



Climate-responsive design practices: A transdisciplinary methodology for achieving sustainable development goals in cultural and natural heritage

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ARTICLE INFO

Handling Editor: Jing Meng

Keywords:

Sustainable development
Sustainable development goals
Circular economy
Energy
Responsible consumption
Soil footprint
Waste reduction

ABSTRACT

The 17 Sustainable Development Goals (SDGs) defined by the United Nations represent a blueprint for the adoption of global practices and policies to foster sustainability in societies and increase efficiencies in resources uses. The Italian National Trust, FAI, has embraced these goals, developing a holistic and transdisciplinary methodology to promote a more sustainable approach to preserve its natural and built heritage. This methodology combines heritage protection with the SDGs in various macro-areas of interventions, including energy, water, biosphere, responsible consumption, and sustainable communities. The aim is to increase access to affordable and clean energy, reduce water, waste, and soil footprints, promote responsible consumption, and develop human capital. The paper proposes a set of strategies to achieve the SDGs in heritage, involving the collaboration of several stakeholders, ranging from institutions to citizens. The methodology is applied to a specific Italian case study, Casa Macchi in Morazzone, to highlight the challenges in achieving the dual objective of preserving the historic building and promoting sustainability in the built environment.

1. Introduction

The sustainable development «(...) *meets the needs of the present without compromising the ability of future generations to meet their own needs*» (World Commission on Environment and Development, 1984). Several policies have been developed to make our planet and economy climate-neutral, focusing particularly on buildings, infrastructures, renewable energy sources (RES), and industries. In particular, the 17 Sustainable Development Goals (SDGs), developed by the United Nations in 2015 (United Nations, 2015), represent the blueprint for the adoption of specific practices to face the interlinked challenges of climate change, biodiversity loss, health crisis, and socio-economic disparities by 2030. In this context, cultural heritage is universally recognized as a driver for the sustainable development (United Nations Educational, Scientific and Cultural Organization, 2013), green and energy transition (Potts, 2021), and resilience (United Nations, 2017), thanks to its ability to connect communities through shared culture (Potts, 2021), intrinsic creativity (European Commission, 2021), and opportunities for economic growth (Lucchi, 2023a). Both natural and built heritage contribute positively to climate adaptation and mitigation (United Nations, 2015), RES harvesting (Shetabi, 2015), use of local,

raw, and durable materials (Lucchi, 2023c), and traditional construction techniques (Lucchi, 2023c), that require low energy for production (Lucchi, 2023b), transportation, and recycling (Association for Preservation Technology, 1992).

Heritage preservation is thus an important action for supporting the sustainable development (Potts, 2021), and allows specific advantages as stated by the International Council of Monuments and Sites (ICOMOS), such as:

- (i) Protection of urban landscapes, cultural specificities, and environmental, social, and economic uniqueness of a territory (International Council on Monuments and Sites, 2011a).
- (ii) Keeping and retrofitting of old climate-responsive buildings based on passive design, local material, and traditional constructive techniques (International Council on Monuments and Sites, 1999) with the linked aim of waste reduction, materials recycle, and resource conservation (International Council on Monuments and Sites, 2013).
- (iii) Incubation of local traditions, practices, and values (e.g., crafts, arts, food products, music, performances), to support for local

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community identity, culture, and traditional activities ([International Council on Monuments and Sites, 2018](#));

- (iv) Development of tourism and related jobs (e.g., retails, entertainment, cultural production) ([International Council on Monuments and Sites, 2002](#)), improving the spatial attractiveness, territory revitalization proper values, and tax revenues ([Department for Development and Economic Cohesion, 2021](#)).

The sustainable preservation of historic buildings and centers, however, necessitates continuous and expensive interventions for management, maintenance, and revitalization ([International Council on Monuments and Sites, 2011b](#)). Low public and private investments lead to physical deterioration of historic towns and centers, driving more people to abandon those areas. Depopulation and abandonment further exacerbate the problems, reducing even more investments and resulting in several drawbacks, such as loss of cultural and historical significance over time ([Cervesato, 2022](#)), demographic decline and changes (e.g., decreasing birth rates, aging population, and loss of suburban residents) ([International Council on Monuments and Sites, 2011b](#)), lack of services and job opportunities ([De la Torre, 2013](#)). At the same time, an extremely rapid development of a historic area can lead to problems as well, with uncontrolled construction of new buildings in adjacent areas, mass tourism, and setting of new touristic businesses and activities, lacking an appropriate planned development ([United Nations Educational, Scientific and Cultural Organization, 2015](#)).

In light of this, tailored actions and approaches are needed to ensure a sustainable development for heritage areas, involving practices related to urban design, architecture, economics, and social engagement ([Stephenson, 2008](#)), but also territorial re-naturalization, construction of new infrastructures, building reconversion or reuse, as well as social inclusion efforts ([Australia ICOMOS, 1979](#)). Several studies have focused on the role of heritage preservation in urban and social regeneration, exploring interdisciplinary fields ([Lerario, 2022](#)). For instance, Misirlisoy et Günçe developed a holistic model for the adaptive reuse of abandoned or disused historic or heritage buildings ([Misirlisoy and Günçe, 2016](#)), demonstrating their significance in generating positive impacts at both urban and social levels. Furthermore, [Yıldız et al., \(2020\)](#) incorporated heritage preservation of historic buildings into sustainable development models for urban renovation projects, while [Alba-Rodríguez et al. \(2021\)](#) showcased its role in preventing the depopulation of cities through regeneration efforts. Jiang et al. emphasized the importance of active collaboration between different stakeholders (e.g., public, and private institutions, local actors, authorities) to facilitate the heritage urban development ([Jiang et al., 2023](#)). These collaborations are also recognized for activating circular economy strategies ([Ikiz Kaya et al., 2021](#)), favoring sustainable management ([Seduikyte et al., 2018](#)), assessing heritage-compatible strategies ([Lucchi and Agliata, 2023](#)), improving livability, stakeholders' engagement ([Gonçalves et al., 2021](#)), and environmental sustainability of conservative areas ([Lucchi, 2023c](#)).

However, current literature also points out a general lack of a methodological approach to explore the interconnections among sustainable development strategies, cultural heritage preservation, and socio-cultural effects. Furthermore, concrete complete examples to carry on specific sustainability projects are very limited, and among them, performance gaps between conservation intentions and actual implementation are usually found ([Gonçalves et al., 2021](#)).

1.1. Aim of the research

The literature analysis has allowed to identify some important gaps on sustainable development strategies applied to heritage preservation for urban and social regeneration, including:

- Limited exploration of interdisciplinary fields to demonstrate how they can contribute to the overall understanding of sustainable

development strategies in heritage preservation and urban renovation.

- Absence of in-depth explorations of the connections between the SDGs and the sustainable preservation of cultural heritage.
- Limited exploration of the implications of sustainable heritage preservation on urban renovation and social regeneration, also to serve as models and inspiration in similar contexts.
- Performance gap between conservation intentions and their actual implementation during the design and construction stages.
- Absence of sustainability indicators for evaluating the effectiveness and long-term sustainability of these actions.

To overcome the present gaps, this cross-cutting research aims to develop a transdisciplinary methodology for the implementation of Sustainable Development principles and practices for heritage preservation and urban renovation, with a specific focus on historic buildings and towns in the scenario of climate change. This methodology integrates diverse perspectives and multidimensional approaches to define a sustainable intervention on natural and cultural heritage, including energy, water, biosphere, responsible consumption, and sustainable communities. It is founded upon comprehensive schemas, which are based on both qualitative and quantitative key indicators defined by the SDGs and internationally recognized. Consequently, it can be employed to inform decisions regarding heritage preservation and regeneration interventions, involving active collaboration among restorers, conservators, designers, public administrations, and heritage authorities. Its application to Casa Macchi in Morazzone (Italy, Province of Varese) allows for a better understanding of how to implement the methodology in a concrete context.

1.2. Outline of the paper

The study is structured in two main parts:

- Sustainable Development methodology for natural and cultural heritage (section 2).
- Application of the methodology to a case study (section 3).

Section 2 presents the sustainable development methodology, grounded in the SDGs ([United Nations, 2015](#)), but with a specific focus on heritage preservation and urban renovation. The methodology transposes the general aims of SDGs' global warming reduction, carbon emissions decrease, and water and soil preservation, in specific targets for natural and architectural heritage preservation. These targets are structured on the following macro-areas of intervention: (i) energy (section 2.1); (ii) water footprint (section 0); (iii) biosphere (section 2.3); (iv) responsible consumption and production (section 2.4), and (v) sustainable communities (section 2.5).

This methodology is then applied to Casa Macchi (Section 3), a heritage complex characterized by historical, architectural, naturalistic, and social values located in the town of Morazzone. After a brief introduction of the case study, the building and urban survey and assessment (section 3.1), and the sustainable conservation design project (section 3.2) are explained. The design project is then verified according to the SDGs indicators (section 3.3). Finally, section 4 outlines the conclusions.

