

Article

Seismic Vulnerability Assessment and Sustainable Retrofit of Masonry Factories: A Case Study of Industrial Archeology in Naples

Giovanna Longobardi * and Antonio Formisano 

Department of Structures for Engineering and Architecture, School of Polytechnic and Basic Sciences, University of Naples "Federico II", Piazzale Tecchio 80, 80125 Naples, Italy; antoform@unina.it

* Correspondence: giovanna.longobardi@unina.it

Abstract

Masonry industrial buildings, common in the 19th and 20th centuries, represent a significant architectural typology. These structures are crucial to the study of industrial archeology, which focuses on preserving and revitalizing historical industrial heritage. Often left neglected and deteriorating, they hold great potential for adaptive reuse, transforming into vibrant cultural, commercial, or residential spaces through well-planned restoration and consolidation efforts. This paper explores a case study of such industrial architecture: a decommissioned factory near Naples. The complex consists of multiple structures with vertical supports made of yellow tuff stone and roofs framed by wooden trusses. To improve the building's seismic resilience, a comprehensive analysis was conducted, encompassing its historical, geometric, and structural characteristics. Using advanced computer software, the factory was modelled with a macro-element approach, allowing for a detailed assessment of its seismic vulnerability. This approach facilitated both a global analysis of the building's overall behaviour and the identification of potential local collapse mechanisms. Non-linear analyses revealed a critical lack of seismic safety, particularly in the Y direction, with significant out-of-plane collapse risk due to weak connections among walls. Based on these findings, a restoration and consolidation plan was developed to enhance the structural integrity of the building and to ensure its long-term safety and functionality. This plan incorporated metal tie rods, masonry strengthening through injections, and roof reconstruction. The proposed interventions not only address immediate seismic risks but also contribute to the broader goal of preserving this industrial architectural heritage. This study introduces a novel multidisciplinary methodology—integrating seismic analysis, traditional retrofit techniques, and sustainable reuse—specifically tailored to the rarely addressed typology of masonry industrial structures. By transforming the factory into a functional urban space, the project presents a replicable model for preserving industrial heritage within contemporary cityscapes.

Keywords: masonry buildings; industrial archeology; seismic vulnerability assessment; local collapse mechanisms; retrofit interventions



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1. Introduction

Masonry is undoubtedly one of the oldest and most widely used construction materials throughout history. It was employed not only for residential buildings—often clustered together in historical centres across Italy and other parts of Europe [1]—but also for industrial structures constructed in the 19th century, prior to the widespread use of alternative

materials [2]. A significant portion of this industrial heritage consists of reinforced concrete (RC), precast RC, and steel moment-resisting frames, which are commonly analyzed in the research field [3,4].

Recent seismic events in Mediterranean countries, such as the Emilia-Romagna earthquake in Italy (2012), the Central Italy earthquake (2016), Turkey (2023), and Morocco (2023), have highlighted the vulnerability of historical structures, including industrial buildings. Like many masonry residential structures, these industrial constructions often fail to withstand seismic forces for several reasons. A common issue is the absence of “box behaviour,” which ensures greater resistance by connecting adjacent masonry panels and horizontal slabs, and by avoiding roof thrust on the masonry. Additionally, these buildings were constructed without seismic considerations, using materials with poor mechanical properties, as they predate modern seismic codes [5–8].

Among industrial structures, a moderate percentage was originally designed to carry only gravitational loads, with many featuring load-bearing masonry. A significant number of these buildings, especially from the early 1930s, had mixed structures combining masonry and reinforced concrete, while steel structures became more common by the 1980s [9].

In the latter half of the 20th century, interest in industrial heritage preservation began to develop, initially in England during the Industrial Revolution. In Italy, this movement gained momentum around the 1970s, sparking an interest in the study of industrial architecture through the emerging field of “Industrial Archaeology” [10,11].

These industrial buildings typically feature long spans and medium heights. Following World War II, many were abandoned due to bomb damage and decreased production, leading to the collapse of roofs or vertical structures and leaving them in an advanced state of decay.

The industrial archeology movement aims to recover this valuable industrial heritage by consolidating and improving the structural behaviour of these buildings, ensuring their reuse for cultural or public purposes. This approach is vital for revitalizing entire urban areas that have fallen into disrepair.

Several successful examples of adaptive reuse in Europe demonstrated the potential of repurposing industrial buildings for contemporary urban landscapes. Notable projects include the Tate Modern in London, a former power station converted into a leading art gallery, and Zollverein Shaft XII in Essen, Germany, which transformed an old coal mine into a cultural and creative hub. These examples show how industrial heritage can be preserved while contributing to urban regeneration and cultural enrichment [12–14].

In this context, the authors propose a seismic evaluation and consolidation plan for a former metalwork factory located in San Giovanni a Teduccio, a neighbourhood on the eastern outskirts of Naples. Given its historical and architectural significance, the research integrated structural analysis with conservation principles to preserve the site’s character while improving safety. The first phase involved the reconstruction of the factory’s historical and architectural evolution, focusing on its fifty-four units.

Subsequently, static non-linear analyses were performed revealing a very low safety coefficient in the y direction. Furthermore, an assessment of out-of-plane failures indicated the building’s susceptibility to overturning due to inadequate connections.

Based on these findings, a retrofitting strategy was developed, including traditional consolidation techniques (*scuci e cuci*, grout injections) to strengthen masonry walls and install metallic tie rods to improve the so-called box-like behaviour. Lightweight laminated timber roofs were proposed to replace collapsed ones, enhancing both seismic and thermal performance while preserving the building’s integrity.

The plan also sought to revitalize the complex and its surroundings, transforming them into a dynamic urban space that blends modern functionality with historical preservation.

