study of the Spanish Quarter of Naples (building number 1)

3.2.3. Collection and analysis of the damages present in the buildings

Once the fieldwork has been completed, a thorough analysis of the observed damages is necessary to determine their causes, conduct a diagnosis, and identify potential remedies for their repair and rehabilitation.

First, the existing level of façade deterioration in the neighborhood is mapped onto a district plan for the 56 built blocks comprising the 63 buildings examined in this study. As shown in Figure 8, only 16 blocks— less than 30% of the total—have undergone rehabilitation works in recent years, in many cases more than a decade ago, and they generally exhibit mild to moderate deterioration. Of the remaining 70%, 15 blocks display an uneven conservation condition, having been subject to partial rehabilitation interventions affecting only the façades of some of the buildings within each block, while the rest show an advanced to critical level of deterioration.

Figure 8. Level of façade deterioration in Naples' Spanish Quarter

The highest number of recently rehabilitated vertical enclosures is concentrated along Via Toledo, while the level of deterioration of the vertical building envelopes increases as one moves further into the neighborhood in a westward direction.

After analyzing the data recorded in the 63 completed forms for the buildings of the Spanish Quarter of Naples, it is observed that the damages present in the vertical building envelope are limited to a small range of issues, affecting various construction systems, present in the vast majority of properties that have not undergone recent maintenance or rehabilitation operations.

These damages are compiled in tables that summarise the diagnosis of the identified lesions. The process involves: identifying and coding each instance of damage according to whether it affects a structural (STR), constructive (CT), or ornamental (O) element; describing the pathology; determining its cause; locating the damage within the overall façade system, distinguishing between the plinth, main body, and crowning; determining the extent of impact, specifying whether it occurs as an isolated occurrence, is confined to specific areas, or is generalised; identifying the affected materials among those present in the façades analysed (stonework, renders, and paint layers); and, finally, establishing the urgency of intervention. This is classified as *imminent* (typically within 24–48 hours) when there is a very high risk of collapse or detachment onto the public thoroughfare, or a danger of total or partial structural failure (with evidence of active cracks or fissures); *high* when there is a risk of partial detachment of finishes or other minor elements onto the public thoroughfare (due to inactive cracking, corrosion, or water infiltration); and *medium/low* when the damage is primarily aesthetic or superficial (minor fissures, moisture staining, etc.) (Table 2).

Table 2. Diagnosis of the damages present in the façades of the buildings in the Spanish Quarter of Naples

<table>
<tr><th colspan="7">DAMAGES PRESENT ON THE FACADES OF THE BUILDINGS IN THE SPANISH NEIGHBORHOOD</th></tr>
<tr><td>DAMAGE:
Deterioration of the plinth cladding on the facade</td><td colspan="6">CODIFICATION: CT1</td></tr>
<tr><td colspan="7">DESCRIPTION: Within the first one and a half meters above ground level, the plinths of the buildings display various forms of deterioration, most notably detachments and staining due to capillary moisture, efflorescence, surface soiling, and graffiti.</td></tr>
<tr><td colspan="7">CAUSE: These deteriorations result from the capillary rise of moisture from the ground, facilitated by the porous nature of the facade walls. The precipitation of salts transported during this process gives rise to surface efflorescence. In addition, atmospheric pollution and human intervention contribute to the occurrence of various stains commonly observed on these wall surfaces.</td></tr>
<tr><td>AFFECTED MATERIALS</td><td>Stone</td><td colspan="2">Renders/ Paints</td><td>Wood</td><td>Glass</td><td>Metal</td></tr>
<tr><td>LOCATION WITHIN THE FAÇADE</td><td colspan="2">Plinth</td><td colspan="2">Main body</td><td colspan="2">Crowning</td></tr>
<tr><td>EXTENT OF AFFECTATION</td><td colspan="2">Isolated</td><td colspan="2">Localised</td><td colspan="2">Generalised</td></tr>
<tr><td>URGENCY OF INTERVENTION</td><td colspan="2">Medium/Low</td><td colspan="2">High</td><td colspan="2">Imminent</td></tr>
<tr><td>DAMAGE:
Deterioration of the entrance porticos</td><td colspan="6">CODIFICATION: CT2</td></tr>
<tr><td colspan="7">DESCRIPTION: in most of the neighborhood's buildings, the entrance portals are constructed of natural stone and are affected by moisture retained within the material, which contributes to chromatic alteration, disintegration, erosion, and the accumulation of salts detrimental to the stone. Furthermore, the presence of crusts and stains of varying nature and consistency is a recurrent phenomenon.</td></tr>
<tr><td colspan="7">CAUSE: these deteriorations are primarily due to the capillary rise of moisture from the ground, which becomes retained within the complex internal pore structure of the material, resulting in staining. The decrease in external temperatures during winter leads to an expansion of the retained water, producing a wedge effect that causes cracking, fracture, and localized detachment of the stone elements. Moreover, the dissolution of certain constituents may result in erosion, pitting, or fluting of the stone, while the precipitation of transported salts leads to the formation of surface efflorescence. Finally, atmospheric pollution and human intervention contribute to various stains on these surfaces, similar to those observed on the plinth cladding.</td></tr>
<tr><td>AFFECTED MATERIALS</td><td>Stone</td><td colspan="2">Renders/ Paints</td><td>Wood</td><td>Glass</td><td>Metal</td></tr>
<tr><td>LOCATION WITHIN THE FAÇADE</td><td colspan="2">Plinth</td><td colspan="2">Main body</td><td colspan="2">Crowning</td></tr>
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<tr><td>URGENCY OF INTERVENTION</td><td colspan="2">Medium/Low</td><td colspan="2">High</td><td colspan="2">Imminent</td></tr>
<tr><td>DAMAGE:
Facade cladding degradation</td><td colspan="6">CODIFICATION: CT3</td></tr>
<tr><td colspan="7">DESCRIPTION: the facade claddings of the upper floors display varying degrees of deterioration. Clear evidence of soiling, widespread fissuring, and partial material disintegration is observed, with detachment affecting the different layers, including paint and render, irregularly distributed across the various facade panels.</td></tr>
<tr><td colspan="7">CAUSE: the observed deterioration is mainly due to insufficient maintenance and the non-renewal of the protective coating upon the end of its service life. These damages are further intensified by atmospheric pollution and the erosive impact of meteorological factors.</td></tr>
<tr><td>AFFECTED MATERIALS</td><td>Stone</td><td colspan="2">Renders/ Paints</td><td>Wood</td><td>Glass</td><td>Metal</td></tr>
<tr><td>LOCATION WITHIN THE FAÇADE</td><td colspan="2">Plinth</td><td colspan="2">Main body</td><td colspan="2">Crowning</td></tr>
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<tr><td>URGENCY OF INTERVENTION</td><td colspan="2">Medium/Low</td><td colspan="2">High</td><td colspan="2">Imminent</td></tr>
<tr><td>DAMAGE:
Facade decorative elements degradation</td><td colspan="6">CODIFICATION: O1</td></tr>
<tr><td colspan="7">DESCRIPTION: the majority of facades incorporate decorative elements, such as moldings that define floor slab edges, emphasize openings, or terminate the cornice line, typically crafted in stone. These elements suffer from the same types of deterioration observed in the entrance portals. The upper portions, particularly horizontal planes where rainwater accumulates and debris deposits, are the most affected. This leads to moisture staining, uneven washing of the facade, and colonization by organisms such as mold and lichens, occasionally resulting in partial detachment and</td></tr>
</table>