2. Sustainable development methodology for natural and cultural heritage

The Italian National Trust (in Italian "Fondo Ambiente Italiano", FAI ([Fondo Ambiente Italiano, 2023](#))) is an Italian non-profit foundation that collaborates with various stakeholders (e.g., private citizens, businesses, and institutions) to preserve and manage a wide range of properties, including buildings, pastures, and gardens across Italy. For each of them, it takes care of natural and built heritage, deeply considering

the challenges that impact their preservation.

Since the last decade, climate change effects have posed new challenges in the safeguarding of natural and cultural heritage, urging FAI to develop specific strategies, activities, and tools to design and integrate sustainability goals in the preservation of its natural and built heritage properties. The adopted strategies involve initiatives to enhance both climate mitigation and adaptation. Mitigation initiatives aim to reduce the impact of climate change by minimizing the emission of greenhouse gases into the atmosphere due to buildings' operation, but also those related to events, staff mobility, and construction sites. Climate adaptation initiatives aim to prevent or minimize the environmental damages through maps of risks and the adoption of resilience plans in synergy with local authorities.

Recently, FAI has decided to integrate past and current activities and tools into a transdisciplinary methodology for designing, assessing, educating, and presenting concrete results on sustainable practices for natural ecosystems, biodiversity, urban landscapes, and historical monuments.

This methodology has been built upon a comprehensive examination of several conceptual documents, dealing with both sustainability and cultural heritage. The most noteworthy and influential contributions have been the 17 SDGs by the United Nations (United Nations, 2015), the Policy Guidance by International Council on Monuments and Sites (ICOMOS) (Labadi et al., 2021) and the Thematic Indicators for Culture by the United Nations Educational, Scientific and Cultural Organization (UNESCO) (United Nations Educational, Scientific and Cultural Organization, 2021). All those three documents have provided a reference guideline for the development of FAI's methodology, as the focus of each document was different. The SDGs by the United Nations provide a framework on the challenges related to environmental sustainability and climate change mitigation. Heritage is explicitly referenced only in Target 11.4 ("strengthen efforts to protect and safeguard the world's cultural and natural heritage", (United Nations, 2015)). A revision of the SDGs from a heritage perspective is present in the ICOMOS document (Labadi et al., 2021). In this guidance, implications between the sustainable goals and heritage are outlined. The document recommends to further analyze the impact of heritage on a sustainable development process, through the development of specific indicators and the dissemination of case studies. The purpose of the document by UNESCO (United Nations Educational, Scientific and Cultural Organization, 2021), instead, is to measure the role of cultural heritage as a contributor to a sustainable development from an economic, social, and environmental point of view. Some thematic indicators are proposed, assessing the interconnections among heritage and environment safeguard, cultural diversity and knowledge, economic prosperity, and social cohesion.

FAI's methodology has been built upon considerations and critical analysis of those documents, integrating and expanding these frameworks with the strategies derived from the everyday work of the Italian National Trust for preserving, conserving, restoring, enhancing, and managing its cultural and natural heritage properties. The results of past and ongoing activities of FAI have been crucial elements in the development of the methodology, enriching the theoretical foundation with the practical skills gained during interventions in the field.

In this methodology, heritage is placed at the center of the process, as an indispensable legacy to be safeguarded and transmitted to future generations for ensuring the Sustainable Development according to its definition (World Commission on Environment and Development, 1985). The interconnections pointed out in (United Nations Educational, Scientific and Cultural Organization, 2021) have been restructured and consolidated into five macro-areas of intervention, to better detail the complex effects of heritage preservation and renovation on the environment and on society (Fig. 1):

- Energy.
- Water footprint.
- Biosphere.



Fig. 1. The macro-areas of intervention for the Sustainable Development developed by FAI according to the SDGs (Source: Authors' elaboration).

- Responsible consumption and production.
- Sustainable communities.

Each macro-area of intervention aims to achieve the appropriate strategies to ensure heritage preservation and urban renovation, according to the Sustainable Development strategies. Alongside them, the strategies related to the macro-area "Sustainable communities" (SDGs 4, 8, 9, 11, 13, and 17) are cross-cutting strategies that concern all other areas of intervention. In the following sections, each macro-area is analyzed in detail defining the link with the SDGs.

The methodology can be easily adapted to different types of heritage (e.g. buildings, urban areas, and natural landscapes) and local contexts, taking into account specific regulatory, cultural and legal requirements. To achieve this objective, the methodology is based on a comprehensive approach to heritage preservation, which considers not only physical conservation but also socio-economic and cultural aspects. By addressing multiple dimensions of sustainability, it offers a holistic framework that can be applied to different heritage sites worldwide. Furthermore, by starting from the SDGs, it is possible to exceed the scale of local legislation, thus allowing for replication and adaptation to various cultural and natural heritage sites with different characteristics, contexts, and challenges. Furthermore, the reference to the SDG indicators for defining the level of sustainability allows for the standardization of the evaluation and comparison process across various interventions, locations, legislative frameworks, and project design approaches based on internationally recognized qualitative and quantitative indicators.

2.1. Energy

In response to the global energy crisis and evolving legislative mandates, the energy efficiency solutions and RES implementation have become imperative for the built environment. This strategic shift aims to reduce energy consumptions, mitigate environmental footprints, and optimize energy and environmental costs and impacts. These ambitious targets generate preservation concerns, particularly in heritage-sensitive zones. A key dilemma lies in the potential detrimental effects on the intrinsic heritage value caused by the introduction of new technologies, such as External Thermal Insulation Composite Systems (ETICS),

photovoltaic (PV) panels, or wind turbines. The selection of these interventions results from a careful study of the history, characteristics, and conservation status of each property, facilitated by a detailed diagnostic survey. The monitoring of energy consumption and carbon dioxide (CO₂) emissions is important to assess the efficacy of these strategies. To reach high energy targets, FAI is implementing a comprehensive action plan with a Greenhouse Gases (GHG) emission reduction target of 35% by 2030 and climate neutrality target by 2040. Energy initiatives align with the following SDGs (Table 1):

- SDG 7 “Affordable and Clean Energy”, by promoting compatible interventions for integrating energy efficiency and RES in heritage buildings and protected landscapes.
- SDG 11 “Sustainable Cities and Communities”, by adopting sustainable practices to create more sustainable and resilient urban areas.
- SDG 12 “Responsible Consumption and Production”, by focusing on energy efficiency and RES implementation advocacy.
- SDG 13 “Climate Action”, by reducing GHG emissions and achieving climate neutrality objective in heritage properties.

2.2. Water footprint

To reduce the water footprint, FAI preserves and enhances traditional knowledge on water recovery, conservation, and reuse to cut wastage. It promotes the use of non-potable water for feasible purposes and employs historical and innovative technologies for rainwater and greywater harvesting and reuse. Through a meticulous analysis of asset water consumption and collection capacity (rainwater, lake, or shallow groundwater), a reduction target of 20% by 2030 for both potable and non-potable water consumption has been defined, with a particular emphasis on increasing non-potable water collection capacity. Water footprint initiatives align with the following SDGs (Table 2):

- SDG 6 “Clean Water and Sanitation”, by implementing water-saving technologies, introducing the water balance, and improving water saving targets by 2030.
- SDG 11 “Sustainable Cities and Communities”, by restoring ancient sustainable systems for drainage and watering.
- SDG 12 “Responsible Consumption and Production”, by focusing on sustainable water consumption and management in the heritage properties, and their surroundings also thanks to awareness campaigns.

2.3. Biosphere

Soil is a non-renewable resource and a common good, but today it is at risk globally due to increasing consumption and depletion. Jeopardization of biodiversity is due to the loss and degradation of habitats, pollution, climate change, and to the presence of invasive exotic species. Protecting endangered species is crucial as they play a fundamental role in the health of ecosystems and human life. This threatens food production, water supply, natural biodiversity, and climate stability. Cultural heritage provides ecosystem services by contributing to the conservation of biodiversity, soil quality, CO₂ sequestration, and water cycle regulation. In this context, FAI’s central goal is to advance human well-being and its connection with nature by promoting biodiversity awareness and conservation initiatives that protect and enhance plant and animal species. This mission is synergistic with preserving the historical and architectural value of its heritage sites. To achieve this, biosphere initiatives align with the following SDGs (Table 3):

- SDG2 “Zero hunger”, by making originally productive areas productive again.
- SDG 3 “Good Health and Well-being”, by protecting biodiversity and ecosystems to contribute to soil conservation.

- SDG 11 “Sustainable Cities and Communities”, by regenerating agricultural and forested areas that are made accessible to the public, with the support of substantial financial investments.
- SDG 12 “Responsible Consumption and Production”, by focusing on the use of resilient species and the elimination of non-harmful biological solutions for the environment.
- SDG 13 “Climate Action”, by strengthening resilience and adaptation to climate-related hazards and natural disasters.
- SDG 14 “Life below water”, by protecting marine heritage areas and its biodiversity.
- SDG 15 “Life on Land”, by preserving and restoring biodiversity and sustainable use of gardens, and protected landscapes.

These objectives have been incorporated into the guidelines for biodiversity conservation and management of the heritage properties. These guidelines are applicable in all environmental contexts (e.g., forested areas, pastures and alpine meadows, historical gardens and parks, orchards, and urban green areas).