This approach aligned with urban regeneration strategies, promoting the sustainable transformation of industrial heritage into functional cultural, commercial, or public spaces, while preserving its historical value.

Since masonry industrial buildings are relatively rare—largely because most of these structures were constructed using RC or steel—this study represents a distinctive and timely contribution. In the absence of specific guidelines for the seismic retrofitting of historic masonry industrial buildings and considering the decline in scientific attention to this structural typology in recent decades, this research plays a pivotal role in the field.

Adopting a multidisciplinary approach that integrates structural engineering, heritage conservation, and sustainable urban planning, this paper outlines a coherent methodology for the assessment and retrofit of masonry industrial buildings. This methodology is based on a progressive evaluation framework, starting from a territorial-scale analysis and narrowing down to the detailed study of individual structures. The proposed strategy aims not only to improve seismic safety but also to enhance the cultural and functional value of industrial heritage, offering a potential reference model for future interventions in similar urban contexts.

2. The Decommissioned Factory in the Suburb Area of Naples

2.1. Locations and Historical Development

The former factory is located in the San Giovanni a Teduccio neighbourhood, on the eastern outskirts of Naples. Covering an area of about 2.35 square kilometres, San Giovanni is home to approximately 25,000 residents. The industrial zone, positioned between the sea and the railway (as shown in Figure 1), was once a hub of industrial activity. Over the centuries, the area became densely populated with factories, many of which have since been decommissioned. As a result, the neighbourhood is now dotted with abandoned industrial buildings in various stages of decay, reflecting the decline of its industrial past and presenting significant challenges for redevelopment.



Figure 1. Location of the industrial area under study. Source: Google Earth, 2025.

The former factory, known as the Corradini factory after its last owning company, was established in 1872 and emerged as a key metalworking industry in the former Kingdom of the Two Sicilies, covering approximately 3000 square metres. The complex consists of about fifty-four units, constructed over various periods and featuring a diverse range of architectural styles.

In 1882, entrepreneur Giacomo Corradini purchased the factory following the bankruptcy of its previous owner, Carafa. Under Corradini's leadership, the site was transformed into the region's most important industrial centre. He expanded the factory by adding new buildings, starting with the original structure in 1888 and continuing in 1897, capitalizing on its strategic coastal location adjacent to the railway. The factory flourished during both World Wars, significantly increasing production until 1945, when it began to decline due to bombings that damaged two chimneys.

Despite post-war reconversion efforts, the company never fully recovered and permanently ceased operations in 1949. In 1999, ownership was transferred to the municipality of Naples.

A few years later, in 2003, the area was assigned to the "Porto Fiorito" society, which aimed to develop a tourist harbour and revitalize the now-abandoned site.

In December 2022, the Municipality of Naples approved a technical and economic feasibility project for the restoration of the historic buildings, with the aim of transforming the area into a district for artistic and cultural production, integrated with structures and spaces for collective use.

Due to their significance, as they reflect historical architectural practices and serve as evidence of industrial archeology, the complex is protected by the Superintendence bond according to Law 1089/39 [15].

2.2. *The Units Within the Complex and Their Main Structural Features*

The factory consisted of fifty-four units built during various periods, primarily during the expansion phases of the late 19th and early 20th centuries. Each unit or group of units served specific functions, allowing the complex to be divided into three distinct zones: a residential area for workers, a functional area, and production facilities. The latter included changing rooms, an electrical central station, and various production areas, such as a cast iron foundry, boiler workshop, and mechanical workshop. Additionally, there were chemistry laboratories, a carpentry shop, and coal storage facilities, while shipping offices and general warehouses were located at the far end of the site.

The complex showcases a wide range of architectural styles. Some structures feature load-bearing tuff masonry with wooden truss roofs, while others represent early examples of reinforced concrete construction, characterized by small pillars and roofs supported by steel beams. The buildings generally follow a regular layout, typically rectangular in shape and designed with sufficient height to accommodate the machinery.

Regrettably, many buildings have collapsed due to abandonment and a lack of maintenance. Numerous structures are now inaccessible, overgrown with vegetation, and present safety concerns, particularly as roof tiles have fallen due to water infiltration. In some cases, vertical panels made of yellow tuff have collapsed due to the lack of connections between adjacent masonry walls. Where masonry piers remain intact, they are affected by crushing caused by deteriorating mortar. Additionally, roofs have suffered from the degradation of wooden elements, resulting in partial collapses. All openings are devoid of windows, and the reinforced concrete lintels show significant cracking.

Figure 2 depicts the structures and their current state of decay.