volumetric loss of the elements due to material degradation and the wedge effect caused by the crystallization of infiltrated water or root growth.					
CAUSE: existence of horizontal planes susceptible to the accumulation of dust, debris, and rainwater, facilitating infiltration and retention within the internal pore structure of the material.					
AFFECTED MATERIALS	**Stone**	Renders/ Paints	Wood	Glass	Metal
LOCATION WITHIN THE FAÇADE	Plinth	**Main body**	Crowning		
EXTENT OF AFFECTATION	Isolated	**Localised**	Generalised		
URGENCY OF INTERVENTION	Medium/Low	**High**	Imminent		
DAMAGE: **Window frame degradation**	**CODIFICATION: CT4**				
DESCRIPTION: the window frames, especially wooden ones, frequently display significant deterioration, with rot observed predominantly in the lower portions in direct contact with the window sill.					
CAUSE: the observed deterioration is primarily due to the exposure of the wood to exterior moisture and insufficient maintenance.					
AFFECTED MATERIALS	Stone	Renders/ Paints	**Wood**	Glass	Metal
LOCATION WITHIN THE FAÇADE	**Plinth**	**Main body**	Crowning		
EXTENT OF AFFECTATION	Isolated	Localised	**Generalised**		
URGENCY OF INTERVENTION	**Medium/Low**	High	Imminent		
DAMAGE: **Window glass defects**	**CODIFICATION: CT5**				
DESCRIPTION: in most cases, the window glass in older units consists of single glazing, which does not meet current insulation standards, leading to substantial energy losses, diminished interior comfort, and higher energy consumption for heating and cooling the spaces.					
CAUSE: the windows consist of single glazing without an air cavity and with a thin profile.					
AFFECTED MATERIALS	Stone	Renders/ Paints	Wood	**Glass**	Metal
LOCATION WITHIN THE FAÇADE	**Plinth**	**Main body**	Crowning		
EXTENT OF AFFECTATION	Isolated	Localised	**Generalised**		
URGENCY OF INTERVENTION	**Medium/Low**	High	Imminent		
DAMAGE: **Degradation of metal components**	**CODIFICATION: CT6**				
DESCRIPTION: the windows and balconies have metal protection elements, such as railings, which are largely affected by widespread oxidation, with specific areas where corrosion exhibits various stages of progression.					
CAUSE: the deterioration results from insufficient maintenance and failure to renew the protective coatings on the metal, leading to exposure to air and water, which in turn causes oxidation and corrosion of the material.					
AFFECTED MATERIALS	Stone	Renders/ Paints	Wood	Glass	**Metal**
LOCATION WITHIN THE FAÇADE	**Plinth**	**Main body**	Crowning		
EXTENT OF AFFECTATION	Isolated	**Localised**	**Generalised**		
URGENCY OF INTERVENTION	**Medium/Low**	**High**	Imminent		
DAMAGE: **Distortions and damage to installations**	**CODIFICATION: O2**				
DESCRIPTION: the buildings are impacted by the proliferation of various electrical and HVAC installations, which detract from the building's aesthetic value. Furthermore, insufficient maintenance has led to some installations experiencing damage, such as breakages, or being overtaken by vegetation growth, particularly in the case of gutters designed to channel water from the rooftops.					
CAUSE: this type of damage is anthropogenic in nature, arising from the absence of adequate spatial planning to house the installations in these historic buildings, compounded by insufficient cleaning and maintenance.					
AFFECTED MATERIALS	Stone	Renders/ Paints	Wood	Glass	Metal
LOCATION WITHIN THE FAÇADE	**Plinth**	**Main body**	Crowning		
EXTENT OF AFFECTATION	Isolated	**Localised**	Generalised		
URGENCY OF INTERVENTION	**Medium/Low**	High	Imminent		

These coded damages were represented in façade elevation damage maps for each of the 63 buildings (Figure 9).

Figure 9. Façade damage map of Building No. 56

3.3. Set of proposed strategies for the sustainable recovery of the vertical building envelope

After identifying the set of damages present in the façades of the buildings studied, the final step is to propose a range of possible strategies for repairing the various issues, addressing the different scenarios detected during the analysis of the data collected in the forms: level of deterioration, extent of the affected area, etc.

These remedial measures aim to rehabilitate the façades of the studied buildings in order to restore the urban image of the neighborhood, meeting the beauty standards established for these historic ensembles [20].

The Building Regulations of Naples restrict interventions on the external envelopes of these historic buildings, including finishes, colors, and architectural and decorative elements. They even limit minimal interventions—such as painting, cladding, and metal elements—requiring consistency between the materials, colors, and formal characteristics selected for rehabilitation and the original ones [21].

The Technical Implementation Regulations (NTA) in Zone A, in turn, regard the façades of these buildings as identity-defining components of the urban fabric and therefore prioritize and steer interventions toward a conservative restoration/rehabilitation of all compositional elements, including openings. They make the acceptance of proposed modifications conditional upon their proper justification and documentation, and require typological coherence and technical documentation according to the category of intervention [22].

The sustainability of the proposed intervention is always a fundamental premise too, both in terms of the choice of materials used, which should be more natural and environmentally friendly, and the durability of the intervention over time. This is in line with the well-known phrase "the most sustainable material is the one that is not used," which underscores the importance of the compatibility of the employed systems with the original materiality of the building as a key factor. Similarly, in addition to ensuring the proper performance of the proposed systems, it is necessary to provide strategies aimed at guaranteeing their protection, establishing an appropriate maintenance plan.

Also, with sustainability in mind, it is necessary to propose strategies for improving the energy efficiency of the vertical building envelope, leading to a reduction in the building's energy demand and an increase in comfort within the interior spaces, thereby improving the quality of life of its inhabitants.

3.3.1. Strategies for the rehabilitation of façade plinths

The façade cladding on the ground floors, at least on the part in contact with the ground, generally has a materiality distinct from the rest of the façade. These claddings are typically affected by humidity due to capillary rise. There are various types of remedial techniques, which can be grouped according to the element they act upon: the wall (Table 3), the ground (Table 4), or non-invasive systems (Table 5).