2.4. Responsible consumption and production

Circular economy is an important issue to regulate FAI’s sustainable purchases and actions, ranging from sustainability of restoration projects and their construction sites to event management. Responsible consumption initiatives align with the following SDGs (Table 4):

- SDG 11 “Sustainable Cities and Communities”, by paying attention to the impact of construction sites and the voluntary adaptation to the MEC.
- SDG 12 “Responsible Consumption and Production”, by improving recycle and reuse, adopting strategies to reduce waste in its heritage sites and other activities.

All the SDGs considered in the UNESCO’s dimension “Environment & resilience” have been taken into account (United Nations Educational, Scientific and Cultural Organization, 2021). Only SDGs 9.1 “Quality infrastructure” and 16.4 “Recovery of stolen assets” are not pertinent as FAI’s activities do not relate to neither infrastructures nor stolen assets.

2.5. Sustainable communities

Extensive attention is given to the sustainable communities through educational activities and awareness campaigns, events at heritage sites involving local institutions, small and medium-sized businesses, cooperatives, universities, and social entities. These projects help the education of individuals about heritage conservation and, in some cases, even on the preservation of our legacy through virtuous actions and contributions. These activities are closely linked to awareness campaigns dedicated to specific themes (e.g., 6.b.1, 12.8.1, 13.1.1). Concurrently, the development of cultural industries and tourism activities targeting the public is crucial to generate economic drivers. Finally, the establishment of partnerships with both public and private entities is paramount for developing initiatives involving institutions. Sustainable communities’ initiatives align with the following SDGs (Table 5):

- SDG 4 “Quality education”, by implementing training, education, and awareness campaigns related to the preservation and valorization, sustainable development, sources’ conservation for cultural and natural heritage.
- SDG 8 “Decent work and economic growth”, by promoting new jobs in the sustainable tourism and cultural sector.
- SDG 9 “Industry, innovation and infrastructure”, by increasing the access to information and communications technology.
- SDG 11 “Sustainable Cities and Communities”, by high economic investments, public fundraising, and active participation.

Table 1
Energy strategies realized by FAI according to SDGs (source: Authors' elaboration).

SDG	SDGs target	SDGs indicator	FAI's strategy
	7.1 By 2030, ensure universal access to affordable, reliable and modern energy services	7.1.1 Proportion of population with access to electricity 7.1.2 Proportion of population with primary reliance on clean fuels and technology	Refurbishment and opening to the public properties with difficult accessibility, isolated, or closed (e.g., Podere Casa Lovara, Casa Macchi) Elimination of LPG-powered heating systems in properties by 2026 and their replacement with heat pumps
	7.2 By 2030, increase substantially the share of renewable energy in the global energy mix	7.2.1 Renewable energy share in the total final energy consumption	Purchase and supply of electricity from RES for all the properties by 2024 Heritage-compatible RES integration in properties without access to the electricity grid (e.g., Podere Casa Lovara) Replacement of less efficient HVAC systems with heat pumps possibly combined to RES
	7.3 By 2030, double the global rate of improvement in energy efficiency	7.3.1 Energy intensity measured in terms of primary energy and GDP	Participation in Energy Communities by 2040 Improvement of the energy performance of the building envelope through measures such as ventilated roofs and thermal insulation Improvement of the energy performances of HVAC systems (e.g., Villa Necchi Campiglio) Replacement of outdated and inefficient light bulbs with Light Emitting Diode (LED) Introduction of centralized lighting and HVAC control systems in buildings open to the public (e.g., Villa Necchi Campiglio) Reaching of the carbon neutrality target by 2040 RES share improvement in heritage-compatible buildings
	11.4 Strengthen efforts to protect and safeguard the world's cultural and natural heritage ^a	11.4.1 Total per capita expenditure on the preservation, protection and conservation of all cultural and natural heritage, by source of funding (public, private), type of heritage (cultural, natural) and level of government (national, regional, and local/municipal)	Conservation and reuse of the architectural heritage in FAI's properties (buildings, villages, ruins)
	11.6 By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management	11.6.2 Annual mean levels of fine particulate matter (e.g., PM2.5 and PM10) in cities (population weighted)	Promotion of mobility by installing electric columns and car charging stations in urban properties Voluntary adherence to the MEC events by promoting public, electric, and alternative transports (e.g., car-sharing) in all properties
	12.2 By 2030, achieve the sustainable management and efficient use of natural resources	12.2.1 By 2030, achieve the sustainable management and efficient use of natural resources	Use of heritage-compatible RES solutions, such as geothermal and heat pumps for major interventions
	12.8 By 2030, ensure that people everywhere have the relevant information and awareness for sustainable development and lifestyles in harmony with nature	12.8.1 By 2030, ensure that people everywhere have the relevant information and awareness for sustainable development and lifestyles in harmony with nature	Advocacy and education campaign "FAI for the climate" on energy efficiency and RES implementation
	13.2 Integrate climate change measures into national policies, strategies and planning	13.2.2 Total greenhouse gas emissions per year	Reaching of the carbon-neutral target by 2040 GHG emissions analysis in all properties from 2024
	13.3 Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning ^a	13.3.1 Extent to which (i) global citizenship education and (ii) education for sustainable development are mainstreamed in (a) national education policies; (b) curricula; (c) teacher education; and (d) student assessment	Education and awareness programs for students and teachers in schools of all levels on energy efficiency and RES in cultural heritage, with a focus on FAI's properties

^a Goal considered by the UNESCO's conceptual framework (United Nations Educational, Scientific and Cultural Organization 2021).

- SDG 16 "Peace, justice and strong institution", by promoting inclusive and non-discriminatory policies and activities.
- SDG 17 "Partnership for the goals", by promoting and coordinating interventions in synergy with local bodies, Research Institutions, Universities, producers, professionals, and individual citizens.




All the SDGs considered in the other UNESCO's dimensions have been taken into account (United Nations Educational, Scientific and Cultural Organization, 2021). As previously, SDGs 9.1 "Quality infrastructure" and 16.4 "Recovery of stolen assets" are not pertinent as FAI's activities do not have an influence on infrastructure or stolen assets. Otherwise, SDGs 8.a "Increase Aid for Trade", 10.2 "Social inclusion", 12.a "Sustainable consumption", 16.10 "Fundamental freedoms", and 16.a "Prevention of violence" are not pertinent as pertain to developing countries where FAI does not operate.

2.6. Considerations on the application of the methodology

The assessment of the interconnected effects among heritage and the five areas of intervention is carried out within a project outlined as in the flowchart in Fig. 2. Each project refers to a specific and unique heritage place, and the first step is a detailed survey and audit of the property and its natural and urban surroundings. The indications from the audit and the assessment of the five areas of intervention help in drafting and refining the preservation project, up to its final version.

The tangible and intangible heritage contained in FAI properties represents an immense wealth and, simultaneously, harbors significant complexity. Each site possesses distinct characteristics, varying in intensity, and offers possibilities for sustainable development. These possibilities are further influenced by regional or local policies, as well as by individuals involved in political and social processes addressing growth and responses to climate change. The outlined methodology is

Table 2
Water footprint strategies realized by FAI according to SDGs (source: Authors' elaboration).

SDG	SDGs target	SDGs indicator	FAI's strategy
	6.4 By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity	6.4.1 Change in water-use efficiency over time	Presence of flow restrictors and dual flushes to make the use of fresh water more efficient in all buildings
	6.5 By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate	6.4.2 Level of water stress: freshwater withdrawal as a proportion of available freshwater resources 6.5.1 Degree of integrated water resources management	Water balance of FAI's properties by 2024 20% reduction of water footprint by 2030 Reuse of historical tanks and construction new tanks for rainwater collection to be used for garden irrigation Integration of rainwater with water from the aqueduct or shallow groundwater for toilet flushing Restoration of old water-related ecosystems
	6.6 By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers, and lakes ^a 6.b Support and strengthen the participation of local communities in improving water and sanitation management	6.6.1 Change in the extent of water-related ecosystems over time	Awareness campaign (#Savethewater) to improve the understanding of the value of water and reduce water consumptions
	11.4 Strengthen efforts to protect and safeguard the world's cultural and natural heritage ^a	11.4.1 Total per capita expenditure on the preservation, protection, and conservation of all cultural and natural heritage, by source of funding (public, private), type of heritage (cultural, natural) and level of government (national, regional, and local/municipal)	Conservation and reuse of ancient solutions for water preservation and waste limitation in FAI's properties
	12.2 By 2030, achieve the sustainable management and efficient use of natural resources	12.2.1 Material footprint, material footprint per capita, and material footprint per GDP	Reduction of water consumptions of 20% by 2030 Climatic adaptation with regulation of meteoric water, rainwater collection Advocacy and education campaign "#Savethewater" for encouraging a responsible water use
	12.8 By 2030, ensure that people everywhere have the relevant information and awareness for sustainable development and lifestyles in harmony with nature	12.8.1 Extent to which (i) global citizenship education and (ii) education for sustainable development are mainstreamed in (a) national education policies; (b) curricula; (c) teacher education; and (d) student assessment	

^a Goal considered by the UNESCO's conceptual framework (United Nations Educational, Scientific and Cultural Organization 2021).

inherently applied across various scales, encompassing institutional activities at the national level to strategies implemented at the local level. The application intensity varies, contingent upon the potential of the territories and communities involved.

