Industrial Heritage Rethinking: Flexibility Design for Eco-Friendly Environments

Stefania De Gregorio *, Mariangela De Vita and Anna Paris

Abstract: The conscious and efficient reuse of historic buildings has turned out to be a fundamental point of European programs for the management and conservation of the Architectural Heritage. In this context, the Industrial Heritage shows architectural and spatial peculiarities that facilitate its change of use and performance updating. In fact, the large internal spaces limit the issue of material compatibility to retrofit interventions on the casing. Often the interventions of reuse of the industrial heritage are solved with new architectures designed to be completely inserted inside the original envelope, remaining independent from it. This work presents the reuse project of an industrial building in the city of Sagunto, Spain, where the logic of the “box within the box” is re-proposed with the aim of spatial and constructive flexibility. The research shows a design methodology that allows the new functional modules inside the old building to be designed according to flexibility requirements and how flexibility design is a means for environmental sustainability in the occasion of disused industrial heritage reuse.

Keywords: environmental sustainability; reuse; flexibility; adaptive design; Nave de Talleres Generales; Sagunto

1. Introduction

During the last 20 years, in the construction sector the design of energy efficiency buildings has become a priority theme, addressed by both politicians, planners and scientific researchers [1–7]. Over time, the investigation and analysis methods of the eco-friendly design have led to an evolution of the theories that underpin environmental sustainability in architecture. This development in thinking of sustainable places and spaces has certainly been conditioned mostly by the update of regulations and standards but also by “trends” [8].

For these reasons, it is worthy to note the investigation of how the evolution of eco-friendly thinking and consequently design methodology has also had an impact on objective definitions in general and, in particular way, on construction techniques and performance requirements [9,10].

From the analysis of the literature and of the state of art, it emerges that the theory of temporariness in buildings and construction has contributed enormously in offering technologically flexible and adaptive solutions to the issue of sustainable reuse of cultural heritage. In architecture, temporariness can be expressed in different ways: temporariness of use (reuse), of location (mobile and transportable architecture), of duration (for example, ephemeral architecture) and of materials (constructive and technological issues) [11]. When these “changes over time” affect historic buildings and architectural heritage, temporariness is often limited to reuse due to the constraint linked to a fixed location and to the protection and conservation of both construction aspects and materials and techniques present in the artifact [12–14].

In 2018, with the Davos and Leewarden declarations [15,16] the ideas of reuse applied to architectural heritage were developed from a theoretical point of view, finding its
natural place in the terms “adaptive reuse”. Since then, this reuse notion materialized into numerous research and design applications: a recent study, through the systematic literature review (SLR) approach embedded in the Preferred Reporting Items for Systematic Review and meta-Analysis (PRISMA) protocol and key informant interviews with Subject Matter Experts (SMEs), analyzed the benefits and challenges of applying the adaptive reuse of existing buildings as a sustainable approach for climate change mitigation [17]; several works have developed multi-criteria approaches and indicators to optimize the adaptive reuse process in accordance with the Sustainable Development Goals (SDGs) 2030 and the European Quality Principles [18], to provide a scientific decision-making basis for multiple agents to improve the adaptability of historic buildings in a complex urban context [19] and to define the investment opportunity for the rehabilitation and reuse of cultural heritage buildings for circular cities [20].

The fruition changing of the architectural heritage needs to be supported by a design consistent with the purposes of a new and temporary use, subject to future modifications. Therefore, in order for this adaptivity to be guaranteed, the requirement of technological flexibility becomes essential: in summary, it could be said that technological flexibility is a way of attributing the contents of temporariness to historic architecture as well [21].

To make the fixity and static nature of the historical envelope coexist with the mutability linked to reuse, one possibility is to intervene by creating a “box within a box”, i.e., by defining new functional modules that are flexible, temporary and with low material impact on the historic structure, which can allow the compatibility of the new activities with the original architecture. This solution has been adopted many times, giving rise to many masterful examples of design: think of the cloud by Fuksas [22] and the Prometheus by Renzo Piano [23], as well as the intervention in the School of Architecture, Marne-la-Vallée Paris, by Bernard Tschumi Architects [24].