Table 3. Anti-humidity treatments are applied to the wall

ANTI-HUMIDITY TREATMENTS APPLIED TO THE WALL (AHT-W)	
SOLUTION: AHT-W-1 **Chemical inhibitor barrier**	**SUITABILITY:** this technique is especially effective for brick or stone masonry walls with high porosity [23].
DESCRIPTION: injection of resins or water-repellent solutions into the lower part of the wall, at a minimum height of 15 cm above ground level, to create a waterproof barrier that blocks the capillary rise of water. These products react with the materials composing the masonry, forming a permanent hydrophobic layer.	
SOLUTION: AHT-W-2 **Physical inhibition barrier**	**SUITABILITY:** used in cases where invasive intervention on the walls is feasible [24].
DESCRIPTION: It consists of the insertion of impermeable sheets or membranes at the base of the walls to physically interrupt the upward movement of moisture.	
SOLUTION: AHT-W-3 **Wall consolidation injections**	**SUITABILITY:** interventions particularly suitable for historic and monumental buildings [25].
DESCRIPTION: Solutions based on lime or other environmentally friendly materials are used to consolidate the masonry, reducing its capillary network and, consequently, its capacity to absorb moisture.	
SOLUTION: AHT-W-4 **Damp-proof plasters**	**SUITABILITY:** applicable to any type of wall, particularly recommended for those constructed with lime mortars [26].
DESCRIPTION: application of macroporous plasters, extending at least 50 cm above the height affected by rising damp, which promote moisture evaporation and prevent the formation of efflorescence on the surface. These plasters are typically made of breathable materials, such as hydraulic lime, ensuring adequate vapor permeability and high durability. The finishing paints applied to these plasters must also possess high breathability, such as silicate or silane–siloxane paints (see Table 9).	

Table 4. Anti-humidity treatments are applied to the ground

ANTI-HUMIDITY TREATMENTS APPLIED TO THE GROUND (AHT-G)	
SOLUTION: AHT-G-1 **Active drainage system**	**SUITABILITY:** particularly useful for buildings experiencing moisture problems due to saturated soils or high groundwater levels [27].
DESCRIPTION: drainage systems involving the installation of pipes at the base of the wall, which collect and remove excess water, reducing hydraulic pressure and thereby preventing capillary rise through the enclosure.	
SOLUTION: AHT-G-2 **Ground stabilization injections**	**SUITABILITY:** particularly useful for buildings experiencing moisture problems and foundation failures [28].
DESCRIPTION: a system similar to wall consolidation, but in this case acting on the soil. Lime or resin injections are carried out to reduce the permeability of the ground, thereby hindering the upward movement of moisture toward the wall.	

Table 5. Non-invasive treatments

NON-INVASIVE TREATMENTS (NIT)	
SOLUTION: NIT-1 **Electrophysical moisture removal**	**SUITABILITY:** a system applicable to historic buildings, as it does not involve invasive interventions and preserves the integrity of the existing structures [29].
DESCRIPTION: This technology uses electromagnetic pulses to reverse the flow of water, driving it into the ground and gradually drying the walls.	
SOLUTION: NIT-2 **Biodry system**	**SUITABILITY:** a system suitable for historic buildings, as it does not require invasive interventions and preserves the integrity of existing structures [30].
DESCRIPTION: an innovative and sustainable solution. A device installed without invasive interventions, designed to reverse the capillary flow of water through a physical principle, promoting the drying of walls without energy consumption, radiation emissions, or negative environmental impacts.	

In addition to these remedial treatments, strategies for the recovery of plinths must also include solutions aimed at protecting the construction system to ensure the durability of the intervention over time, while also establishing the maintenance plan to be followed.

In this case, water-repellent products play a crucial role. These are products designed to protect façades from moisture and degradation caused by water infiltration, acid rain, atmospheric agents, and, in urban contexts, exposure to acidic substances such as urine. These treatments create an invisible barrier that prevents water and other aggressive agents from penetrating the surfaces while maintaining the breathability of the materials. They are effective solutions to preserve the integrity and aesthetics of façades, reducing maintenance costs and improving the sustainability of buildings.

These are liquid products applied to the surface with a brush, roller, or spray gun, creating a layer that repels water through a beading effect, preventing it from penetrating the surface. There is a wide range of solutions available on the market, including protectors for water or more aggressive agents such as urine, or highly penetrating products such as graffiti removers (Table 6).

Table 6. Water-repellent products for façade protection

WATER-REPELLENT PRODUCTS (WRP)	
SOLUTION: WRP-1 **Silicone Resin-Based Treatments**	**SUITABILITY:** suitable for most types of supporting bases: concrete, natural stone, brick, etc.
DESCRIPTION: products with high penetration capability, forming a water-repellent barrier without altering the aesthetic appearance of the surfaces [31].	
SOLUTION: WRP-2 **Nanotechnology-based water repellents**	**SUITABILITY:** ideal for absorbent materials such as sandstone, terracotta, and concrete.
DESCRIPTION: They use nanoparticles to create a water- and oil-repellent effect, protecting surfaces from stains, mold, and moisture. They enhance the resistance of surfaces to atmospheric agents [32].	
SOLUTION: WRP-3 **Multifunctional protective membranes**	**SUITABILITY:** particularly suitable for façades exposed to extreme weather conditions [33].
DESCRIPTION: products that combine hydrophobic properties with UV protection and resistance to atmospheric pollutants.	
SOLUTION: WRP-4 **Siloxane Treatment Systems**	**SUITABILITY:** particularly suitable for exposed concrete and natural stone. They ensure long-lasting protection and breathability [34].

DESCRIPTION: These repellents penetrate the capillaries of the materials, reducing water absorption without forming surface films, thereby ensuring the wall's breathability.	
SOLUTION: WRP-5 **Urine-resistant hydrophobic treatments**	**SUITABILITY:** suitable for urban environments with high levels of pedestrian and animal traffic [35].
DESCRIPTION: - Advanced-formulation coatings based on fluoropolymers and polysiloxanes: these materials create a protective layer that repels both polar liquids (water) and non-polar liquids (oil and urine). - Specific nanotechnology treatments: certain nanotechnology-based products, enriched with neutralizing agents, are formulated to resist human and animal urine, providing long-term protection. - Multifunctional oleophobic systems: they combine hydrophobic and oleophobic properties in a single solution, effectively protecting surfaces from both moisture and aggressive agents such as urine.	
SOLUTION: WRP-6 **Anti-graffiti hydrophobic treatments**	**SUITABILITY:** suitable for virtually all façade materials: mortars, stuccoes, stone, and concrete [36].
DESCRIPTION: These are oil-repellent or anti-graffiti impregnations, composed of nano silanes, siloxanes, and fluorinated compounds. They create a protective layer that, without reducing surface permeability, prevents paint from penetrating the façade, facilitating subsequent cleaning of graffiti.	