3. Application of the methodology to a case study

To illustrate the application of this methodology, the recent case study of Casa Macchi has been selected because it allowed the implementation of the majority of the SDGs indicators. Casa Macchi is a historic Italian complex located in Morazzone, a small town founded in Roman times near Varese, in the northern part of Italy. Morazzone has a population of 4,000 inhabitants and covers an area of 5.5 km². During the late 19th and early 20th Centuries, it held a wealth of architectural and cultural heritage belonging to economically solid bourgeois families, which underwent significant transformations over the last century (Fig. 3a). Since the 1960s, the Italian economic and construction boom has led to a substantial modification of its urban morphology (Fig. 3b).

Like many provincial towns, it has witnessed an increase in population and a simultaneous desire for housing modernization. This situation generated a strong implementation of new construction and building renovations, reducing the architectural quality and heritage preservation of the traditional features (Fig. 4) (Dalla Gasperina, 2017). These significant cultural and urban changes have profoundly influenced the life in the town and the commercial fabric. Many small shops have closed (e.g., grocery stores, delicatessen, blacksmiths, carpenters, shoemakers, knitwear stores, bakeries, fruit vendors), making way for large shopping centers, stores in the provincial capitals, and online shopping.

Inside this scenario, Casa Macchi is one of the few remaining examples of those affluent homes (Dalla Gasperina, 2017). The complex consists of a main house, a rural building, and a garden (Fig. 5).

The main house dates back to the 17th-century, and it is an 800 m²

two-story structure (Fig. 6a). The first floor hosts the representative rooms, while the second floor accommodates the private rooms with a veranda, a glass gallery that provides a view on the surroundings (Dalla Gasperina, 2017). Its interior is composed of twenty-three rooms, adorned with simple tempera decorations, cornices, architectural baseboards, and decorated ceilings, showcasing the historical lifestyle of Lombard bourgeoisie during that era. The house is richly furnished with household items, art objects, fabrics, paintings, and prints, making it a valuable historical document (Fig. 6b).

The rural building is adjacent to the main house, located on the south-east side. It is a 17th-century two-story rustic building with a small courtyard. The farmhouse in the past was used for agricultural purposes (e.g., barns, stables with feeding troughs). The ground floor also features a 20th-century orangery used to shelter exotic and citrus plants (e.g., lemons, mandarins, citrons, oranges) in the cold seasons. The structure is significantly damaged due to long-term abandonment and the addition of recent superstructures. However, the spaces still retain an agricultural atmosphere typical of the rural architecture (e.g., rustic plaster, mixed masonry, wooden floors and roofs, lack of alignment between openings) (Fig. 6c). Both buildings host a swift's nest; in the main building, the nest is located in a turret originally intended as a belvedere.

The private garden, approximately 1,300 m² in size, lies between the house and the rural building. This garden reflects the taste of the 19th-century and includes an aviary, a well, a grove of palm trees, flowerbeds bordered with rocks, and lemon pots. A low brick wall, interrupted by an iron gate, separates the garden from an agricultural area of about 6,000 m², which serves as a lawn. The complex was closed in 1979, leading to a dual situation. On the one hand, the original rooms, furnishings, and decorations remained unchanged as arranged and furnished in the original design (Peregalli, 2022). Just essential modernizations were made, such as functional interventions on the electrical systems and the construction of a new bathroom (1960s). On the other hand, the

Table 3
Biosphere strategies realized by FAI according to SDGs (source: Authors' elaboration).

SDG	SDGs target	SDGs indicator	FAI's strategy
	2.4 By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality ^a	2.4.1 Proportion of agricultural area under productive and sustainable agriculture	Making originally productive areas productive again
	3.9 By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination	3.9.1 Mortality rate attributed to household and ambient air pollution 3.9.2 Mortality rate attributed to unsafe water, unsafe sanitation and lack of hygiene (exposure to unsafe Water, Sanitation and Hygiene for All (WASH) services) 3.9.3 Mortality rate attributed to unintentional poisoning	Awareness raising and advocacy to promote soil conservation in Italy and Europe Elimination of agricultural use of glyphosate, a probable carcinogenic pesticide for humans
	11.3 By 2030, enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries 11.4 Strengthen efforts to protect and safeguard the world's cultural and natural heritage ^a	11.3.1 Ratio of land consumption rate to population growth rate	Adoption of biologic and biodynamic methods for agriculture Requalification of relevant areas, gardens, parks, abandoned or disused agricultural lands in FAI's properties
	11.7 By 2030, provide universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and persons with disabilities ^a 11.a A Support positive economic, social and environmental links between urban, peri-urban and rural areas by strengthening national and regional development planning	11.4.1 Total per capita expenditure on the preservation, protection and conservation of all cultural and natural heritage, by source of funding (public, private), type of heritage (cultural, natural) and level of government (national, regional, and local/municipal) 11.7.1 Average share of the built-up area of cities that is open space for public use for all, by sex, age and persons with disabilities	Conservation of green areas and biodiversity (gardens, courtyards, grass areas) in FAI's properties Management of 73 properties, including 55 open to the public and 18 under restoration Open private green areas to the public inside FAI's properties without paying a ticket Lobbying activities to promote land management policies and tools at national and international level (e.g., European research projects, political activities, network with other foundations)
	12.2 By 2030, achieve the sustainable management and efficient use of natural resources 12.4 By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil to minimize their adverse impacts on human health and the environment 12.8 By 2030, ensure that people everywhere have the relevant information and awareness for sustainable development and lifestyles in harmony with nature	11.a.1 Number of countries that have national urban policies or regional development plans that (a) respond to population dynamics; (b) ensure balanced territorial development; and (c) increase local fiscal space 12.2.1 By 2030, achieve the sustainable management and efficient use of natural resources 12.4.1 By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil to minimize their adverse impacts on human health and the environment 12.8.1 Extent to which (i) global citizenship education and (ii) education for sustainable development are mainstreamed in (a) national education policies; (b) curricula; (c) teacher education; and (d) student assessment	Use of resilient species for climatic adaptation strategies in FAI's gardens Elimination of chemical fertilizers or pesticides and the selection of non-harmful biological solutions for the soil and the environment Development of specific guidelines for adopting and implementing a sustainable conservation plan and site in heritage buildings and areas to reduce waste and chemicals Advocacy and education campaigns "Save the soil" and "FAI for biodiversity" for safeguarding the natural environments
	13.1 Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries ^a	13.1.1 Number of deaths, missing persons and directly affected persons attributed to disasters per 100,000 population 13.1.2 Number of countries that adopt and implement national disaster risk reduction strategies in line with the Sendai Framework for Disaster Risk Reduction 2015–2030 13.1.3 Proportion of local governments that adopt and implement local disaster risk reduction strategies in line with national disaster risk reduction strategies	Climate adaptation and mitigation strategies for hydrogeological instability and natural disasters to ensure safe public access Mapping of the risk levels of properties in cooperation with local governments
	14.5 By 2020, conserve at least 10 per cent of coastal and marine areas, consistent with national and international law and based on the best available scientific information ^a	14.5.1 Coverage of protected areas in relation to marine areas	Protecting marine heritage areas and its biodiversity in the marine properties (e.g., Baia di Ieranto)
	15.1 By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements ^a 15.2 By 2020, promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests and substantially increase afforestation and reforestation globally	15.1.1 Forest area as a proportion of total land area 15.1.2 Proportion of important sites for terrestrial and freshwater biodiversity that are covered by protected areas, by ecosystem type 15.2.1 Progress towards sustainable forest management	33 ha of woods with high biological and cultural diversity, fully open to the public 17 of properties located partially or entirely within protected areas (SPA, SCI, UNESCO sites) Adoption of a 100% sustainable management policy for the forest areas, in line with FAI's biodiversity goals by 2030

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Table 3 (continued)

SDG	SDGs target	SDGs indicator	FAI's strategy
	15.3 By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world	15.3.1 Proportion of land that is degraded over total land area	Recovery and protection of 863 ha of landscape
	15.4 By 2030, ensure the conservation of mountain ecosystems, including their biodiversity, in order to enhance their capacity to provide benefits that are essential for sustainable development	15.4.1 Coverage by protected areas of important sites for mountain biodiversity 15.4.2 Mountain Green Cover Index	Environmental redevelopment of properties in high mountains to reactivate pastures, restore mountain huts, and revive traditional dairy farming and grazing (e.g., Alpe Pedroria and Madrera; Monte Fontana Secca)
	15.8 By 2020, introduce measures to prevent the introduction and significantly reduce the impact of invasive alien species on land and water ecosystems and control or eradicate the priority species	15.8.1 Proportion of countries adopting relevant national legislation and adequately resourcing the prevention or control of invasive alien species	Adoption of climate adaptation strategies through the replacement of existing species with resilient ones (e.g., Palazzo Moroni)

^a Goal considered by the UNESCO's conceptual framework (United Nations Educational, Scientific and Cultural Organization 2021).

buildings were significantly damaged by water infiltrations, with ceilings partly collapsed, superficial finishings completely ruined. Dust, mold, and lack of maintenance further jeopardized the preservation of decorations, woodwork, and fabrics.