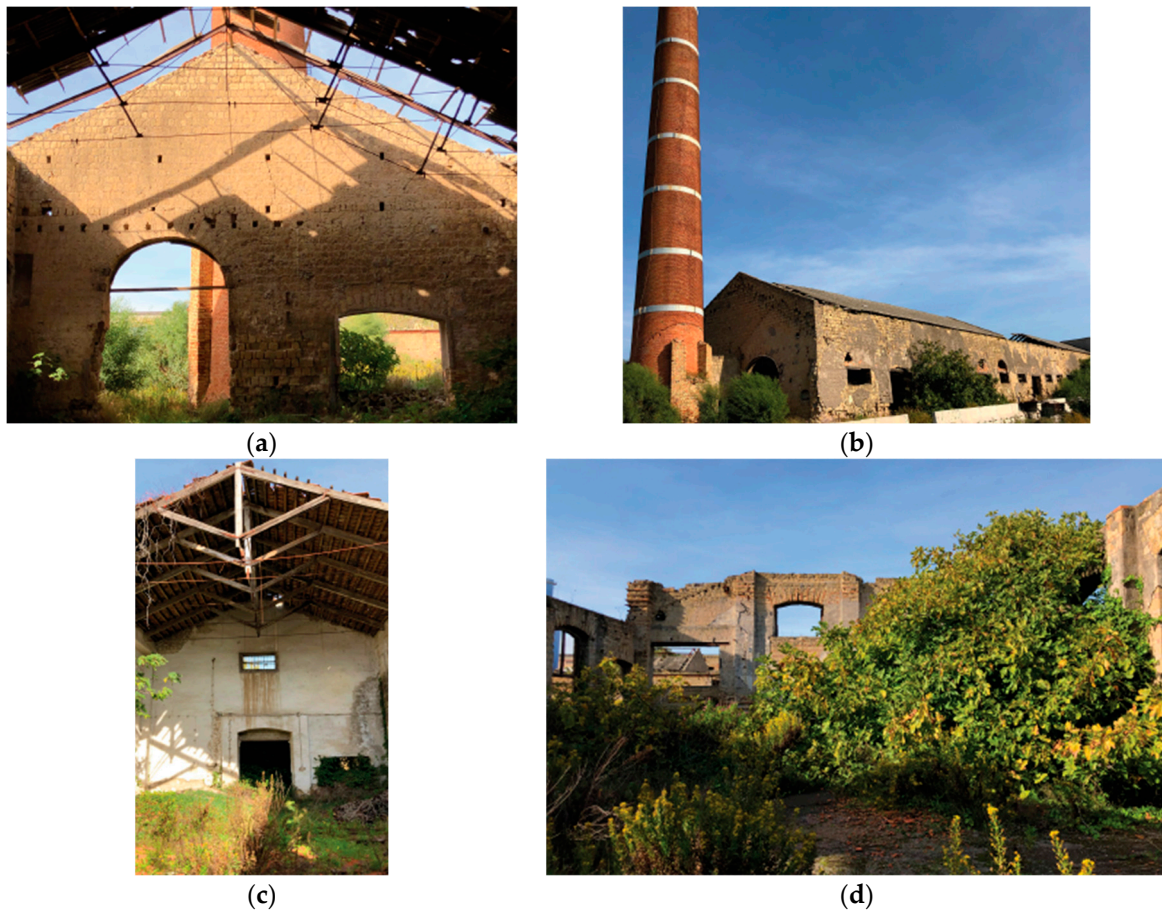


Figure 2. (a) A typical construction in the area; (b) the last chimney; (c) detail of a roof structure visible due to the failure of a vertical masonry wall; (d) invasive vegetation.

3. Seismic Analysis Through Macro—Elements Approach

3.1. Modelling Phase

After assessing the primary structural and architectural properties, the next step involved evaluating the seismic vulnerability of the industrial complex. From the various units within the area, eight production fabrics were selected and modelled using the 3Muri software (Version 14) provided by the S.T.A.DATA company (Turin, Italy).

The selected structures are identified in Figure 3.



Figure 3. Identification of the production buildings under evaluation.

This software is designed for analyzing both existing and new structures constructed of masonry or reinforced concrete. It is suitable for a wide range of constructions, including residential buildings, industrial facilities, and monumental complexes such as churches and other culturally significant edifices [16,17]. The programme utilizes a frame by macro-elements (FME) approach, based on the observations of damage experienced by actual buildings following earthquakes. In this method, each masonry wall is represented by three parts: the first two components are masonry piers and spandrels, placed adjacent to and above/below the openings, respectively, which represent deformable areas where damage is likely to occur, while the third component is the node, which is treated as a rigid block with an infinitely rigid behaviour.

The models of the fabrics were created according to the lowest level of knowledge (KL1), which involves a confidence factor (F_C) equal to 1.35 for the calculation of the design parameter, as specified in the current Italian Technical Code and its Ministerial Circular [7,8].

Table 1 provides a summary of the mechanical properties of the tuff masonry used in the vertical structures.

Table 1. Mechanical properties of the tuff masonry walls.

| Mechanical Parameters | Values |
|-----------------------------|--------|
| E [N/mm ²] | 1410 |
| G [N/mm ²] | 450 |
| f_m [N/cm ²] | 200 |
| τ [N/cm ²] | 4 |
| w [kN/m ³] | 16 |

As the masonry structure adjoins a reinforced concrete block, which was added during a later phase of the original complex, it was included in the structural modelling. In the absence of experimental testing, the mechanical properties of both the concrete and the reinforcing steel were estimated through simulated design, reflecting the typical construction practices of the period. These properties are summarized in Tables 2 and 3.

Table 2. Mechanical properties of concrete.

| Mechanical Parameters | Values |
|-------------------------------|--------|
| E [N/mm ²] | 29,962 |
| G [N/mm ²] | 12,484 |
| f_{cm} [N/cm ²] | 20.7 |
| f_{ck} [N/cm ²] | 20 |
| w [kN/m ³] | 25 |
| γ_c | 1.5 |
| α_{cc} | 0.85 |

Table 3. Mechanical properties of steel.

| Mechanical Parameters | Values |
|-------------------------------|---------|
| E [N/mm ²] | 206,000 |
| G [N/mm ²] | 79,231 |
| f_{ym} [N/mm ²] | 244.4 |
| f_{yk} [N/cm ²] | 315 |
| w [kN/m ³] | 79 |
| γ_s | 1.15 |

Figure 4 illustrated the three-dimensional and the meshed models of the structure with the identification of the three macro-elements mentioned above.