The tables highlight the compatibility of each product or system according to the building type and the materials of the existing construction systems and materials, which should be taken into account when selecting the most appropriate product. It is also essential that the treatments do not alter the original color of the surface and are resistant to ultraviolet rays and atmospheric agents, in order to prevent deterioration that could compromise the aesthetics of the coatings [37]. Furthermore, it is necessary to assess whether the products included in Tables 2 and 5 (**AHT-W** and **WRP)** should be applied uniformly or only to specific ~~point~~ areas, generally the first 30 cm above the ground level, which is the area most affected by runoff water and rain splashes. In areas affected by human or animal urine, it is recommended to use specific products and extend the application up to a height of approximately 1 meter to adequately protect the surface. In the case of anti-graffiti paint, it is advisable to cover the entire base of the façade, as it may be almost entirely affected.

The maintenance plan for the façade bases will involve replenishing these protective products once their lifespan has expired, which can range from 3 to 10 years, depending on the treatment selected and its quality.

3.3.2. Strategies for the rehabilitation of the blind parts of the upper facades

The upper part of the facades, from the junction with the plinth to the crowning, typically features continuous coatings, primarily lime-based renders, which serve as the protective layer of the vertical envelope, over which a thin coat of paint is applied. The state of conservation of this construction system varies notably among the studied buildings, necessitating different treatments. Recently rehabilitated buildings only require a simple cleaning. The rest suffer varying degrees of degradation, which require the replacement of only the paint layer, in cases where the thick plaster layer remains intact, or the complete replacement of both plaster and paint when the deterioration is more advanced.

Therefore, strategies must be developed for: façade cleaning, using both mechanical (Table 7), physical (Table 8), and chemical (Table 9) techniques, ensuring the integrity of the systems, eliminating any traces of dirt or crust without damaging the healthy material, preserving the natural patina, and avoiding an increase in the surface porosity. These methods should be tested in limited wall areas to verify their effectiveness, safety, and actual needs [38]; substitution of paints, once again considering aspects of durability and sustainability, while improving the performance of the original materials whenever possible, and ensuring compatibility with the substrate (Table 10); substitution of plasters, again taking into account the sustainability and compatibility of the chosen materials with the original ones, while also improving performance, primarily in relation to the energy efficiency of the building envelope (Table 11).

Table 7. Mechanical facade cleaning systems

MECHANICAL FACADE CLEANING SYSTEMS (CS-M)	
SOLUTION: CS-M-1 **Mechanical brushing**	**SUITABILITY:** a technique particularly suitable for historic buildings, as it does not damage the surface.
DESCRIPTION: simple brushing of the surface to remove loosely adhered dirt. Brushes with different types of bristles, natural or synthetic, may be used depending on the hardness of the layer to be removed. Tests should be carried out to determine the most suitable option for each façade.	
SOLUTION: CS-M-2 **Abrasive sandblasting**	**SUITABILITY:** particularly effective for the removal of hard and well-adhered crusts on large exterior surfaces, due to the expansion of the projected material (appropriate protective measures should be adopted for workers to prevent inhalation and skin contact with particles).
DESCRIPTION: high-pressure projection of abrasive particles onto the surface. The distance between the nozzle and the wall, as well as the angle of incidence, should be determined through preliminary tests. Traditionally used materials, such as sand or quartz, can be replaced with other natural or synthetic abrasive agents; in the latter case, industrial by-products can be employed, reducing the environmental impact of the cleaning process while remaining virtually harmless to workers [39]. A variation of this technique is micro-blasting, performed at low pressure, suitable for more vulnerable or delicate areas.	
SOLUTION: CS-M-3 **High-pressure water cleaning**	**SUITABILITY:** effective for removing adhered dirt on large surfaces (carries risks of mineral dissolution, efflorescence formation, or water infiltration into the building).
DESCRIPTION: application of a high-pressure water jet, replacing the abrasive agent used in the previous system. Currently, this type of cleaning is often combined with the use of drones, which facilitate the work, reducing time, costs, and the hazards associated with this technique for operators (working at height) [40].	

Table 8. Physical action facade cleaning systems

PHYSICAL ACTION FACADE CLEANING SYSTEMS (CS-PH)	
SOLUTION: CS-PH-1 **Laser surface cleaning**	**SUITABILITY:** effective for removing dirt or hard, strongly adhered crusts in localized areas. Not suitable for large surfaces.
DESCRIPTION: It uses a pulsed light beam that allows for extremely precise operation on delicate surfaces or those of high historical and artistic value [41]. Tests will be necessary to determine the most effective type of beam, distance, and intensity without damaging the sound surface.	
SOLUTION: CS-PH-2 **Misted water cleaning**	**SUITABILITY:** widely used on vulnerable surfaces to remove loosely adhered dirt (lower likelihood of infiltration risk).
DESCRIPTION: Application of a water mist jet. This method is less aggressive than high-pressure water cleaning, achieving a gentler cleaning effect.	

Table 9. Chemical action facade cleaning systems

CHEMICAL ACTION FACADE CLEANING SYSTEMS (CS-CH)	
SOLUTION: CS-CH-1 **Alkaline cleaners**	**SUITABILITY:** they are suitable for cleaning heavily soiled surfaces, with stains that are difficult to remove, such as grease, resins, and atmospheric pollutants. They are also effective for eliminating organic stains, such as mold.
DESCRIPTION: products with a high pH, above 7, typically ranging from 8 to 14, such as sodium, potassium, or ammonium hydroxide; mixed with liquid or nebulized water in varying concentrations. They are applied in gel or liquid form, either concentrated or diluted, with a waiting period to allow reaction with the stain, leading to its breakdown and facilitating cleaning through subsequent water application. Due to their high pH, these products possess strong degreasing power.	
SOLUTION: CS-CH-2	**SUITABILITY:** highly effective for removing cement