Casa Macchi was donated to FAI in 2015, along with all its belongings (e.g., furnishings, furniture, paintings, prints, silverware, linen, dishes, tableware, clothing, shoes), to be transformed into a living museum for the renovation of the town. A complete restoration and re-functionalization project were realized to make the complex accessible to the public, preserving the original heritage significances, and atmosphere. The main house has been restored to host in a house museum (also known as "memory museum") that opened in December 2022, while the ongoing restoration of the rural building aims to convert it into a museum for agricultural artifacts. Thanks to an innovative Program Agreement signed by the Lombardy Region, the Municipality of Morazzone, and FAI in 2017, its restoration was positioned as the catalyst for the regeneration and revitalization of the historic town.

The design project has been divided in three phases:

- Phase 1: Building and urban survey and assessment, aimed at exploring the past and current state of the building, the key-features of its natural and architectural heritage and its relationship with the urban surroundings (section 4.1).
- Phase 2: Sustainable conservation design project, exploiting the results of the Phase 1 analysis to develop a project harmonizing the sustainability objectives, the characteristics of the building, and the planned future development of both the building and the surrounding town (section 4.2).
- Phase 3: Verification of the final project, assessing the actual outcomes of the methodology application and checking its consequences on an urban scale (section 4.3).



Each phase is detailed in a specific following section.

3.1. Building and urban survey and assessment

A crucial phase of a project aimed at making more sustainable a building is the building inspection and audit. In fact, this procedure

Table 4

Responsible consumption and production strategies realized by FAI according to SDGs (source: Authors' elaboration).

SDG	SDGs target	SDGs indicator	FAI's strategy
	11.6 By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management	11.6.1 Proportion of municipal solid waste collected and managed in controlled facilities out of total municipal waste generated, by cities	Adoption of guidelines for sustainable management of FAI's construction sites by 2030, including the reduction of construction waste and the adoption of Green Procurement as requested also by the Minimum Environmental Criteria
	12.1 Implement the 10-Year Framework of Programmes on Sustainable Consumption and Production Patterns, all countries taking action, with developed countries taking the lead, taking into account the development and capabilities of developing countries	12.1.1 Number of countries developing, adopting or implementing policy instruments aimed at supporting the shift to sustainable consumption and production	Adoption of sustainable procurement strategies by voluntary adherence to the MEC (paper, printers, events, furniture, construction, waste ...) and the adoption of guidelines to reduce the impact of restoration sites
	12.2 By 2030, achieve the sustainable management and efficient use of natural resources	12.2.1 Material footprint, material footprint per capita, and material footprint per GDP 12.2.2 Domestic material consumption, domestic material consumption per capita, and domestic material consumption per GDP	Adoption of guidelines for sustainable management of its construction sites by 2030, including the use of recycled materials, the reuse of reclaimed materials, and the reduction of construction waste
	12.5. By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse	12.5.1 By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse	Preservation of historical materials, reducing demolition waste and reusing local elements and materials within a circular economy framework (furniture, architectural elements, plant parts) Implementation for waste separation for visitors and staff Composting of garden waste
	12.7 Promote public procurement practices that are sustainable, in accordance with national policies and priorities	12.7.1 Promote public procurement practices that are sustainable, in accordance with national policies and priorities	Voluntary adherence to the MEC and drafting of guidelines for public procurement of institutional activities
	12.b Develop and implement tools to monitor sustainable development impacts for sustainable tourism that creates jobs and promotes local culture and products ^a	12.b.1 Implementation of standard accounting tools to monitor the economic and environmental aspects of tourism sustainability	Voluntary adherence to MEC for favoring sustainable touristic events

^a Goal considered by the UNESCO's conceptual framework (United Nations Educational, Scientific and Cultural Organization 2021).

allows for the collection of a huge number of data and information, needed for a systematic assessment of the current performances of the building in all the sustainability macro-areas. A detailed study involves on-site visits, acquisition of specific measurements and data, and analysis of the integrated building-surroundings context, allowing the recognition of the main aspects that lead to specific or overall building inefficiencies. Additionally, this phase may include the use of specific tools for building simulation and the evaluation of key performance indicators. This broad and holistic analysis also helps in the identification of the most effective and suitable solutions to implement.

In Casa Macchi analysis, the audit phase included a complete set of tests and investigations, carried out by several different experts in each field. This work was aimed at providing a detailed knowledge of the building and its historical evolutions, changes, and surroundings at current state. The purpose was double: check and identify all the areas where heritage preservation projects were more urgent and needed and properly design the improvement action, also considering all the aesthetic and artistic constraints. As an example, all the roofs and the basements have been carefully inspected, substituting the hugely damaged wooden beams, and repairing the other ones. Besides, the energy audit was supported by non-invasive diagnostic techniques (e.g., infrared thermography, heat flux meter) and environmental monitoring to understand the building performances and indoor climates. The absence of a proper heating and cooling system led to a comprehensive survey of the houses' volumes to choose the optimal position for installing the generators without creating an impact on the overall complex. Also, the existing electrical systems were analyzed to identify which existing traces could be reused and where new ones could be created to minimize their impact (e.g., concealed in the attic and void space and exposed in other areas). This survey has been used also for simulating purposes. In fact, a dynamic Building Energy Model (BEM) of the rural building has been implemented (Lucchi and Schito, 2023a), using as inputs all the features of the building enclosure (e.g., walls, windows), and an esteem of the internal gains due to visitors and artificial lighting. This work has been aimed at evaluating the possibility of an experimental refurbishment of the small building, transforming it into an educational space with a reduced environmental impact, but with a specific attention to aesthetic integration. Additional details on the main house allow the creation of a comprehensive BEM, simulating both the rural building and the main house, to analyse the energy fluxes of all the complex. Moreover, the study of local hydrogeological setting required a geological investigation to reactivate the original water resources. This involved piezometric, precipitation, and water chemistry analyses to facilitate the water reuse. Finally, the biosphere issue involved the historical-architectural investigation of the swift towers and the botanical-naturalistic assessment of the green areas to identify resilient and native plants. The activities to be introduced at Casa Macchi originated from a careful study of the historical and current activities in the town of Morazzone. This involved identifying cultural, touristic, and commercial gaps to address.

3.2. Sustainable conservation design project

Considering the results of the building and urban analysis, a sustainable design project was developed to transform the building for museum purposes. The most challenging part was the transformation of the main building into a house-museum. Thus, several interventions were realized to overcome architectural barriers and improve safety aspects (e.g., seismic safety, fire safety) necessary for public opening. In all cases, only heritage-compatible interventions were selected with the support of the local Heritage Authority, Universities, and designers. The heritage preservation project encompassed the conservative restoration and structural consolidation of the main house following the criterion of the "minimum intervention". Reintegration was chosen over restoration, opting for repair rather than replacement, and acknowledging historical lacks and fragilities as opportunities. To this purpose, the preservation of

Casa Macchi aimed to eliminate the causes and manifestations of damage and vulnerability, primarily linked to the presence of water and lack of maintenance (e.g., collapse of numerous portions of decorated ceilings, decay of wooden floor structures) (see also section 3.2.4). Recovery works included the restoration of historical windows, radiators, and existing chimneys, as well as the remediation of original masonries, the replacement of roofing materials, the recovery of rainwater, and the structural consolidation. Repairs and integrations, where possible, utilized old and second-hand materials, such as old roof tiles for both roofs and floors (Fig. 7a), restored radiators for the museum path (Fig. 7b), old wooden shutters as sliding panels for the ticket shop (Fig. 7c), used handles, mirrors, and chandeliers replacing those in the house, now broken and no longer functional.

According to the methodological framework, the description of the sustainable conservation project is divided into energy (section 3.2.1), water footprint (section 3.2.2), biosphere (section 3.2.3), responsible consumption and production (section 3.2.4), and sustainable communities (section 3.2.5).

3.2.1. Energy

The public opening of the house museum introduces some consideration on the energy efficiency and environmental sustainability of the design project. The main goal is the balance among human comfort, heritage preservation, and minimization of energy consumption. This achievement is more challenging here, where it is crucial to safeguard not only the building and its artifacts but also the typical atmosphere of the ancient place (Lucchi and Schito, 2023b). The key SDGs indicators for this strategy are:

- Refurbishment and opening to the public of the property (SDGs indicators 7.1.1, 11.4.1).
- Improvement of the energy efficiency of the building envelope with heritage-compatible interventions (SDGs indicators 7.3.1, 11.4.1).
- Replacement of inefficient or non-functioning heating systems with efficient HVAC systems, especially heat pumps (SDGs indicators 7.2.1, 12.2.1): with the twofold aim of increase people's comfort but keep the non-renewable primary energy needs at a minimum (SDGs indicator 7.3.1), those systems have been installed only for a limited volume of the museum.
- Preservation of the historical electrical system through the restoration of original chandeliers, the replacement of outdated and inefficient light bulbs with Light Emitting Diode (LED), and the integration of a centralized control system (SDG indicator 7.3.1).
- Selection of heritage-compatible RES technologies (SDGs indicators 7.2.1, 7.3.1, 12.2.1).
- Purchase and supply of electricity from RES (SDG indicator 7.2.1)
- Creation of an energy communities (SDGs indicator 7.2.1).
- Development of awareness campaigns on energy efficiency, RES, and climate mitigation (SDGs indicators 12.8.1 and 13.3.1).