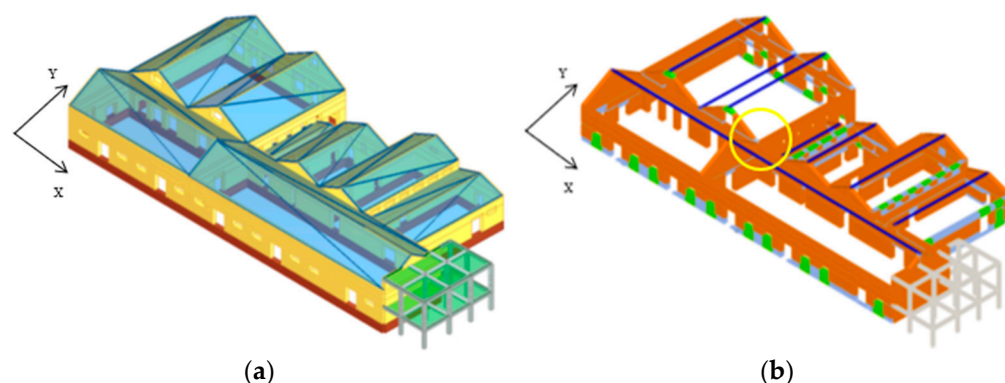


Figure 4. (a) Three-dimensional view of the structure numerical model; (b) meshed model of the structure with masonry piers (in brown), spandrels (in green), rigid nodes (in light blue), steel elements (in blue), and reinforced concrete columns (in grey). The yellow circle indicated the position of the control node.

The numerical analyses in the as-built configuration were performed considering only the self-weight of the existing masonry panels, without the contribution of additional vertical loads, due to the absence of roofing and the advanced state of deterioration observed on site.

In the retrofit scenario, however, the loads associated with the reconstructed roofing were included, as the intervention is intended to restore the structural continuity necessary for the reuse of the internal spaces.

3.2. Pushover Analysis Results

The pushover analyses were conducted by monotonically increasing horizontal loads applied to the structure until its collapse. Non-linear analyses were performed considering 24 load combinations in accordance with current regulations.

These combinations were derived from two different inertial force distributions. The first group consisted of forces proportional to static loads, while the second group featured a uniform distribution based on a homogeneous acceleration profile throughout the height of the building.

Table 4 summarizes the results for the two most critical combinations, expressed in terms of the coefficient α , which is defined as the ratio between the capacity peak ground acceleration and the demand one.

Table 4. Results of static non-linear analyses.

| Nr | Direction | Seismic Load | Eccentricity [cm] | α_{SLV} |
|----|-----------|----------------------|-------------------|----------------|
| 10 | +X | Static Forces | −221.1 | 2.276 |
| 23 | −Y | Uniform Distribution | 504.4 | 0.149 |

According to Figure 5, which depicts the damage incurred by the complex of fabrics along the most vulnerable direction (Y), the primary issue observed is the shear mechanism affecting the vertical panels of the two largest structures. Several panels exhibited signs of tensile failure, and certain masonry parts at the roof level experienced compression-bending phenomena.

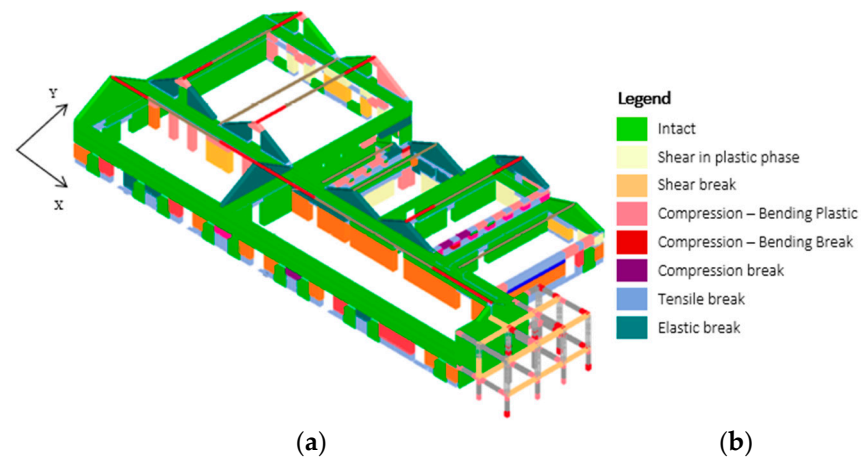


Figure 5. (a) Damage on the structure 3D model along the Y direction; (b) legend of mechanisms.

3.3. Kinematic Analysis

In addition to evaluating the global behaviour of the production buildings within the complex, the study also focused on the first-mode mechanisms due to the observed absence of the so-called “box behaviour” during in situ inspections.

Local collapse mechanisms, or first-mode mechanisms, involve structurally independent components of a building known as “macro-elements.” These mechanisms can lead to both partial and global overturning, as well as bending phenomena (vertical or horizontal). Out-of-plane failures may occur due to a lack of connections between adjacent vertical panels, insufficient connections between vertical and intermediate horizontal slabs, or the thrust from roof structures that generates significant stress on the masonry walls [18–20].

The investigation of these local mechanisms employs limit analysis, which is based on the equilibrium of walls modelled as a series of rigid blocks. These blocks are assumed to possess unlimited compressive strength but zero tensile resistance. The low tensile strength of the masonry results in collapse due to loss of equilibrium, the evaluation of which depends on the geometry and constraints of the walls.

It is important to recognize that more advanced and complementary approaches have been developed to address some of the simplifications inherent in traditional methods. For example, recent studies [21,22] present evolutions of Rigid Body Analysis (RBA) that, while still based on the decomposition of the structure into rigid blocks, incorporate critical factors such as interface flexibility and material-crushing effects. These enhancements enable more realistic seismic response predictions by capturing local damage phenomena that significantly influence the structure’s overall capacity.

For each mechanism analyzed, the masonry is transformed into a kinematic chain (an unstable system), identifying rigid bodies capable of rotating or sliding relative to one another.