Acidic cleaners	residues, lime deposits, or rust stains. However, care must be taken to prevent contact with surfaces such as concrete, glass, or marble, which can be damaged by these acids.
DESCRIPTION: They are characterized by their low pH, below 7 in this case, such as hydrofluoric or hydrochloric acid, the most common types. They can be applied pure or diluted, using a brush or applicator, left to act for a short period—seconds or minutes—and then rinsed thoroughly with water (the use of gloves and protective goggles by operators is required).	
SOLUTION: CS-CH-3 **Solvents based on organic compounds**	**SUITABILITY:** highly suitable for cleaning non-porous surfaces. However, on stone façades, they may damage the surface, and therefore their use is not recommended.
DESCRIPTION: products used to remove dirt or stains insoluble in water, such as oils and greases, as well as graffiti. Before applying the solvent to the specific area of the stain, the surface should be moistened. After allowing it to act, the product is removed with a spatula or brush, avoiding contact with clean, undamaged surfaces, and subsequently rinsed with water (operator protection is required due to potential toxicity).	
SOLUTION: CS-CH-4 **Biocidal agents and enzymatic cleaning solutions**	**SUITABILITY:** biocides are effective for the removal of mold, lichens, and algae. Enzymatic cleaners, effective for the removal of other organic stains.
DESCRIPTION: The former are chemical products, and the latter are natural proteins, which cause the decomposition of organic matter. Enzymatic cleaners are more environmentally friendly. They are applied to the stain and left to act, after which both the product and the decomposed organic material are removed by brushing the surface.	
SOLUTION: CS-CH-5 **Latex**	**SUITABILITY:** effective for soot stains and other contaminants and encrustations, and suitable for application on a wide variety of materials commonly found on façades, such as brick, concrete, stone, etc.
DESCRIPTION: These are products formulated based on latex. They are applied to the surface either diluted or pure, after pre-wetting it, and left to polymerize for typically 5 to 10 minutes, during which an elastic film forms that adheres to the dirt. The film is then removed manually or with a brush, carrying the dirt with it, followed by rinsing with water.	

Table 10. Replacement of paints

HIGH-PERFORMANCE PAINTS (P)	
SOLUTION: P-1 **Mineral silicate paints**	**SUITABILITY:** suitable for interventions on historic façades, being compatible with mineral and lime-based substrates (commonly found in masonry and architectural heritage structures) [42].
DESCRIPTION: mineral products based on potassium silicate, which do not form an impermeable film but penetrate the substrate, chemically reacting with it (silicification), making them especially durable and breathable. In addition, they exhibit high resistance to atmospheric agents and UV radiation.	
SOLUTION: P-2 **Silane-siloxane-based coatings**	**SUITABILITY:** They are suitable for use in architectural heritage, similar to silicate paints. The choice between the two types will depend on factors such as building exposure, urban microclimate, the nature of the existing substrate, and the aesthetic or conservation requirements of the project.
DESCRIPTION: paints that combine breathability with increased water repellency due to the presence of organic resins. They provide effective protection against rainwater, creating a self-cleaning effect, while allowing water vapor to diffuse, reducing the risk of film detachment or flaking and ensuring strong adhesion to the substrate. Additionally, they exhibit high resistance to UV radiation and weathering.	
SOLUTION: P-3 **High solar reflectance coatings (HSR)**	**SUITABILITY:** suitable for historic or protected buildings, as they do not alter the compositional or aesthetic characteristics of the building envelope. Particularly recommended in urban contexts affected by the "heat island" effect, as they can reduce façade surface temperatures by up to 10–15°C [43].
DESCRIPTION: These are paints that combine reflective pigments and specific binders to maximize solar reflectance and thermal emissivity, capable of reflecting a large portion of the solar radiation incident on the façade surface. This limits heat accumulation in the underlying construction materials and helps reduce the building's energy	

consumption for cooling interior spaces during the warm season.	
SOLUTION: P-4 **Solar paints**	**SUITABILITY:** they integrate seamlessly into the aesthetic of the architectural context, offering a wide range of colors and finishes, making them ideal for the restoration of buildings in historic city centers.
DESCRIPTION: These are paints capable of producing hydrogen fuel, one of the cleanest energy sources available today, from solar energy and atmospheric moisture. They are composed of a combination of titanium oxide nanoparticles and a synthetic variant of molybdenum disulfide, which captures water vapor from the air and condenses it, promoting the decomposition of oxygen and hydrogen molecules. The hydrogen is then collected in electrochemical cells or engines for subsequent use [44].	
SOLUTION: P-5 **Photocatalytic self-cleaning coatings**	**SUITABILITY:** compatible with existing construction systems, both in modern and historic buildings. Particularly recommended for urban contexts affected by high levels of atmospheric pollution [45] [46].
DESCRIPTION: Their technology is based on the use of photocatalysis. This chemical process involves titanium dioxide (TiO_2) nanoparticles, activated by light—either solar or artificial—which react to decompose contaminants present on the façade surface, such as fine dust, smog, bacteria, mold, and volatile compounds. At the same time, these paints create superhydrophilic or hydrophobic surfaces that repel water, facilitating the natural cleaning of the façade with rainwater, which carries away dirt and contaminants as it flows downward.	

Table 11. Replacement of renders

ECO-FRIENDLY RENDERS (R)	
SOLUTION: R-1 **Lime and lime mortar-based renders**	**SUITABILITY:** a technique particularly suitable for historic buildings due to the compatibility of lime with the underlying substrate materials [47].
DESCRIPTION: coatings based on natural lime or "bastard" lime-cement mixtures, offering good compatibility with the original substrates while ensuring breathability, resistance to atmospheric agents, and aesthetic integration with the existing architectural context.	
SOLUTION: R-2 **Eco- renders**	**SUITABILITY:** suitable for both new constructions and rehabilitation interventions in historic contexts, where material compatibility is essential.
DESCRIPTION: a next-generation material distinguished by its eco-friendly composition and low environmental impact production cycle, achieved through the reuse of agro-industrial waste and discarded construction materials, such as eggshells, rice husk ash, natural lime, and *cocciopesto* (Roman mortar made from lime and ceramic tile or brick fragments). Its technical and ecological properties offer notable advantages, including the reduction of condensation formation, improvement of indoor air quality due to high breathability, and contribution to CO_2 emission reduction both during production and throughout the building's service life, thanks to its ability to absorb carbon dioxide (carbonation) [48].	
SOLUTION: R-3 **Thermal insulating renders**	**SUITABILITY:** suitable for interventions in historical contexts, as it is compatible with mineral substrates and traditional construction systems, without altering their physical and chemical characteristics.
DESCRIPTION: an innovative and sustainable solution that incorporates cork particles into the plaster. It represents an alternative to traditional lime mortars, being ecologically sustainable and capable of providing high technical performance without compromising the environment. The mixture consists of cork granules bound with natural or low-environmental-impact resins. It is applied through projection, creating a continuous layer with high breathability and excellent insulating properties, thanks to its low thermal conductivity, which helps limit heat loss and improves the overall energy efficiency of the building envelope. It also offers advantages in terms of acoustic comfort, resistance to atmospheric agents, and long-term durability [49].	

Once the possible therapeutic interventions based on the conservation status of each facade have been outlined, recommendations for their protection and maintenance must be provided. All continuous coating layers applied to the exterior substrate contribute to the protection of the construction system, thereby ensuring its durability. Paint, which constitutes the outermost protective layer and is in direct contact with atmospheric agents, plays a highly significant role in this context.

As with water repellents, there are various types of paints and different qualities within each category, which result in varying service lives, typically ranging from 5 to 10 years, with common intervals being 5, 7, or 10 years. It will be necessary to establish a replacement plan for the system that does not exceed the period specified in the product's technical data sheet.