From an architectural point of view, the discussion on the advisability of “hiding” the original envelope with a new more internal envelope is very interesting and stimulating. However, this work focuses on methodology to design a “box within a box” from a technological point of view and with the aim of environmental sustainability through flexibility. The methodology was validated through the application to a case study: an old factory in the city of Sagunto, in Spain. The research has the aim of defining new modules which, in addition to responding to the functional needs of reusing the internal space of the structure, have a multi-scale vocation. For this reason, the methodology develops from context analysis (environmental and urban) up to the definition of the design detail of the building components.

The theme of industrial architecture lends itself perfectly to this type of installation: in fact, the factories are characterized by large internal spaces that offer great possibilities for redesign and remodulation [21,25,26]. Furthermore, adaptive reuse has found a preferential application in industrial heritage: studies range from a database approach to examining the relationship between function and interventions [27,28] to the sustainable development of the surrounding area in terms of improving the quality of life for the local society and empowering the cultural dimension, as well as making it a popular tourist destination [29], designed with new spaces and new functions for disused structures [27–31]. The relationship between the new function and the historical memory of the old one is materialized in the technological relationship between the new construction additions and the original structure: inserting a new building within the old one must be dictated by rules derived from the architectural constraints and spatial coherence between the two environments.

In addition, the literature shows how heritage preservation and rehabilitation contribute to climate change mitigation and the development of circular economies [17,32] also confirmed by LCA analyses based on building life and product life cycles [33–36].

Reuse of the building is a tool to ensure its preservation, especially when it is capable of adapting over time through flexibility to the needs of different users [37–39]. A flexibility involves the building in the possibility of changing the space but also the possibility of reuse of the building systems, systems and materials that constitute it [39,40]. A number
of studies indicate multi-criteria decision-making approaches; among these is always the flexibility of the interior space along with the quality and potential of the building [41], adaptability [42] and accessibility, the presence of services and the state of maintenance [43]. In Bottero et al.’s study [42], the authors apply multi-criteria decision making to abandoned buildings located in an industrial valley in northwestern Italy with a strong presence of wool and silk factories, demonstrating the suitability for adaptive reuse. Similarly, Kaya et al. verify adaptive reuse practices in the Netherlands. In addition, Madga et al.’s study [44] focuses on the characteristics that make flexibility of use possible by allowing a change of function, pointing to paradigmatic examples located in Barcelona (Spain) (the Drassanes shipyard, the great cistern of the Dipòsit de les Aigües in the Ciutadella, the old Casa de la Caritat, the Batlló factory, the Hospital de la Santa Creu, Catalan Gas Company office building).

An interesting example of redevelopment of manufacturing heritage is the redevelopment project of pavilion 17c of the “Matadero” (slaughterhouse) in Madrid. The hall is part of a complex of 20 sheds built in 1907 by architect Luis Bedillo. Shed 17c was redeveloped through the design of Arturo Franco and Fabrice van Teslaar in 2007, in which a glass and steel space is proposed within the original envelope, which is configured as a “box within a box” but whose transparency reveals the original space to the user. If the value of this project is manifested in its ability to enhance the historical and symbolic aspects of the building, on the other hand it presents the limitation of a functional rigidity that does not allow the space to vary along with the users’ needs [45].

A further design reference is the “Fabrica de Hielo” in Valencia, where the internal spatial distribution of an old shoe factory has been completely redesigned using naval containers. In 2014, the buildings had been transformed into a pub and leisure center where creativity and good music contribute to the redevelopment of the whole neighborhood of Cabanyal [25].

This case study is part of a broader work carried out in the field of reuse of industrial architecture with a view to sustainability in design. In this case, the technological flexibility of the project provides a further key to give answers to the needs of adaptive reuse widely explored in recent years.