For Life Safety Limit State checks, a simplified verification was carried out. It is satisfied if the spectral seismic acceleration of activation of the kinematics a_0^* is greater than the peak ground seismic acceleration $a_{0,\min}$:

$$a_0^* \geq a_{0,\min} \quad (1)$$

where

$$a_0^* = \frac{\alpha_0 \cdot g}{e^* \cdot F_C} \cdot q \quad (2)$$

in which

- α_0 is the multiplier of the seismic action causing the collapse, obtained through the principle of virtual works;
- g is the gravity acceleration;
- e^* is the participating mass fraction related to the first vibration mode;
- F_c is the confidence factor;
- q is the behaviour factor assumed equal to (2).

$$a_{0,\min} = \frac{S_e(0)}{q} \quad (3)$$

where

- $S_e(0)$ is the ordinate of the elastic spectrum;
- q is the behaviour factor.

Equation (3) corresponds to Equation C8A.4.9 of the Italian Ministerial Circular n.7/2019 [8].

It is valid only for the masonry portions that are restrained to the ground and was used for the checks in the current study, as all the structures consist of a single storey. Particularly, for the complex under study, overturning phenomena was investigated by evaluating the behaviour of perimeter walls.

Figures 6 and 7, along with Table 5, point out that in both cases the checks for the two analyzed walls are not satisfied, leading to their overturning.

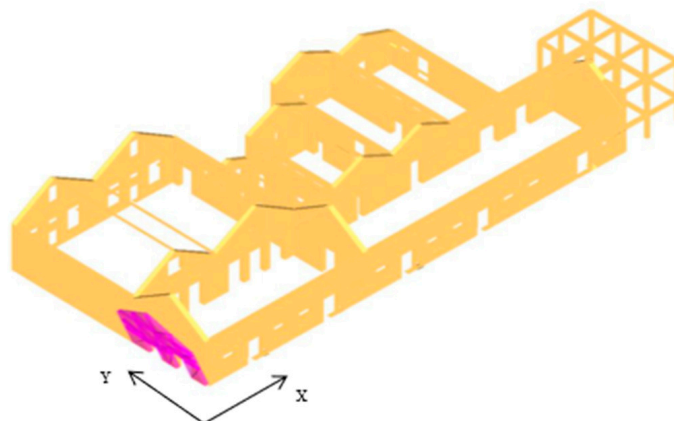


Figure 6. Overturning mechanism of Wall 1.

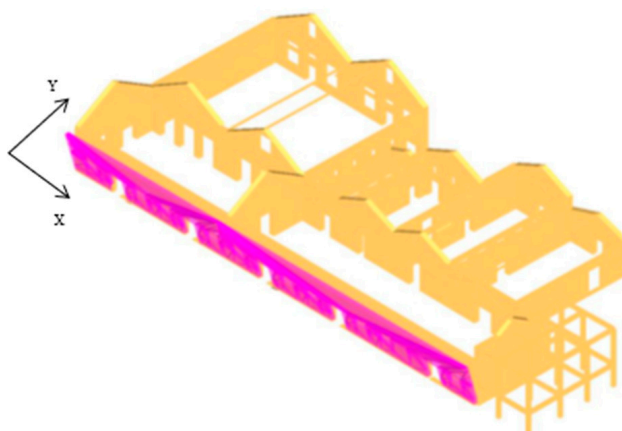


Figure 7. Overturning mechanism of Wall 2.

Table 5. Results for all perimeter walls.

| Wall | Constraint | a_0^* | $a_{0,min}$ | Result |
|------|------------|---------------------|---------------------|--------------|
| [-] | [-] | [m/s ²] | [m/s ²] | [-] |
| 1 | Ground | 1.375 | 2.404 | Not Verified |
| 2 | Ground | 1.909 | 2.404 | Not Verified |
| 4 | Ground | 2.042 | 2.404 | Not Verified |
| 5 | Ground | 2.105 | 2.404 | Not Verified |
| 6 | Ground | 2.021 | 2.404 | Not Verified |
| 7 | Ground | 2.148 | 2.404 | Not Verified |
| 8 | Ground | 2.326 | 2.404 | Not Verified |
| 9 | Ground | 1.967 | 2.404 | Not Verified |
| 10 | Ground | 1.923 | 2.404 | Not Verified |

4. Retrofit Interventions for Consolidation Purposes

4.1. Premise

Given that both global and local analyses have highlighted the significant vulnerability of the complex—particularly its susceptibility to overturning mechanisms due to inadequate connections between consecutive walls—there is an urgent need to consolidate the former factory.

The consolidation plan is aimed at enhancing the seismic performance of the buildings and mitigating the risk of structural collapses. Specifically, the operations are focused on improving both the mechanical strength and ductility of the perimeter masonry walls, while also ensuring adequate internal thermal comfort [23,24].

Since the global analyses highlighted specific vulnerabilities in the transverse direction (Y-axis), most of the interventions were, therefore, proposed along that direction. However, local interventions aimed at preventing overturning were also carried out along the longitudinal direction.

The retrofit of the eight blocks is also designed to support the future development of the entire area, which is currently abandoned and in a severe disrepair state.

4.2. Solutions for Masonry Walls

- *Scuci and cuci* technique

The first step in the consolidation process is the “*scuci and cuci*” technique, a traditional and widely recognized solution for repairing cracked masonry panels. This technique focuses on replacing damaged tuff stones with new ones that are compatible with the existing materials, ensuring enhanced durability over time. The implementation of this technique follows these steps:

1. Temporary Shoring of the Masonry—The wall is stabilized using temporary supports to prevent further damage and ensure safety during the repair process.
2. Plaster Removal—Any existing plaster is carefully stripped away to expose the masonry, allowing for a thorough assessment of its condition.
3. Removal of Damaged Stones—Compromised masonry blocks, along with adjacent stones (approximately 1 m around the cracks), are removed to create a stable foundation for reconstruction.
4. Masonry Cleaning—The exposed area is thoroughly cleaned using high-pressure water to remove dust, debris, and loose material, ensuring proper adhesion of new masonry elements.
5. Masonry Reconstruction—The wall is carefully rebuilt from the base to the top, integrating new stones while maintaining proper alignment and structural integrity.