Regarding the improvement of thermal performance for the blind sections of the building envelope, when addressing architectural heritage, solutions must consider the degree of protection afforded to the facades, which generally dictates that the aesthetic appearance and composition remain unchanged. We have seen that thermal renders, solar paints, and reflective coatings are options to enhance the insulation of the vertical envelope and/or generate energy; however, the thin thickness of these layers and the lack of continuity in the insulation mean they are unable to meet the current standards. The energy rehabilitation of facades in historic buildings typically requires modifications to the original enclosure system, which may be carried out either from the exterior or interior (Tables 12 and 13), while always respecting the original urban image of the building [50].

Table 12. External thermal insulation systems

EXTERNAL THERMAL INSULATION SYSTEMS	
SOLUTION: **External thermal insulation composite system (ETICS)**	**SUITABILITY:** it is necessary to analyze its feasibility, considering the type of finish of the original façade and how the change in thickness affects the existing compositional elements (window ornaments, cornices, etc.).
DESCRIPTION: These are insulation systems composed of EPS, EPS-G, XPS, rock wool, or natural cork panels (the choice will depend on acoustic as well as thermal insulation needs, and the type of finish coating, with natural materials being recommended for sustainability purposes). They are adhered to the substrate, the original façade, using adhesive systems and mechanical anchors. On top of this system, finishes are applied: plaster reinforced with fiberglass meshes (suitable for all types of insulation boards) or ceramic tiles, both small-sized and large formats (using XPS boards), in accordance with the original material of the façade. These systems are characterised by the elimination of thermal bridges. Nevertheless, where there is a need to preserve the materiality of certain decorative elements—found mainly at slab edges and around window openings (precisely the locations where thermal bridges most commonly occur)—the system may not be able to achieve their complete elimination.	

Table 13. Internal thermal insulation systems

INTERNAL THERMAL INSULATION SYSTEMS	
SOLUTION: **Internal insulation systems**	**SUITABILITY:** feasible in all cases as they do not affect the external appearance of the façade.
DESCRIPTION: The solution involves the application of lightweight, self-supporting inner linings filled with thermal insulation, typically rock wool. It preserves the integrity of the external appearance of the façade, but results in a loss of usable space inside the dwellings and does not eliminate thermal bridges at the slab fronts.	

A comprehensive assessment of the energy performance of each building in question should be carried out in order to determine the most suitable system in each case, taking into account the suitability criteria specified in Tables 12 and 13. This assessment should also define the appropriate thicknesses and areal weights (grammages) of the thermal insulation materials to be used, so as to ensure optimal thermal comfort and energy efficiency in accordance with the local climate conditions.

3.3.3. Strategies for the rehabilitation of decorative stone elements

The majority of the facades studied contain stone elements that are part of the compositional system, including imposts, cornices, corners, access portals, and window frames. A significant number of these elements exhibit varying degrees of damage, which necessitate the application of different strategies for their restoration. In some cases, simply cleaning the surface is sufficient, using some of the techniques outlined previously (Tables 6, 7, and 8), depending on the composition of the stain and its hardness and adhesion to the surface. However, in other cases, where advanced degradation is present, material consolidation or even the reintegration of missing volumes will be required. As indicated in Table 2, the urgency of repairing this damage depends on the risk associated with the falling of fragments onto the public thoroughfare, primarily from the building's main body. In the case of entrance portals and ground-floor windows, the level of urgency is medium/low, whereas for the imposts and window surrounds on the upper storeys, as well as the building's crowning cornice, the level of urgency is high.

The consolidation of stone elements must be carried out with compatible materials that allow for the restoration of structural cohesion without altering their primary characteristics, which should be determined beforehand through the petrographic characterisation of each specific stone material. There are numerous products on the market suitable for this purpose [51] (Table 14).

Table 14. Internal thermal insulation systems

CONSOLIDANTS FOR STONE MATERIALS	
SOLUTION: **Mineral-based consolidants**	**SUITABILITY:** they are quite stable and have good durability, but they have a low penetration capacity, and the consolidation process is slow.
DESCRIPTION: Some of the most common include lime water, which forms calcium carbonate through the reaction of calcium hydroxide with atmospheric CO2; silicates, which generate silica; and carbonates, which form calcite crystals, among others. These substances penetrate the pores and deposit these elements within them.	
SOLUTION: **Synthetic and natural organic polymers**	**SUITABILITY:** rarely used because they may promote the growth of microorganisms.
DESCRIPTION: They are deposited on the surface as the solvent evaporates, cementing the particles of the material.	
SOLUTION: **Organosiliconic materials**	**SUITABILITY:** consolidation similar to that achieved with inorganic products, but with a greater penetration capacity.
DESCRIPTION: silanes and siloxanes, which generate a component similar to silica.	
SOLUTION: **Bacterial consolidation**	**SUITABILITY:** highly sustainable.
DESCRIPTION: natural consolidation based on activating the bacteria present in stone materials, generating calcite.	
SOLUTION: **Nano consolidants**	**SUITABILITY:** highly sustainable.
DESCRIPTION: Consolidants based on nanophase calcium hydroxide dispersed in isopropyl alcohol, which transforms into calcium carbonate through a reaction with atmospheric carbon dioxide.	

These products must be previously studied on material samples in the laboratory to determine their effectiveness and suitability. The degree of consolidation achieved by each product will be verified through observation using a scanning electron microscope (SEM), by means of a comparative study with the untreated stone sample. Likewise, attention will be paid to the possible formation of a film by the product, which could modify some of the stone's principal properties in relation to its placement on the façade, such as water absorption capacity and, furthermore, its water-vapour permeability (breathability).

To complete the study, additional tests will be conducted to assess water absorption capacity, at atmospheric pressure (UNE-EN 13755:2008) and by capillarity (UNE-EN 1925:1999), water-vapour permeability (UNE-EN 15803:2010), and resistance to salts (UNE-EN 12370:2020), as well as colorimetric measurements to examine any potential alteration of the stone's natural colour (UNE-EN 15886:2011).

In cases where the reintegration of missing ornamental pieces or parts is necessary, prostheses can be created through anastylosis, reproducing the original volumes and ornaments. This ensures respect for the architectural style without resorting to historical falsifications, distinguishing the new elements from the original ones while preserving the material's natural patina or using mason's marks [52]. The reintegration of the added stone material is typically carried out using fiberglass, carbon, or stainless steel rods, bonded with epoxy resins. If the material loss is not significant, the volume can be restored with restoration mortars that include inorganic pigments, allowing for the imitation of the original stone color [53].