2. Method

The method for flexible design finds its foundations in the Modern Movement (Le Corbusier’s Maison Dom-ino and Loucher, Gerrit Rietveld’s Schröder Haus and Walter Gropius’s Hirsch Kupfer Haus) and has evolved throughout the 20th and 21st centuries acquiring new declinations, each carrying a particular characteristic of flexibility. Indeed, the latter is expressed through adaptability, dynamism, transformability and resilience, with temporariness seemingly overlapping and interchangeable, but in reality, characterizing specific design requirements [46].

Flexible architecture is based on an overarching concept that takes into account various situations that may change over time, either in regular cycles or irregular repetitions. Design should include variations and static spaces for users. We should refer to them as probable situations, thereby making the possibility of future variation inflexible. To regulate every aspect would in fact imply the presumption of knowing in anticipation how users’ needs vary in the future [47].

Flexibility design in the redevelopment of a pre-existing building is confronted with a predefined limit that is represented by the building envelope and with constraints to action that are represented by the parts of the pre-existence that cannot be varied because of their historical, artistic or simply symbolic value. In the redevelopment of the industrial heritage, currently disused, to uses compatible with it, the project must also relate to the nature of the pre-existing spaces that is the bearer of a strong identity, with spaces conceived in their original function to fulfill specific industrial tasks and therefore sized in a way that is compatible with them (in terms of surfaces and height) and responds to determined comfort performance (thermal, acoustic etc.). The strong identity connotation can configure
itself, if not properly managed by the designer, as a strong limitation for the project that cannot find compatible destinations for such a specific use. Thanks to flexibility, on the other hand, such identity on the one hand can be preserved as a founding part of the building’s history and on the other hand can be rethought to make spaces designed for a specific use compatible with completely different uses.

Flexibility design must start from the reference context to the building and component design, scalarly involving four aspects [48]:

1. Buildings’ ability to be repurposed for new uses: at the time of the project, it is necessary to analyze the territorial context in order to identify a use that is truly in the interest of the community, in order to ensure the preservation of the building through use over time; at the same time, it is necessary to act from a technological point of view with reversible construction systems that allow in the future to completely transform the use of the building according to the changing needs of the context;

2. The modifiability of space size: which allows the amount of space to be increased to serve a given function;

3. The modifiability of the subdivision of space: which allows you to choose how to use a given space with respect to its temporary function;

4. The modifiability of the building envelope: which allows the performance of the envelope to vary both as a function of climatic changes and as the intended use changes over time; in addition, the modifiability of the envelope allows the building to be easily maintained.

From a methodological point of view, we can identify two macro-phases: the first one that scaled analysis of the area and the building that provides the basic information for the second phase, which instead deals specifically with the flexible industrial building redevelopment project.

2.1. Identification of Compatible Uses in the Specific Territory

The analysis of the neighborhood considers various aspects, such as history, polarities, roads and functions. Examining the neighborhood’s historical evolution helps to understand how it has been experienced and transformed over time and identify correlations between its main function, social class and development of the building, road network and main services. The analysis of the neighborhood’s polarities (places of interest) and road network enables us to understand the prevailing flows of people and evaluate the building’s position in relation to them. Identifying the prevailing functions helps to determine which services are necessary and currently missing in the neighborhood. Based on this information, potential uses can be identified and verified for compatibility with the building’s characteristics. Finding a useful function to meet the neighborhood’s needs is essential to ensure that the building being redeveloped is actually used and can be actively preserved through use.

Once the functions that are compatible with the existing building and would ensure its maintenance through its use have been identified, mutually compatible functions must be chosen from among them. Indeed, overlapping one or more functions makes it possible to increase the number of users and the time of use of the building (which can be used by people with different interests) and at the same time to reduce the space occupied by the actual functions to the benefit of free space. This is a critically important analysis in the design because a wrong choice of functions leads to increased complexity in the design phase of flexibility.

2.2. Identification of Local Resources

The identification of resources in the territorial context has the function of both identifying identity elements in the pre-existence and having available a supply map of resources to be used in the flexibility project. Depending on whether or not the resources meet the requirements of the building body with respect to the chosen use, it will be possible to identify which resources can be used and how. The analysis of this area aims to map tangible
and intangible resources, focusing on potential resources that could be transformed into products and components to develop new local economies. In addition, the analysis looks at resources that are already available as products and scraps from companies rooted in the area.