The energy retrofit was different for the main house and the rural building. In the first case, the conservation of heritage significance of historical finishes did not allow any intervention on the insulation of the building envelope. Also, the original windows were restored by applying safety and anti-UV films, preserving the historical features, which, in many cases, include single-pane glasses. Otherwise, in the rural building more advanced design solutions for energy efficiency are considered, such as insulation of walls and roof, and replacement of damaged windows. In both cases, the installation of heating and lighting systems was intricate due to their non-functioning or inefficiency. Furthermore, as the cooling system was obviously absent in the original building configuration, those interventions also introduced energy demands that were not present before. Consequently, the design of those systems was oriented to keep these needs, and the associated carbon emissions, as lower as possible. This result, as an example, to the installation of heating and cooling system only in a limited area of the house, even if

Table 5
Sustainable communities strategies realized by FAI according to SDGs (source: Authors' elaboration).

SDG	SDGs target	SDGs indicator	FAI's strategy
	4.4 By 2030, substantially increase the number of youth and adults who have relevant skills, including technical and vocational skills, for employment, decent jobs and entrepreneurship ^a 4.7 By 2030, ensure that all learners acquire the knowledge and skills needed to promote sustainable development ^a	4.4.1 Proportion of youth and adults with information and communications technology (ICT) skills, by type of skill 4.7.1 Extent to which (i) global citizenship education and (ii) education for sustainable development are mainstreamed in (a) national education policies; (b) curricula; (c) teacher education and (d) student assessment	Promotion of virtual tours, apps, podcasts, and courses for visitors and staff on heritage preservation and sustainable preservation Activities for all school levels (school trips and educational visits, competitions, online courses for teachers and students) National FAI's days for schools with exclusive school visits conducted by young individuals trained by FAI volunteers and their teachers on the topics of environment, landscape, and agriculture Continuous training of operators with lessons held by university professors Opening new jobs in the cultural sector both at FAI's headquarter in Milan and single properties on the Italian territory
	4.c By 2030, substantially increase the supply of qualified teachers 8.3 Promote development-oriented policies that support productive activities, decent job creation, entrepreneurship, creativity and innovation, and encourage the formalization and growth of micro-, small- and medium-sized enterprises, including through access to financial services * 8.9 By 2030, devise and implement policies to promote sustainable tourism that creates jobs and promotes local culture and products ^a	4.c.1 Proportion of teachers with the minimum required qualifications, by education level 8.3.1 Proportion of informal employment in total employment, by sector and sex 8.9.1 Tourism direct GDP as a proportion of total GDP and in growth rate	Definition of policies for the sustainable tourism (e.g., convention with local public transportation, organization of sustainable visits in construction or operational phases) Wi-fi installation in all FAI's properties
	9.c Significantly increase access to information and communications technology and strive to provide universal and affordable access to the Internet in least developed countries by 2020 ^a	9.c.1 Proportion of population covered by a mobile network, by technology	
	11.3 By 2030, enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries 11.4 Strengthen efforts to protect and safeguard the world's cultural and natural heritage ^a	11.3.2 Proportion of cities with a direct participation structure of civil society in urban planning and management that operate regularly and democratically 11.4.1 Total per capita expenditure on the preservation, protection and conservation of all cultural and natural heritage, by source of funding (public, private), type of heritage (cultural, natural) and level of government (national, regional, and local/municipal)	Activation of collaborations in the local area with municipalities, local authorities, universities, or local associations for promoting the sustainable development Promotion of environmental policies, landscape protection, and climate mitigation (e.g., FAI for the climate, Save the soil, Save the water, Let's change agriculture) Investment of 143.6 million euros from 1975 in cultural and natural heritage restoration for the benefit of the community, through private and public funds Investment of more than 100.000 euros for regular maintenance of cultural and natural heritage "Places of the Heart" census to report the places that are important to the community, identified by citizens through the votes of the community FAI Spring and Autumn Days that open usually inaccessible sites and also involve public fundraising and active participation, thanks to the commitment of the territorial Delegations and volunteers
	11.7 By 2030, provide universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and persons with disabilities	11.7.1 Average share of the built-up area of cities that is open space for public use for all, by sex, age and persons with disabilities	
	11.a A Support positive economic, social and environmental links between urban, peri-urban and rural areas by strengthening national and regional development planning	11.a.1 Number of countries that have national urban policies or regional development plans that (a) respond to population dynamics; (b) ensure balanced territorial development; and (c) increase local fiscal space	Territorial development actions through the industry created by cultural and outreach activities Lobbying activities to promote the development of land management policies and tools (Save the water, Save the soil, FAI for the climate, FAI for biodiversity)
	12.b Develop and implement tools to monitor sustainable development impacts for sustainable tourism that creates jobs and promotes local culture and products ^a	12.b.1 Implementation of standard accounting tools to monitor the economic and environmental aspects of tourism sustainability	Cultural industry creation connected to the properties with a touristic vocation
	16.7 Ensure responsive, inclusive, participatory and representative decision-making at all levels ^a 16.b Promote and enforce non-discriminatory laws and policies for sustainable development ^a	16.7.2 Proportion of population who believe decision-making is inclusive and responsive, by sex, age, disability and population group 16.b.1 Proportion of population reporting having personally felt discriminated against or harassed in the previous 12 months on the basis of a ground of discrimination prohibited under international human rights law	Inclusive decision-making process and participatory actions Promotion of non-discriminatory policies inside the organization
	17.14 Enhance policy coherence for sustainable development	17.14.1 Number of countries with mechanisms in place to enhance policy coherence of sustainable development	Sustainable development project implemented in accordance with national policies, as the FAI develops its activities based on the principle of subsidiarity to the Italian State Participation in national and local debates on transformations that affect territories, landscape

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Table 5 (continued)

SDG	SDGs target	SDGs indicator	FAI's strategy
	17.15 Respect each country's policy space and leadership to establish and implement policies for poverty eradication and sustainable development	17.15.1 Extent of use of country-owned results frameworks and planning tools by providers of development cooperation	plannings, ecological and energy transitions, also through advocacy and lobbying activities with the main national and European government institutions
	17.16 Enhance the Global Partnership for Sustainable Development, complemented by multi-stakeholder partnerships that mobilize and share knowledge, expertise, technology and financial resources, to support the achievement of the SDGs in all countries, in particular developing countries	17.16.1 Number of countries reporting progress in multi-stakeholder development effectiveness monitoring frameworks that support the achievement of the SDGs	Promotion and coordination of territorial and building interventions in synergy with local administrative bodies, Research Institutions, Universities, producers, professionals, and individual citizens
	17.17 Encourage and promote effective public, public-private and civil society partnerships, building on the experience and resourcing strategies of partnerships	17.17.1 Amount in United States dollars committed to public-private partnerships for infrastructure	Sustainable development project implemented in accordance with national policies, as the FAI develops its activities based on the principle of subsidiarity to the Italian State

^a Goal considered by the UNESCO's conceptual framework (United Nations Educational, Scientific and Cultural Organization 2021).

that choice would lead to visitors staying in possible uncomfortable thermal conditions. The design of the generation, distribution, control, and emission systems has been meticulously made, by pinpointing the zones where the installation of terminal units and generation systems would preserve the aesthetic appearance of the museum without compromising its energy efficiency. Besides, when possible, restored radiators were installed, in the perspective of an efficient circular economy.

Regarding the artificial lighting system, the original electrical system was preserved and incorporated alongside necessary supplementary systems and updated light bulbs. All the 50 historical chandeliers were restored to maintain the authentic ambiance of the museum house. LED lighting was chosen as alternative to the old light bulbs, permitting both high energy savings and desired levels of color rendering. The lighting system is regulated by a centralized control system, remotely managed by the museum staff to switch on/off the lights in homogeneous

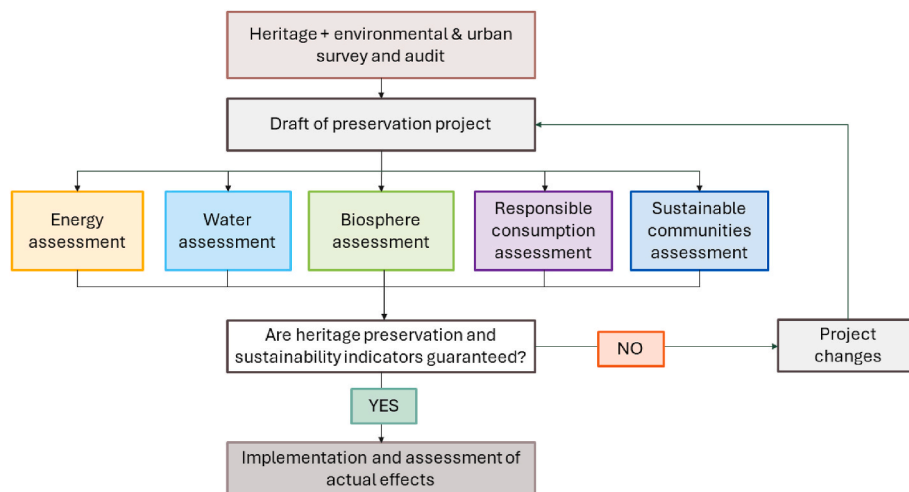


Fig. 2. Flowchart of the methodology and its application (source: Authors' elaboration).