This operation is recommended for all vertical panels affected by crushing phenomena, as well as those exhibiting cracks or other defects.

- Consolidating injections

The planned intervention for the perimeter masonry panels of the analyzed blocks involves the application of consolidating injections in areas where mortar is missing. In this case, the injected mixture must be closely compatible with the original mortar's properties to ensure optimal adhesion and chemical–physical compatibility.

The execution of this consolidating solution follows these steps:

1. Removal of Existing Plaster—Any remaining plaster is carefully stripped away to expose the masonry, allowing for proper intervention.
2. Repointing of Joints—The joints between masonry elements are cleaned and redefined to enhance adhesion and structural integrity.
3. Drilling of Holes—Holes with a 30 mm diameter are drilled at the intersection points of the stones to ensure an even distribution for the injection process.
4. Installation of Injection Tips—Specialized nozzles are inserted into the drilled holes to facilitate the controlled injection of the binding mixture. If the masonry is significantly degraded, injections are performed from the bottom up to reinforce the lower part of the panel without overloading it with additional weight, as would occur if the process was performed in the opposite direction. Furthermore, when dealing with poor masonry conditions, it is recommended to minimize the injection pressure and allow the mixture to flow by gravity.
5. Internal Cleaning of Holes—The drilled holes are washed with pressurized water to remove dust and debris, ensuring optimal penetration of the binding agent.
6. Sealing of Holes—Once the injection process is complete, the holes are carefully sealed to restore the surface and maintain a cohesive finish.

- Insertion of metal tie rods

To achieve the so-called “box effect,” which is essential for ensuring a good response of a masonry structure under seismic actions, the installation of metal tie rods is planned.

These tie rods are also intended to counteract the overturning phenomena affecting the perimeter walls of the units, as highlighted by kinematic analysis.

The tie rods, featuring a circular cross-section of 20 mm, are to be fabricated from S275 steel to ensure sufficient strength and compatibility with the masonry structure. They are spaced at intervals of approximately 5–6 m and utilize external anchorage systems consisting of threaded-end bars and anchor plates.

The main phases of their installation are outlined below:

1. Temporary Shoring of the Masonry—The perimeter wall is stabilized with temporary supports to ensure safety and prevent further structural movement during the intervention.
2. Removal of Existing Plaster (If Present)—Any plaster covering the masonry is carefully removed to expose the structure and allow for the proper installation of the reinforcement system.
3. Drilling of Holes—Holes are drilled at regular height intervals in a rectangular pattern to ensure the even distribution of the reinforcement.
4. Preparation and Insertion of Tie Rods—Steel tie rods are prepared and inserted into the drilled holes to strengthen the structure and counteract tensile forces.
5. Installation of Retaining Components—Anchoring devices, such as plates or end fittings, are installed to secure the tie rods and effectively distribute applied forces.
6. Tensioning of Tie Rods—The tie rods are gradually tensioned to provide the necessary structural reinforcement and enhance the overall stability of the masonry.

7. Sealing of Holes and Grooves—The process is completed by sealing the holes and any grooves with compatible materials, ensuring both structural integrity and aesthetic continuity.
 - Steel tie-beams on the top of masonry panels

A further operation aimed at increasing the box behaviour of the units is the insertion of steel tie-beams to be placed atop the masonry panels, further reinforcing the structure's overall stability.

Specifically, a double UPN 240 profile is proposed for use. The two profiles are connected by transverse connectors that pass through the masonry. Horizontal plates are installed at the top, linking the two profiles and providing a base for welding vertical plates, which will support the struts of the new roof structure.

These interventions are designed to greatly enhance the seismic resilience of the masonry walls, ensuring the long-term safety and structural integrity of the complex.

Figure 8 provides the representation of the above-described interventions.

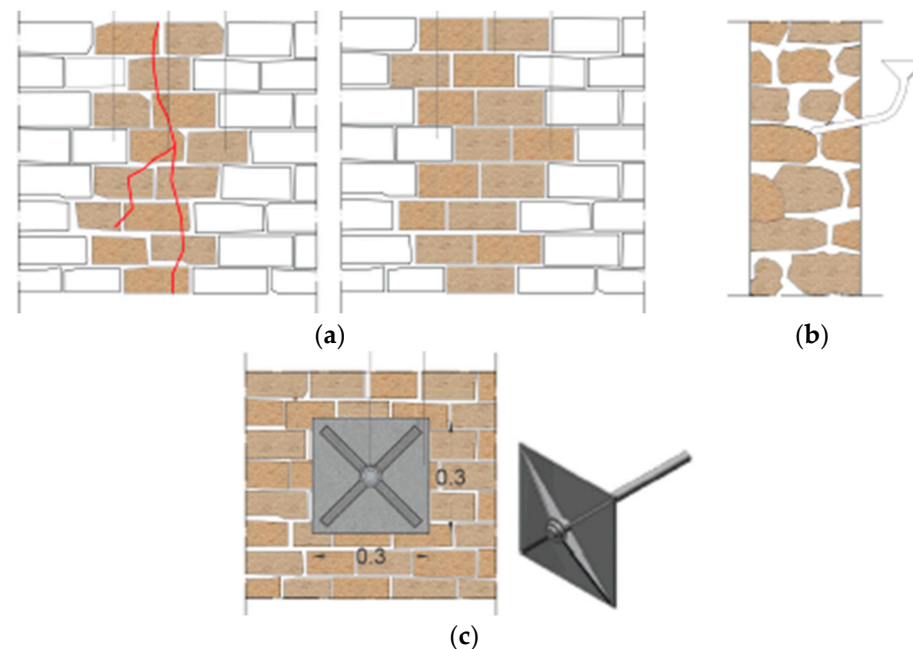


Figure 8. Illustration of the different consolidating operations planned for the masonry: (a) *scuci and cuci* technique; (b) consolidating injections; (c) insertion of metal tie rods.