2.3. Identification of Pre-Existing Building Values and Design Invariants

The purpose of analyzing a building is to gain a comprehensive understanding of it, in order to identify its strengths to be leveraged and its critical issues to be addressed. Conducting a historical analysis enables one to trace the building’s transformations from its construction to the present day and to distinguish its authentic and incongruous parts [49] and to identify the immaterial and symbolic values. This knowledge can inform design decisions that respect the building’s values and authentic parts, while transforming the incongruous parts. Understanding the building’s historical evolution also permits the identification of the construction techniques and materials used in each era. By comparing these with the relevant regulations of the time, one can ascertain the minimum performance required of the building and its components, as well as identify materials and systems used in similar buildings within the same territorial context.

The pre-existing building also needs to be analyzed from a distributional and spatial point of view in order to identify which circulation/access spaces can be varied (also with respect to their historical/symbolic value) and which ones can be rethought according to the new intended use. Further analysis on the building concerns the envelope with respect to both its state of maintenance and degradation and the environmental comfort performance correlated with the initial industrial use. This information will make it possible to identify what interventions need to be carried out to make the building responsive with the requirements that its new function demands [50].

2.4. The Design of Flexibility

Once compatible uses, local resources, valuable parts of the building from a historical, artistic or symbolic point of view and design invariants have been identified, it is possible to proceed with the flexible building redevelopment project.

From a spatial point of view, it should be considered that three categories of space with different characteristics come into play in flexibility that guide the project:

- Occupied space: it is a static space in which functions are placed that cannot be varied; think for example of spaces strongly related to the installations component or functional spaces to make flexible/dynamic spaces related to it;
- Dynamic space: it is the space that varies in both size and mode of use; multiple use of space allows efficient use of space; the more functions that can be superimposed, the more space is saved;
- Indifferent space: it is the access/concurrence space that allows movement in the space by switching from one function to another and that while free is not affected by variations; it is also a static space but is not related to activities specifically related to the intended use of the building.

The spatial design described above follows a well-defined methodological process that can be schematized in the following stages:

- To analyze the relationship between the various uses of the available space and consider how people will move through it as they go about their day; this involves charting interactions between uses and areas for movement or access in the most realistic and adaptable way possible. It is crucial to include the perspective of the person(s) who will be using the space.
- To identify functional macro-areas (accesses, routes, parking spaces, specific functions), assessing the relevance of the facility component for each function.
- To design the installations with respect to the macro-areas by identifying which of them are flexible (as they serve dynamic functions) and which are stable and therefore can be included among the design invariants and allocated in the occupied spaces.
To define what the specific requirements of each functional area are in two respects: (i) to define minimum and maximum use spaces and identify dimensionally a basic module; (ii) to define the environmental performance of the space according to the various uses.

To design one or more macro-modules resulting from the combination of basic modules that allow for dimensionally and functionally different spaces congruent with the requirements determined in the previous phase and the pre-existence.

To design a building system compatible with the pre-existence and the size and performance requirements of the macro-modules.

To design from a technological point of view the ways in which the macro-modules can be varied such that the space is dynamic and the ways in which the building system can be varied such that the environmental performance of the envelope is compatible with all identified uses.

3. Results

The described methodology was verified through application in a case study in order to prove its validity. The case study was chosen because it presents characteristics that are strongly representative of the industrial heritage of the 1900s: a large undivided space, rhythmically punctuated by naves, in which the spatial, typological and distributive configuration present a high symbolic value and in which the construction system used (constituting the envelope and load-bearing structure) assumes a historical and testimonial value with respect to the construction techniques used and the materials at the time considered “innovative”. The project is related to large spaces, intended in their original function for activities serving the neighboring port area of Sagunto. The building, which is located in the Puerto de Sagunto, is called NAU, Nave de Talleres Generales, is located near the seaport and is the largest of the still existing industrial buildings. Because of its size and architectural type, it constitutes what has been called on some occasions the “Industrial Cathedral” of the entire complex.