Finally, it is necessary to apply protection systems that ensure the durability of the intervention over time. These products are typically water repellents (Table 5). As is established for the baseboards of the facade, the surfaces to be covered must be properly studied, always aiming to avoid compromising the breathability of the stone in order to prevent the reappearance of degradation phenomena linked to moisture and environmental pollution [54]. In general, they will be applied to areas susceptible to water accumulation, such as horizontal projections: the upper faces of cornices, imposts, and door and window frames, as well as elements in contact with the ground level, due to the potential exposure to rainwater and runoff, extending up to a height of between 15 and 30 cm.

3.3.4. Strategies for the rehabilitation of windows

Windows represent one of the most critical elements of a building's envelope in terms of energy loss. Therefore, they are an element that requires special attention when discussing the sustainable rehabilitation of historic buildings. Heat or cooling losses can depend both on the quality of the glazing and the airtightness of the frame. The overall performance of the window frame is expressed through the thermal transmittance of the glass (Ug), the frame (Uf), and the air permeability [55].

In many cases, when the degradation of the materials comprising the joinery is significant (mainly in the case of wooden joinery), combined with the deficiencies of the glazing, often consisting of a single thin sheet of glass, the strategy will be to replace the windows with new systems—whether conventional or high-performance systems—that allow for improvements not only in thermal insulation but also in the building's energy autonomy (Table 15).

Table 15. Replacement with new window systems

<table>
<tr><th colspan="2">HIGH-EFFICIENCY WINDOWS</th></tr>
<tr><td>SOLUTION:
Wooden, PVC, or recycled aluminum windows with a thermal break and double or triple glazing</td><td>SUITABILITY: The material of the frame most consistent with the original will be chosen in each case.</td></tr>
<tr><td colspan="2">DESCRIPTION: These are windows with highly insulating frames and double or triple glazing, which, when combined with high-performance seals, achieve the desired standards.</td></tr>
<tr><td>SOLUTION:
Perovskite photovoltaic glass</td><td>SUITABILITY: tested in residential environments, yielding promising results [56].</td></tr>
<tr><td colspan="2">DESCRIPTION: state-of-the-art solution involving the use of photovoltaic glass based on perovskite cells. These innovative materials, capable of converting sunlight into electrical energy even under diffuse light conditions, offer a dual function: shading and energy production. They exhibit good performance in terms of efficiency and transparency.</td></tr>
<tr><td>SOLUTION:
Silicon solar cells</td><td>SUITABILITY: suitable for façades with high solar exposure.</td></tr>
<tr><td colspan="2">DESCRIPTION: technologically more advanced than perovskites, but they achieve optimal performance only in the presence of direct radiation and offer lower transparency [57].</td></tr>
<tr><td>SOLUTION:
Photovoltaic windows with kesterite-based energy storage</td><td>SUITABILITY: suitable for urban contexts with limited available surfaces for photovoltaic installation [58].</td></tr>
<tr><td colspan="2">DESCRIPTION: These solutions integrate storage systems, making them autonomous.</td></tr>
</table>

However, in other cases, the window frames are in good condition, but they still present deficiencies in terms of their energy performance due to the poor insulation of the glazing. The glass surfaces can be responsible for up to 25-30% of the total energy losses in a building [59]. Therefore, we can opt for more conservative solutions that improve performance by simply acting on the existing elements (Table 16), without proceeding to a complete replacement of the component.

Table 16. Systems for improving the thermal efficiency of existing glazing

SYSTEMS FOR IMPROVING THE THERMAL EFFICIENCY OF EXISTING GLAZING	
SOLUTION: **Solar films**	**SUITABILITY:** solution suitable for existing windows with insulation deficiencies due to the glass.
DESCRIPTION: These films block a significant percentage of solar radiation (especially infrared rays), reducing the internal greenhouse effect and helping to manage cooling loads. The films can reduce thermal absorption by up to 79%, while maintaining high transparency (up to 85%) and ensuring visual comfort. A sustainable solution that can prevent the need for replacing existing materials [60].	

3.3.5. Strategies for the restoration of metal elements

The restoration and conservation of metallic elements—particularly wrought iron or cast iron railings and balconies—constitute a fundamental intervention for the protection of architectural heritage, especially in urban contexts such as the Spanish Quarter, where these components form an integral part of the aesthetic and compositional identity of the buildings. As revealed by the field study conducted, these elements are affected by varying degrees of deterioration: incipient corrosion, characterized by a thin and discontinuous oxide layer; moderate corrosion, with a uniform and continuous oxide layer but without significant loss of cross-section; advanced corrosion, exhibiting evident scaling and an appreciable loss of cross-section; pitting attack, with severe cross-sectional loss at localized points; or critical corrosion, with very substantial cross-sectional losses leading to mechanical failure of the element. Therefore, it is necessary to implement curative treatments that completely remove rust from the surfaces through thorough cleaning (Table 17), followed by the replacement of missing components (Table 18), the protection of the entire assembly (Table 19), and the establishment of a maintenance plan to ensure the long-term durability of the intervention.

Table 17. Cleaning systems for metallic surfaces

CLEANING SYSTEMS FOR METALLIC SURFACES	
SOLUTION: **Mechanical systems**	**SUITABILITY:** suitable for oxidized and/or corrosion-affected surfaces.
DESCRIPTION: suitable for oxidized and/or corrosion-affected surfaces.	
SOLUTION: **Physical systems**	**SUITABILITY:** suitable for delicate areas and areas with ornaments.
DESCRIPTION: laser technology, which allows for selective and non-invasive use.	
SOLUTION: **Chemical systems**	**SUITABILITY:** suitable for oxidized and/or corrosion-affected surfaces. In particularly delicate areas or in the presence of decorative elements, it is preferable to use stripping gels.
DESCRIPTION: application of rust converters based on tannates or phosphates, which transform ferrous materials into stable and inert compost, or stripping gels.	

Table 18. Restoration of metallic elements

REINSTATEMENT OF MISSING ELEMENTS	
SOLUTION: **Substitution**	**SUITABILITY:** when corrosion has significantly reduced the section of any element.
DESCRIPTION: Reconstruction of missing parts using welding techniques compatible with the original material.	

SOLUTION: **Selective substitution**	**SUITABILITY:** When it is necessary to replace a small part of an element.
DESCRIPTION: selective replacement with new sections, respecting the original construction techniques.	

Table 19. Protective treatments for metallic elements

PROTECTIVE TREATMENTS FOR METALLIC ELEMENTS	
SOLUTION: **Anticorrosive primer**	**SUITABILITY:** applicable to any metallic surface.
DESCRIPTION: There is a wide variety of products, ranging from versatile synthetic primers suitable for any metallic surface to those specifically designed for iron, steel, etc. In any case, a smooth and uniform layer will be applied over the entire surface to prevent oxidation.	
SOLUTION: **Synthetic enamels**	**SUITABILITY:** applicable to any metallic surface.
DESCRIPTION: A thin layer is applied to the surface, without the need for prior priming, capable of protecting the metal from all types of weathering factors.	
SOLUTION: **Paints**	**SUITABILITY:** applicable to any metallic surface.
DESCRIPTION: These are specialized paints for metallic surfaces, which typically include antioxidant protection. However, it is also common to apply them over a prior anti-corrosive primer.	