4.3. Operations on the Roof and Other Retrofitting Interventions

Since most of the structures have collapsed roofs, it is essential to reconstruct them to create enclosed and comfortable interior spaces.

The design specifically proposes the implementation of cool roofs, which offer significant advantages from both technological and sustainable perspectives.

A cool roof features a ventilation layer positioned between the insulation and the covering layers. This thin ventilation space helps reduce thermal losses from indoor environments, thereby alleviating humidity issues.

From a technological standpoint, the ventilated roof should include, from the inside to the outside:

- Timber beams;
- Wooden decking;
- Vapour barrier designed to protect the thermal insulation from moisture/vapour coming from the interior environment; it is placed on the warm side of the insulation;

- Thermal insulation made of fibrous or cellular material, commonly using fibreglass or rock wool panels with a variable thickness;
- Waterproof membrane: a continuous element that protects the roof from weather conditions;
- Ventilation layer created by a continuous air gap between the roofing elements and the layer underneath;
- Roof covering with ventilation openings at the ridge and eaves for airflow.

The new roofs will be constructed using laminated wood beams, which will be connected to UPN-shaped steel profiles that serve as the curb.

This intervention not only enhances the structural integrity of the building but also emphasizes sustainability. By preventing the formation of condensation, the ventilated cool roof reduces moisture-related issues that could affect the timber beams, ultimately prolonging their lifespan. This is an important consideration for heritage buildings, as moisture accumulation can lead to the deterioration of such structures over time.

Furthermore, the cool roof contributes to improved thermal comfort, which is a crucial issue in contemporary building design, also including historic buildings [25,26].

With the new European policies focused on reducing energy consumption, achieving thermal efficiency is a key factor [27,28]. A well-designed retrofitting intervention, especially addressing heat and cooling loss, is essential to meet these goals.

Roofs, in particular, are a significant source of heat loss or gain, and by implementing a ventilated roof system, it is effectively possible to minimize these thermal dispersions. This not only supports the building's sustainability but also aligns with current energy-saving initiatives, reducing the overall environmental impact of the retrofit [29].

Additionally, an important intervention involves the installation of steel frames to reinforce the frames of the openings, replacing the damaged pre-existing reinforced concrete lintels. This enhancement will improve the structural integrity of the openings and ensure long-lasting durability.

Following this reinforcement of the window and door frames, double-glazed windows with thermal insulation will be installed. These energy-efficient windows will significantly contribute to the internal thermal comfort of the various units, reducing heat loss in winter and minimizing heat gain in summer, thus improving overall energy efficiency and indoor climate control.

Figure 9 illustrates the structural details of the proposed retrofit interventions for the masonry portions of the industrial complex.

4.4. Local Mechanisms After Retrofit Interventions

Given the building's susceptibility to local collapse mechanisms—particularly out-of-plane overturning—metal tie rods were designed to mitigate these vulnerabilities. The design process employed the 'Tie Beams Calculation' module, which assisted in determining the appropriate diameter of the tie rods. Their effectiveness was then verified using the 'Kinematic Analysis' module within the same software suite. This tool facilitates the evaluation of local collapse mechanisms and assesses the structure's overall capacity to resist various failure modes. Specifically, the following checks were performed: masonry punching, anchor penetration, and tie rod yield strength.

After designing the metal ties to be installed along the structure short direction to prevent the overturning phenomena involving, the local collapse mechanism checks were repeated. The achieved results, illustrated in Table 6, were successfully satisfied, demonstrating the effectiveness of the implemented intervention.

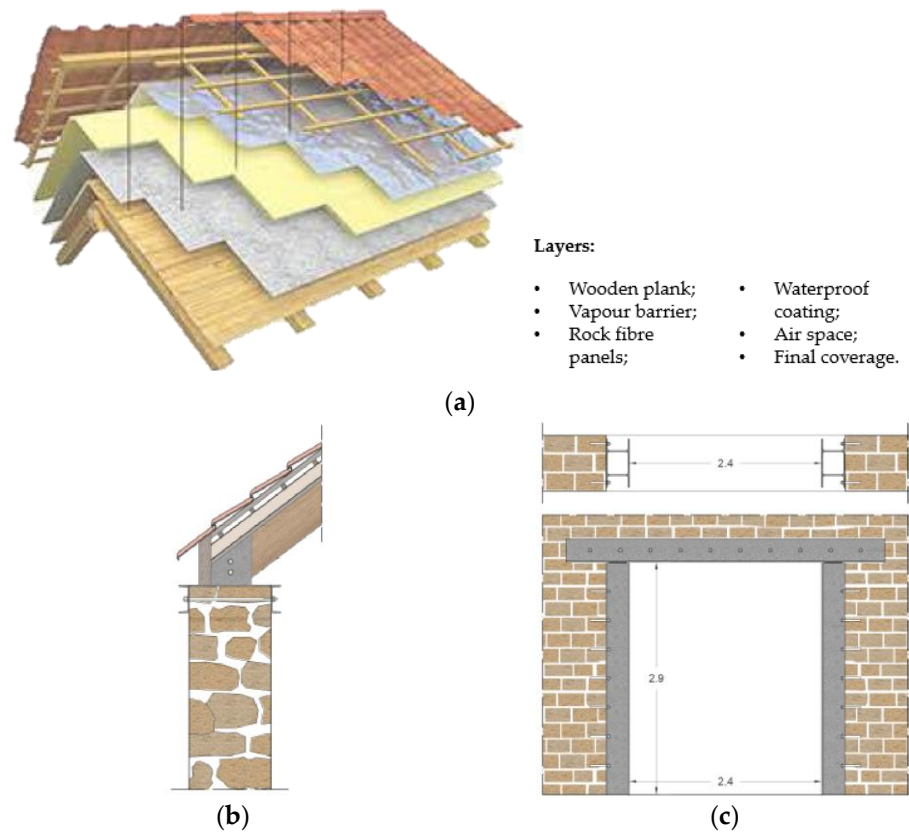


Figure 9. Other interventions: (a) reconstruction of the roof with a cold roof type; (b) insertion of steel curb; (c) steel frame around the openings.