The analysis of the road system led to the identification of a critical issue in the current access due to the high travel speed of the road and the absence of areas designated for parking. Therefore, in the design phase, the mode of access to the area outside the building was varied in order to ensure entry from a road with travel speed of less than 30 km/h. The analysis of the neighborhood and the identification of the architectural emergencies and services present according to the prevailing age groups of the population highlighted the absence of cultural and recreational spaces (Figure 1).

The construction of the building dates back to 1919, as a single rectangular space whose initial measurements were 70 × 80 m (5600 sqm), and in 1930 it acquired its current size and physiognomy of 120 × 80 m extension (9600 sqm) [51]. Typologically, it is a “factory-ship” construction, and for this externally, its appearance is determined by four parallel ships, connected seamlessly inside, with a pitched roof, and at its apex are skylights that allow the evacuation of gases and the renewal of air. The two central aisles, of equal height, larger than the side aisles, have a width of 22.5 m, while the side aisles have a width of 15 m; this height difference is exploited through corridors to illuminate the central spaces. Figure 2 shows the historical evolution of the factory in order to understand the parts of historical and symbolic value [52–56].

Its interior is one large diaphanous space differentiated only by the different roof height between the side aisles and the two taller central ones. The fasteners are three rows of pillars, H-shaped concrete in the oldest part and steel in the final phase of construction, supporting wooden structures for the lighter roofing material. Initially, the wider central aisles were for boiler making and locomotive repair, while the narrower ones were devoted to foundry and regulation until 1957, when the adjacent machinery and services were assigned to New Works. From 1965 onward, all these vessels were used as foundry workshops, until 1984, when the company began to disappear. The historical analysis highlights the evolution of the space, which has occurred in a typologically, formally and
constructively consistent manner. The only exception is the entrance made in 2000 on the south front, highlighted by a metal canopy, which distorted the original direction of travel and perception of the space. Therefore, in the design phase it will be necessary to restore the historic entrances, enhancing their value also with respect to the internal spatial perception. [57,58].

![Figure 1](image-url)

**Figure 1.** Analysis of the neighborhood and identification of compatible uses in the specific territory.

On the side facades are huge vertical windows surmounted by a semicircular arch whose key is aligned with the height of the frieze. The succession of large windows makes these walls (north and south) look like a glass curtain wall that ensured sufficient illumination of the interior of the industrial production space.

These windows, arranged in pairs, rest on a high plinth with ashlar cladding, giving the facade the verticality needed to counteract the horizontality imposed by the longitudinal dimension of the ship.
Figure 2. Analysis of the historical evolution of the “Nave de Talleres Generales” [52–56].

The roof is made of metal, as is the structure, which consists of Belgian-type iron truss armor. The presence of a metal construction system highlights the area’s connection with the steel industry, of which the building becomes a tangible symbol, which the project should safeguard. The naves are built with reinforced masonry walls; the building rests on an irregular ashlar masonry plinth, surmounted by a rectangular-section molding lath that serves as the impost and curves delimiting the semicircular arches of the entrances, and plastered walls appear on this plinth.

Solid brick forms the central arches and cornices; at the same time, pairs of windows are separated from each other by vertical brick laths that resemble an order of pilasters. Its access orientation is East–West, and this determines the character of the main facades where it is evident at the point of access. Both planimetrically and facade-wise, the building has its own modular rhythm, the identification of which is useful in order to identify a design module compatible with the pre-existence (Figure 3).
The ventilation analysis of the building showed the presence of prevailing winds from the southeast and northwest, which, in view of the geometric conformation of the building and the positioning of the openings, can be exploited to promote the natural ventilation of the building. The solar analysis showed the absence of fully north-facing facades, a fact that is useful in the winter regime but at the same time needs control in the summer regime (Figure 4). The building already has skylights, which are used for lighting but mainly for smoke and gas evacuation from the original steel factory. In the project, it is planned to open these to create ventilation chimneys, by means of a chimney effect, which will serve to ventilate the environment in summer periods.