Fig. 3. The town of Morazzone: (a) cadastral register of Lombardy and Veneto, dating back to 1856; (b) current view (2023) (Source: FAI and Authors' elaboration from Google Maps).

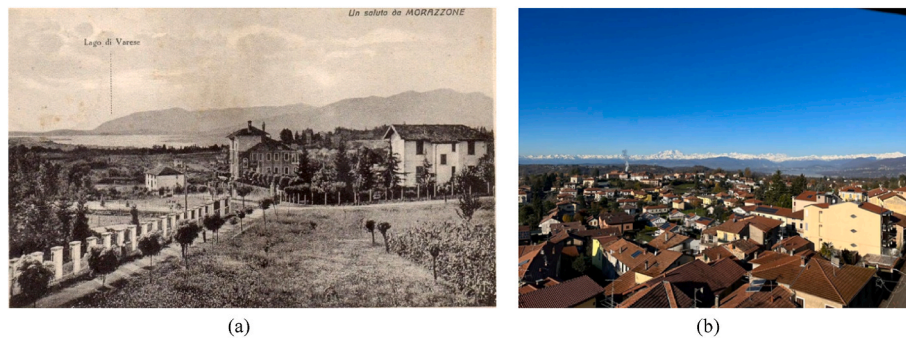


Fig. 4. The town of Morazzone: (a) First half of the 20th-century; and (b) current view (Source: FAI).



Fig. 5. The complex of Casa Macchi in Morazzone (Source: Authors' elaboration).

functional zones of the house and the garden, also according to the presence of visitors and the natural light level. The house museum's atmosphere requires low light levels, in compliance with preservation requirement. New light sources were introduced only in services areas (e.g., ticket office, shop) and, normally, only few lamps are kept on. Furthermore, presence detectors were installed in utility rooms (e.g., restroom, storage) to automatically switch the lamps on and off.

RES integration was not possible in the main house due to the presence of sensitive heritage values that cannot be modified in character and integrity (Lucchi and Schito, 2023b). Nonetheless, it is possible to install a PV system on the rural building. Thus, different conventional and innovative PV panels have been evaluated, seeking the

most beneficial types, positions and sizes in a multi-objective scenario, involving aesthetic, energy, and technical integration (Lucchi and Schito, 2023b). From the range of potential solutions, including Building Attached Photovoltaic (BAPV) and Building Integrated Photovoltaic (BIPV) located both on the roof or façade, ranging from 2 to 30 kW in size, the optimal configuration entails the installation of BIPVs on the roof (Lucchi and Schito, 2023a). Choosing a 5-kWp or a 30-kWp size does not largely improve the amount of saved energy, which ranges between 25% and 35%, due to the little electrical energy requirements of the rural building in day-time hours (mainly electrical lighting and a heat pump for heating and cooling purposes). At the same time, the choice of a large size PV system, covering almost all the roof, allows the production of a high amount of renewable electrical energy (over 15,000 kWh in three of the analyzed configurations), which the main house may exploit. This possibility, which can be considered as the creation of a small energy community, will be subject to forthcoming exploration to determine the optimal size of the PV system to be installed on the rural building. This system aims to meet the highest share of energy needs of the building complex, thus facilitating an extensive RES integration across the entire urban landscape. In parallel, within the "FAI for the Climate" campaign, guided tours and podcasts focusing on the climate mitigation actions implemented here are scheduled for 2024.

3.2.2. Water footprint

The management of water supply is a crucial factor to be consider in the preservation of a historic house open to the public. Supply and use of non-potable water can be exploited for services, irrigation of green areas, and restroom drainage. In this case, the diagnosis was fundamental for deciding heritage compatible interventions with original structures, also considering the presence of an ancient water system. The key SDGs indicators for this strategy are:

- Reuse and restoration of the ancient water systems and their traditional knowledge (SDGs indicators 11.4.1 and 6.6.1).



Fig. 6. Casa Macchi: (a) the main house; (b) indoor view, and (c) the rural building (Source: FAI).

- Sustainable water consumption and management (SDGs indicators 6.4.1 and 12.2.1).
- Presence of tanks for rainwater collection (SDGs indicators 6.5.1 and 12.2.1).
- Reduction of water consumptions of 20% by 2030 (SDGs indicator 12.2.1), and water balance (SDGs indicator 6.4.2).
- Awareness campaigns on water reuse and management (SDGs indicators 6.b.1 and 12.8.1).

In the courtyard of Casa Macchi, the remnants of a well dating back presumably to the 19th-century with a storage capacity of over 5,000 liters have been discovered. In the past, it served as the main water source for the entire complex and, for a certain period, even supplied water to a section of the town. This historical usage is underscored by a now-sealed opening in the enclosing wall that faces the church square. During the 20th-century, once it became exclusive for the complex, the well was equipped with a mechanical extraction system. The diagnostic campaign resulted in proposals for utilizing water resources in a manner that aligns with the nature and historical significance of the well. First, the withdrawals were modulated to optimize the “cistern effect” provided by the structure, avoiding overexploitation that would be incompatible with the characteristics of the groundwater and the stability of the structure. Specifically, the well satisfies the sanitary water needs and supplies water to the toilet flush tanks. The extraction is carried out through the implementation of a submersible pump equipped with a float device, which defines the maximum water level fluctuation, preventing excessive lowering of the water column. The system’s maximum efficiency is ensured by a storage tank for the extracted water, also connected to the drinking water supply network, which will provide support to the well in case of supply problems (e.g., water shortage, abnormal water level reductions, pump malfunctions or maintenance). Furthermore, the house’s gutters are directed towards the agricultural area, where the construction of another rainwater collection tank is planned for irrigation uses. These measures aim to achieve a 20%-reduction in water consumption by 2030. Finally, guided tours and podcasts on the utilization of traditional water technologies, as well as on water conservation for agricultural and sanitary purposes, will be developed as part of the “FAI for the Climate” campaign from 2024.

3.2.3. Biosphere

Biodiversity and green space protection in Casa Macchi is closely connected to the assessment of ecological networks and ecological corridors in the municipality of Morazzone and its neighborhoods, thanks to the presence of huge green areas and gardens. Despite these spaces are not directly inserted into any protected area, their management can create a small oasis within the existing ecological networks. The diagnosis included a detailed inventory of the natural and plant heritage to identify heritage-compatible interventions for conserving biodiversity. The key SDGs indicators for this strategy are:

- Wildlife conservation projects aimed at protecting biodiversity (SDGs indicators 15.1.1 and 15.3.1) also through the restoration of original systems (e.g., swift towers).
- Recovery of the lawn and historical garden (SDGs indicators 11.3.1, 11.4.1, 11.7.1, 15.1.2 and 15.3.1), also adopting sustainable policies for restoration and management (SDGs indicators 15.1.1 and 15.2.1).
- Sustainable farming and agriculture within the green area through the adoption of organic and biodynamic for agriculture (SDGs indicators 2.4.1, 3.9.3, and 11.3.1), also selecting of non-harmful biological solutions (SDGs indicators 3.9.2 and 12.4.1).
- Selection of natural species compatible with the local environment (SDGs indicators 12.2.1, 15.2.1, and 15.8.1).
- Education and awareness campaigns focused on biodiversity and strategies for creating resilient and climate change-adaptive gardens (SDGs indicators 3.9.1 and 12.8.1).

In terms of wildlife conservation, specific measures were implemented to protect and conserve the original biodiversity of the area. The project paid particular attention to preserving the habitats and nesting sites of various species, including swallows, pollinating insects, and other wildlife that contribute to the local ecosystem. The restoration project of the original swift tower of the main house was oriented precisely in this direction. This tower underwent various construction modifications over the years, including the closure of the interior cells with nesting sites for swifts (mid-1970s). The modifications lead to a significant damage that necessitated a complete restoration. This process was accomplished by means of vintage photographs, typological comparisons with other local structures, and studies of the wall plaster layer to identify pre-existing features. The interior cells were reopened for hosting six levels of nesting sites, for a total of 156 holes for nests. Furthermore, 60 nesting cells were revealed. They are distinctive with two chambers, each sealed with artisan-crafted wooden doors made by a local craftsman that can be opened for monitoring and cleaning purposes. To encourage swifts to return and populate the nesting sites, a small amplifier with a timer was installed at the top of the tower. It plays a recording of a duet between swifts at natural volume twice a day, mimicking the natural sounds they would encounter in the wild. Additionally, cork coasters were placed inside the cells to serve as an invitation for the swifts to nest. The main goal of this restoration is to attract the second and third migratory waves of young swifts. Besides, the second swifts tower of the rural building is still actively used (Fig. 8a).