Table 6. Results for all perimeter walls after retrofit intervention.

| Wall | Constraint | a_0^* | $a_{0,min}$ | Result |
|------|------------|---------------------|---------------------|-----------|
| [-] | [-] | [m/s ²] | [m/s ²] | [-] |
| 1 | Ground | 3.386 | 2.404 | Satisfied |
| 2 | Ground | 2.646 | 2.404 | Satisfied |
| 4 | Ground | 2.652 | 2.404 | Satisfied |
| 5 | Ground | 2.741 | 2.404 | Satisfied |
| 6 | Ground | 2.487 | 2.404 | Satisfied |
| 7 | Ground | 2.148 | 2.404 | Satisfied |
| 8 | Ground | 2.537 | 2.404 | Satisfied |
| 9 | Ground | 2.423 | 2.404 | Satisfied |
| 10 | Ground | 2.485 | 2.404 | Satisfied |

4.5. Project Proposal: Transformation of the Site into Student Housing

The proposed intervention aims to revitalize the former industrial area following the structural consolidation of existing buildings, which were originally used as production facilities. The new functions assigned to the site are the result of a thorough analysis of local socio-economic trends and service deficiencies in the surrounding neighbourhood.

In particular, the proximity of the University of Naples' western campus and the Apple Developer Academy—both drawing an increasing number of students—underscores the strategic value of the site. Combined with the limited availability of student housing in the area, these factors informed the decision to transform the former Corradini industrial complex into a university campus.

The project involves the adaptive reuse of the site, including the creation of student residences and an artistic-cultural production district. The design reassigns functions

according to the orientation and architectural characteristics of the existing buildings, preserving their historical identity while adapting them to contemporary needs.

The development plan includes student housing, educational facilities (classrooms, a library, computer labs), shared spaces (conference rooms, exhibition halls, common areas), and cultural, recreational, and food services. Administrative offices and reception areas are also included, along with multipurpose public spaces designed to engage with the broader community.

The intervention aligns with current urban planning instruments, including the General Master Plan and the Urban Development Plan for the San Giovanni a Teduccio coastal area, both of which support the site's redevelopment for residential and service-oriented uses.

Architecturally, the project adopts a conservation-based approach, retaining the identity of the historic structures while upgrading them to meet seismic and functional standards. This blend of heritage preservation and spatial innovation ensures compliance with safety and usability requirements, while enhancing the cultural and social fabric of the area.

5. Conclusions

This paper highlighted the critical importance of seismic evaluation for decommissioned historic industrial buildings, focusing on the structural performance of a former factory located in the San Giovanni a Teduccio neighbourhoods in the outskirts of Naples.

In light of the absence of specific guidelines for the seismic retrofitting of such structures—and amid growing interest in industrial archeology as a catalyst for urban regeneration—this study sought to revive both academic and technical engagement with its topic. By employing a multidisciplinary approach that integrates structural engineering, heritage conservation, and sustainable urban planning, the proposed methodology provided a clear and effective framework for assessing and retrofitting masonry industrial buildings.

The complex spans over 5000 square metres and consists of fifty-four units, which can be categorized into three functional zones: a residential area, a functional area, and a production zone. The site has an elongated shape due to its positioning between the coastline and the railway.

The historical evolution of the complex was marked by numerous events, reaching its peak during the Corradini era. However, after the bombings, production declined, leading to progressive abandonment and a subsequent state of decay.

The study specifically assessed the performance of a block of eight production structures, composed of vertical elements made from yellow tuff masonry, with roofs constructed from timber beams and tile layers where applicable.

Static non-linear analyses were conducted using a macro-element model in the 3Muri software, adhering to the lowest level of knowledge in accordance with current Italian Technical Regulations.

In the initial phase, the global behaviour of the former factory was analyzed, revealing that the most vulnerable direction was along the Y-axis, where a coefficient α_{SLV} of 0.149 was obtained.

Subsequently, out-of-plane mechanisms were examined, particularly focusing on the overturning phenomenon, as the structures lacked connections between adjacent vertical masonry panels. The assessment highlighted the complex's susceptibility to local collapse mechanisms.

Based on these identified deficiencies, a consolidation plan was proposed, aimed at reinforcing the masonry walls through traditional techniques such as the *scuci and cuci* method or consolidating injections, as well as reconstructing the collapsed roofs to

repurpose the internal spaces. Moreover, the effectiveness and benefits of inserting metal tie rods to mitigate overturning mechanisms were demonstrated by conducting additional verification analyses.

Finally, the consolidation plan extended beyond seismic safety improvements to also enhance the building's cultural and functional value. Given the proximity of the University of Naples' western campus, the project proposed converting the former factory complex into student housing. This transformation not only ensured the building's structural and operational viability but also contributes to the broader revitalization of the San Giovanni a Teduccio neighbourhood, an area currently affected by abandonment and urban decay. By repurposing the industrial site, the project had the potential to breathe new life into this marginalized district, transforming it into a vibrant and dynamic hub that promotes community engagement and fosters urban regeneration.

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