The analysis of the building systems related to the climate showed that they do not meet the regulatory minimums in terms of heat loss. Since this is a constrained building, however, it is not possible to intervene on the envelope. Therefore, in the flexibility design, thermal performance will have to be achieved by an envelope that is uncoupled from the existing building.

The flexibility design is based on the idea of the “box within a box”. The original building thus remains unchanged, placing within it a self-supporting structure, a container of functions, which is conceived independently but at the same time connected with its surroundings. This choice also allows the symbolic value of this industrial space to be stressed and emphasized. The boxes placed inside the large factory space do not lean against the walls but remain distant from them, leaving along the perimeter the spaces for travel. In addition, the boxes have a lower height than the height of the factory. The spatial configuration of the boxes thus allows the perception of space to be left unchanged. The
user upon entering will have the perception of one large space with multiple functions (as the factory with its machinery). In this way, moreover, the original structure of the shell and also of the metal supporting structure and roof is left visible, which brings back the symbolic value of the steel company that historically inhabited this space. The Nave de Talleres Generales represents the macro-box, a shell within which a flexible number of boxes are placed, which when added together and joined together allow the creation of various types of configurations, depending on the activities and uses, so as to adapt to the needs required by the user.

The interior space of the building is then divided into four naves (going back to the original concept, which emerged from the historical analyses), delimited by the paths, which assume an important role, having the dual function of walking and display (“indifferent space”). Each aisle will thus have its own destination; the central aisles will house the main functions, namely space for creative workshops for adults and children and cultural halls; the side aisles will have functions serving the main ones, namely exhibition places and services (“dynamic space”). The spaces left vacant become internal green squares used as public and exhibition places (Figure 5).

The focus of the project becomes the paths, which become actual places equipped with exhibition and information panels and rest areas with seating.

In addition, there are green resting spaces, which in combination with natural ventilation, help to mitigate summer overheating of the envelope.

**Figure 4.** Solar analysis of the “Nave de Talleres Generales”.
The focus of the project becomes the paths, which become actual places equipped with exhibition and information panels and rest areas with seating.

Figure 5. Identification of functional macro-areas.
Plant blocks and toilets, considering the plant component, are placed on the perimeter to the building in a pre-existing area and in the center of the building. These are “occupied spaces” that cannot be varied in the future. Given that the pre-existence has a floor level with different heights, the flexibility design includes the construction of a floating floor for the passage of electrical and water systems below it such as to allow the space to be varied according to future needs without having limitations due to the systems.

For each identified use, the minimum and maximum use spaces were defined, and a three-dimensional macro-module with them compatible of $4 \times 4 \times 4$ m was identified. This macro-module was then aggregated a variable number of times depending on the intended use of the space. The supporting structure consists of beams and pillars made of local timber and steel nodes. The designed construction system includes a limited number of nodes (central node, corner node and continuous node) using which multiple desired configurations can be achieved. The structure is then clad using insulated OSB panels. Four types of panels with similar dimensions but different functions were designed: closed panel, glazed panel, door panel and window panel. These panels allow different configurations of the same macro-module depending on the intended use of the area. All connections are made by bolting and screwing, so it is possible both to vary the space between the two OSB cladding panels and to insert additional layers in order to vary the performance of the envelope (Figure 6).

Figure 6. Design of macro-modules resulting from the combination of basic modules that allow for dimensionally and functionally different spaces congruent with the requirements determined in the previous phase and the pre-existence.
4. Discussion

From the analysis of the scientific literature carried out, strongly emerges how the new function, mainly of cultural and social vocation (museum, recreational and aggregation areas for social purposes, etc.), has an intrinsic force of urban and suburban redevelopment; the choice between different types of use seems to be more linked to the state of deterioration and decay of the structure rather than to in-depth analyses of the socio-economic and cultural context needs [17–20,27–31].