Finally, it is necessary to establish a maintenance plan, which involves determining the frequency of reapplication of protective products. This frequency will vary depending on the type of protective coating, the aggressiveness of the environment, and the method of application [61]. Nevertheless, in the case of paints, their service life is comparable to that described for façade coatings.

3.3.6. Strategies for the removal of distorting elements

In addition to repairing the damage present in all the aforementioned construction elements, the rehabilitation of the urban image requires the removal of all components that distort the compositional system of historic façades. All these elements must be documented in the planimetric survey of façade damage in order to locate them within each of the buildings studied and, subsequently, to implement the appropriate measures for their removal and relocation.

Figure 10. Poorly integrated installations within the compositional design of the façade

These mainly include air-conditioning units, which are often installed haphazardly—either on balconies or suspended from anchors fixed to the blind sections of façades. All such devices should be removed and relocated to designated areas on the rooftops. Wiring should be routed through interior courtyards in an orderly manner and under the agreement of the homeowners' associations.

Furthermore, numerous sanitation installations—primarily rainwater drainage systems—display irregular layouts that significantly diverge from the architectural lines of the façades, resulting in a highly undesirable visual impact on the building's urban appearance. A similar issue is observed with electrical wiring, which predominantly affects the upper sections of the façades' plinths (Figure 10).

It is necessary to rectify the layouts of these installations by relocating the former preferably to the sides of the building, thereby minimizing their visual impact. In the case of electrical wiring, conduits should be properly anchored to the façade at the junction between the plinth and the first floor, housing all cables and harmonizing with the aesthetic of the façade through the selected color palette.

Finally, the municipality or homeowners' associations should prohibit the use of exterior balcony clotheslines to prevent the visually disruptive effect of laundry hanging over the public streets in the narrow lanes typical of historic neighborhoods (Figure 11). At the same time, communal clothes-drying areas should be established on the rooftops.

Figure 11. Overhanging clotheslines distort the compositional image of the façades and enhance the perception of narrowness in the streetscape

4. Conclusions

The historic city centers of Europe, many of which have been declared World Heritage Cities by UNESCO, encompass not only public and religious monuments but also a large number of private residential buildings that form part of the valuable architectural heritage that must be preserved for future generations, as they reflect the history, culture, and construction traditions of each country. Unfortunately, the private nature of these buildings often leads to advanced states of deterioration, primarily due to a lack of maintenance by homeowners' associations. This situation compromises habitability and, consequently, results in the progressive abandonment of neighborhoods by residents, which further exacerbates the deterioration. In many cases, these areas become veritable ghettos, housing a large number of residents from other countries alongside local populations with limited resources. Additionally, the improper use of these buildings and public spaces creates further problems, such as the encroachment of streets by vehicles, installations, and clotheslines projecting from facades, all of which degrade the urban image, increase the perceived narrowness of streets, and encourage illegal activities that worsen the state of decay.

It is therefore essential to implement measures aimed at the sustainable urban rehabilitation of these historic centers, restoring their urban dignity, revitalizing the area, and encouraging the arrival of young populations that will ensure the future and continuity of these highly valuable heritage sites. The framework for such interventions should be the European New Bauhaus, adhering to its three fundamental principles: sustainability, beauty, and inclusion, while avoiding recovery processes driven primarily by economic interests that may lead to the feared phenomenon of gentrification. The creation of protocols establishing common premises for interventions in each building ensures a harmonious environment, restoring the beauty and quality of life that both residents and visitors deserve.

The restoration of building facades is among the first actions to be undertaken. The vertical envelope serves both as the public image of the buildings, affecting the entire population beyond just residents, and as the primary structural system that ensures indoor comfort, particularly in terms of thermal conditioning, impacting all levels of the building. The roof, on the other hand, primarily affects only the residents of the uppermost floor. Therefore, facade rehabilitation translates into benefits enjoyed by virtually all inhabitants of the city.

The shared historical origins of these buildings, rooted in specific periods during which these neighborhoods were developed, confer both compositional and material characteristics that are largely common. In most cases, despite differences, they share construction systems that, in turn, exhibit similar types of damage or defects, which may vary in extent or severity depending on factors such as maintenance or previous repair interventions. Consequently, it is relatively straightforward to identify and categorize the typology of pathologies that the project designer must address in each intervention.

Systematizing interventions in the buildings of a given neighborhood can yield numerous benefits, including the reduction of intervention times—both in data collection and in the diagnosis of building conditions—and the uniformity of results, achieving a coherent, restored image of the neighborhood that ensures durability and sustainability.

The protocol proposed in this research provides a custom-designed data collection form focused on identifying the building and evaluating its state of conservation. It allows the collection of general data and specific information about damages, including their location, extent, and illustrative images. These forms proved highly useful during fieldwork in the study of buildings within the selected area of the Spanish Quarter of Naples. They streamlined the process and enabled the compilation of an extensive archive, which subsequently facilitated a comparative analysis that identified common damages in each of the construction systems present in the facades. It was concluded that the pathologies could be reduced to eight types of lesions requiring intervention.

Currently, there is a substantial body of interventions carried out across Europe, many of which are documented in scientific literature. This allows for an understanding of the effectiveness of both traditional and modern materials, as well as a comparison of their advantages and disadvantages in the various situations typically encountered in architectural heritage restoration. A comprehensive bibliographic study has compiled a set of potential therapeutic interventions for the restoration of historic residential facades, with the primary objectives of sustainability, compatibility with original materials (thus ensuring the durability of interventions), and improvement of residents' quality of life. In line with this latter objective, solutions not only aim to restore the original condition of facades but also to enhance certain performance aspects, particularly regarding the efficiency of the building envelope, improving insulation and thereby reducing energy consumption, in accordance with several key Sustainable Development Goals (SDGs).

This collection of proven solutions provides practitioners with a set of starting proposals from which to select the most appropriate intervention for the specific circumstances of each case. This ensures consistent results that safeguard the urban and architectural identity, defining the Spanish Quarter of Naples.

However, the protocol should not be limited to curative interventions alone; it is also necessary to establish maintenance plans to ensure the longevity of the results, which should be provided to the property owners.

The research conducted in the Spanish Quarter of Naples establishes a framework that can be replicated in other European historic centers with similar characteristics, potentially serving as a reference protocol for the sustainable rehabilitation of residential architectural heritage.

Declaration of competing interest

The authors declare that they have no known financial or non-financial competing interests in any material discussed in this paper.

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