NAU case study gave the possibility to verify a methodology, described in Section 2, that includes both context analysis and detailed technological solutions in a single integrated design process consistent with the purposes of adaptive reuse of industrial heritage. The design logic of modularity compatible with the original system made it possible to only partially alter the internal spatial perception, reinforcing the perception of the rhythm dictated by the bays and large windows of the historic envelope (Figure 7). Therefore, it can be said that the architectural project at the same time receives strength and gives strength to the old factory. Compatibility is also guaranteed by the low material impact made possible by the choice of a dry construction technology for the new structure, reversible, flexible and functional for a continuous updating of the intended use. These requirements make it possible to deal in a structured way with the complexity of the reuse of an industrial space in which both the historical and symbolic values that the building conveys and the needs of a society that today no longer needs that space with an industrial vocation and for which it is therefore necessary to identify new and variable uses should be answered.

The architectural and technological choices have a considerable impact on the energy and performance aspects:

- New volumes are generated to be managed with new air conditioning and fluid adduction and deduction systems (the smaller the volumes, the easier and cheaper it will be to heat them);
- New materials, very different in thermal properties from the original ones, are used to make the new functional blocks (if materials are derived from the supply chain and are chosen with adequate attention to their thermo-physical properties, they can substantially contribute to optimizing the energy performance of the entire architectural complex).

Furthermore, the inclusion of new energy-independent functional modules allows the lack of a need to intervene by modifying the environmental performance (in thermo-hygrometric terms) of the original envelope. On the other hand, having energy-independent functional modules, capable of meeting the thermo-hygrometric requirements in relation to the new use of the structure, has an impact on the global thermo-hygrometric behavior of the historic building-new building system as a whole. For this reason, future research developments should deal with global analyses of the thermo-hygrometric performance of

Figure 7. Render of indoor spaces of the “Nave de Talleres Generales” after the flexibility intervention.
the new architectural complex generated by the fusion of the old structure with the new functional modules.

All these issues are also connected with the user’s environmental comfort in relation to the new fruition modes and therefore the renovated building’s activities: in fact, in the new architectural configuration, the resulting space between the historic envelope and the new functional modules becomes a sort of square, a space for meeting, strolling and activities that are generally carried out outdoors but which in this project still take place in an enclosed, internal space, with a very different microclimate from the outdoor space. Therefore, the indoor comfort is a fundamental theme in relation to the new activities and how these activities relate to the architecture that contains them.

The theme of comfort in the reuse of industrial architecture is currently not considered in the assessments relating to the environmental sustainability of the reuse actions of the built heritage. On the contrary, the impact of comfort on the use of plants could be significant precisely because of the need to convert spaces created for industrial aims to work, commercial or leisure spaces.

5. Conclusions

The reuse of industrial heritage, endowed with large spaces that can be repurposed, is itself a sustainable operation as it returns new spaces to the community without consuming land. The flexibility of the project increases the sustainability of the operation. In fact, flexibility ensures in the present day the possibility for the space to be used for a longer time: the possibility for the space to be used according to more functions leads to more users and a longer time of use. Lived spaces are consequently subject to constant maintenance that prevents their decay [12]. In addition, the possibility in the future to vary the space according to changing needs saves resources and continues to ensure the use of the building. The literature review confirmed that flexibility is a foundational requirement of adaptive reuse of industrial heritage, as it becomes a guarantor of both the quality of the space and its ability to change in the future. Therefore, identifying a method for designing flexibility while ensuring that the pre-existing building achieves comfort conditions in accordance with current standards, which is a necessary condition for the building to be effectively used, becomes particularly important. The method can be used by other researchers and designers as it consists of precise and determined steps, but these do not stiffen the design process but on the contrary allow the designer creative freedom of expression within a space of comfort, that is, a process that becomes a guarantor of the sustainability of the intervention and the enhancement of the industrial heritage. In fact, the method described identifies how to address the flexibility project in order to make it a tool for enhancing the pre-existence while developing an eco-friendly environment.

The NAU case study provides an example of how architectural and technological choices can impact the energy and performance aspects of a building, especially when it comes to the reuse of industrial architecture. With the logic of the “box within the box”, by adopting a modularity compatible with the original system, the project manages not to alter the value of the original spatiality while reinforcing the perception of the rhythm dictated by the bays and large windows of the historic envelope. The use of a dry construction technology for the new structure ensures low material impact, reversibility, flexibility and functionality for continuous updating of the intended use. However, the inclusion of new energy-independent functional modules also has an impact on the global thermo-hygrometric behavior of the historic building-new building system as a whole. In addition, the comfort of the indoor space is a fundamental theme in relation to the new activities (work, commercial or leisure spaces) and how these activities relate to the architecture that contains them. In summary, the NAU case study demonstrates the correctness of the method described and the importance of considering both pre-existence, current and future needs aspects in the project and checking that the project meets specific requirements ensuring sustainability.
Author Contributions: Conceptualization, S.D.G. and M.D.V.; methodology, S.D.G.; software, A.P.; validation, S.D.G. and M.D.V.; formal analysis S.D.G.; investigation, S.D.G., M.D.V. and A.P.; data curation S.D.G.; writing—original draft preparation, S.D.G. (Section 1, Section 2, Section 2.1, Section 2.2, Section 2.3, Sections 2.4, 3 and 5), M.D.V. (Sections 1 and 4), A.P. (images); writing—review and editing S.D.G. and M.D.V. The authorship of the images is by the authors. For the images that form part of Figure 2, please refer to the following bibliography: [52–56]. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknowledgments: The NAU project is an advancement of the thesis in Building Engineering-Architecture, University of L’Aquila, title: “Progetto di riqualificazione sostenibile di una fabbrica situata nella Comunità Valenciana”, student: Anna Paris, supervisors: Pierluigi De Berardinis, Luis Palmero and Stefania De Gregorio. The authors thank Pierluigi De Berardinis and Luis Palmero for their support in the NAU project.

Conflicts of Interest: The authors declare no conflict of interest.

References


21. De Vita, M.; Duronio, F.; De Vita, A.; De Berardinis, P. Adaptive retrofit for adaptive reuse: Converting an industrial chimney into a ventilation duct to improve internal comfort in a historic environment. Sustainability 2022, 14, 3360. [CrossRef]


27. Çakır, H.Y.; Edis, E. A database approach to examine the relation between function and interventions in the adaptive reuse of industrial heritage. J. Cult. Herit. 2022, 58, 74–90. [CrossRef]


30. Vizzarri, C.; Sangiorgio, V.; Fatiguso, F.; Calderazzi, A. A holistic approach for the adaptive reuse project selection: The case of the former Enel power station in Bari. Land Use Policy 2021, 111, 105709. [CrossRef]


32. Nocca, F.; De Toro, P.; Vysokhovska, V. Circular economy and cultural heritage conservation: A proposal for integrating Level (s) evaluation tool. Aestimatum 2021, 78, 105–143. [CrossRef]


43. Bottero, M.; D’Alpaos, C.; Oppio, A. Ranking of adaptive reuse strategies for abandoned industrial heritage in vulnerable contexts: A multiple criteria decision aiding approach. Sustainability 2019, 11, 785. [CrossRef]


48. Radognà, D.; Gerhard, K. Environmental and technological flexibility for new housing needs. VITRUVIO 2022, 7, 30–45. [CrossRef]


50. De Gregorio, S.; De Vita, M.; De Berardinis, P.; Palmero, L.; Risdonne, A. Designing the sustainable adaptive reuse of industrial heritage to enhance the local context. Sustainability 2020, 12, 9059. [CrossRef]

52. Portuarios de Sagunto. Available online: [http://portuariosdesagunto.com/galer%C3%ADas-de-fotos/fotos-historicas-puerto-de-sagunto/s30c154](http://portuariosdesagunto.com/galer%C3%ADas-de-fotos/fotos-historicas-puerto-de-sagunto/s30c154) (accessed on 10 November 2022).


Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.