The preservation efforts also concern the restoration of meadows and historical gardens, with a focus on reintroducing native plant species and promoting ecological balance. Furthermore, sustainable farming and agricultural practices are adopted within the green areas of the property to minimize negative impacts on the environment. This sustainable methodology ensures that agricultural activities respect and support the surrounding ecosystem. Finally, existing species were replaced with resilient ones. To achieve this, tree, and shrub species



Fig. 7. Casa Macchi: restoration of (a) old roof tiles; (b) radiators, and (c) old wooden shutters (Source: FAI).



Fig. 8. Casa Macchi: (a) the swift tower; (b) the botanic garden (Source: FAI).



Fig. 9. Casa Macchi: the grocery shop (Source: FAI).

compatible with the natural environments of the territory were chosen, along with species beneficial for the entomofauna (especially pollinating insects and ants), and herbaceous species related to popular uses (such as medicinal and edible herbs) (Fig. 8b). Educational and awareness campaigns focused on biodiversity involve the creation of small books and guided tours dedicated to the historical plants preserved in the garden, swift tower, and wildlife conservation in Casa Macchi.

3.2.4. Responsible consumption and production

As already mentioned, the interventions aim to preserve the historical materials, values, and furniture, minimizing demolition waste and reusing original elements within a circular economy framework. The key SDGs indicators for this strategy are:

- Implementation of sustainable construction site management guidelines (SDGs indicators 11.6.1, 12.2.1, 12.2.2)
- Preservation of historical materials, reuse of recycled and reclaimed materials and local elements within a circular economy framework (SDGs indicator 12.5.1).
- Adoption of Green Procurements and voluntary adherence to the Minimum Environmental Criteria (SDGs indicators 12.1.1, 12.7.1, 12.a.1).

The restoration project aimed to maintain the ambiance of the Lombard bourgeois house, reflecting its original domestic life marked by meticulous care for belongings, as well as emphasizing the repair and reuse of materials and resources, with a focus on waste reduction. This conscious and respectful attitude aligns with the concept of responsible consumption, which is increasingly emphasized in today's context. First, the restoration aimed to minimize waste, including construction-related

waste, through the development of specific guidelines.

Second, efforts were made on the reuse of elements and materials, following a circular economy approach. To this purpose, the following activities were realized: (i) over 200 wooden window frames were restored, incorporating safety and anti-UV films on the glass; (ii) more than 1500 terracotta tiles were state mapped, lifted to create a ventilated wasp nest, and then repositioned and reassembled; (iii) the wood ceilings were preserved and strengthened; (iv) the existing visible and layered electrical system was restored and utilized to narrate the history of electrical installations; (v) original furnishings, radiators, and chandeliers were refurbished. Furthermore, there was a reuse of existing materials and a revival of traditional techniques. Missing or non-functional items were mainly sourced from second-hand suppliers and specialized restorers. For example, the furnishings of the Casa Macchi's shop were revamped using objects from a historic 1920s Milanese grocery store (e.g., stools, candy displays, tin boxes, and a delivery bicycle) that closed due to the pandemic. This not only prevented the waste of antique items but also evoked the atmosphere of early 20th-century stores. Additionally, the ground tiles were crafted by a historical Lombard company employing traditional and environmentally friendly methods, including handmade artisanal decorations.

Finally, sustainable procurement strategies will be implemented for various aspects, including paper, printers, events, furniture, construction, and waste.













3.2.5. Sustainable communities

The involvement of the community has been a crucial aspect throughout the heritage preservation process. This initiative engaged various stakeholder groups, including Public Administrations, Heritage Authorities, local companies, and citizens. The key SDGs indicators for this strategy are:

- Activation of public-private collaborations to favor the sustainable project, according to local policies on landscape protection, and climate mitigation (SDGs indicators 11.3.2, 17.14.1, 16.7.2, 17.15.1, 17.16.1, 17.17.1).
- Cultural industry through the creation of a house-museum and a grocery store that promotes sustainable farming and local food production (SDGs indicators 4.4.1, 9.c.1, 8.3.1, 8.9.1, 11.a.1).
- Education and awareness programs (SDGs indicators 4.7.1, 4.7.2, 4.c.1, 11.4.1, 11.7.1).






The "Program Agreement", stipulated in 2017 within FAI, the Lombardy Region, the Province of Varese, and the Municipality of Morazzone, was the starting point to regulate activities and opportunities of public interest. This negotiated planning addressed the lack of public financial resources, encouraging responsibility and proposal capabilities of public and private actors in the area. This agreement allows for a significant contribution for heritage preservation and urban renovation through the redevelopment of existing roads, and parking areas as well

Table 6
Sustainable Development goals and indicators applied to in Casa Macchi (source: Authors' elaboration).

Casa Macchi's strategies	Related SDGs	Related SDG indicators
Sustainable farming and agriculture within the green area through the adoption of organic and biodynamic methods for agriculture, the elimination of pesticide		2.4.1 3.9.2, 3.9.3 11.3.1 12.4.1 15.3.1
Education, advocacy, and awareness programs on climate change, energy efficiency, RES, water management, and biodiversity		3.9.1 4.4.1, 4.7.1 6.b.1 11.7.1, 11.a.1 12.8.1 13.3.1 16.b.1 17.14.1
Continuous training of operators with post-graduate courses on heritage preservation and sustainable development		4.4.1, 4.7.1, 4.c.1 13.3.1 16.7.2, 16.b.1
Reuse and restoration of the ancient water system for rainwater collection, to be used for both agricultural and sanitary uses		6.5.1, 6.6.1 11.4.1 12.2.1
Reduction of water consumptions both for agricultural and sanitary uses and water balance		6.4.1, 6.4.2 12.2.1
Refurbishment and public opening of Casa Macchi (the main building, the adjacent lawn, and the historical garden) and cultural industry and job creation considering the sustainable tourism strategies and the access to innovative technologies (e.g., podcasts, virtual tour, augmented reality)		4.4.1, 4.7.1 7.1.1, 7.4.1 8.3.1, 8.9.1 9.c.1 11.3.1, 11.4.1, 11.a.1 12.b.1 16.7.2, 16.b.1
Selection of heritage-compatible strategies for improving the energy efficiency of the building envelope of the rural building		7.3.1, 7.4.1
Replacement of less efficient heating systems with heat pumps; installation of heating/cooling systems only in a limited part of the house previously non-conditioned		7.2.1, 7.3.1 12.2.1
Preservation and restoration of historical electrical systems and chandeliers, replacement of less efficient light bulbs with LED, and integration of a centralized control system		7.3.1, 7.4.1
Exploiting RES through the installation of heritage-compatible BIPV on the roof of the rural building, meeting over 35% of its energy needs, possibly sharing surplus energy with adjacent buildings, as well purchase and supply of electricity from RES		7.2.1, 7.3.1 12.2.1
Wildlife conservation projects aimed at protecting biodiversity through the restoration of the historical swift towers, lawn, and garden		11.3.1, 11.7.1 15.1.1, 15.1.2, 15.3.1
Activation of collaborations for developing sustainable development projects in synergy with local administrative bodies, Research Institutions, Universities, producers, professionals, and individual citizens		11.3.2 16.7.2, 16.b.1 17.14.1, 17.15.1, 17.16.1, 17.17.1

(continued on next page)

Table 6 (continued)

Casa Macchi's strategies	Related SDGs	Related SDG indicators
Preservation of historical materials, reducing demolition waste and reusing local elements and materials within a circular economy framework	 	11.4.1, 11.6.1 12.2.1, 12.2.2, 12.5.1
Selection of natural species compatible with the local environment, along with species beneficial for the entomofauna, medicinal and edible species	 	12.2.1 15.2.1, 15.8.1
Voluntary adoption of Green Procurements strategies for various aspects, including paper, printers, events, furniture, construction, and waste		12.1.1, 12.7.1, 12 b.1

as the rehabilitation of the old market.

During the 7-year design project (2015–2022), numerous site visits and remote initiatives were organized to strengthen the connection and the engagement between cultural heritage and its territory. These activities have allowed the creation of a cultural industry around the property. The two fundamental elements of this process include the establishment of a store and the attainment of museum recognition. First, Morazzone hosted various commercial and artisanal activities since the 19th-century, such as a cobbler, a butcher shop, a hairdresser, a tailoring workshop, and a stationery store. However, since the 1970s, many of these shops have closed, leading to a loss of community services that was exacerbated by the economic crisis linked to the Covid-19 pandemic. Thus, this store was designed as grocery store where essential items are available at controlled prices, with particular attention to stationery products for children and local products. In the future, it will serve also as a reference point for group purchases, package pickups, and document printing to address the absence of commercial activities and services in the city center (Fig. 9). Furthermore, Casa Macchi received the “Regional Recognition for Non-State Museums and Museum Collections” by the Lombardy Region (2023) with the aim to progressively enhance the conservation, research, valorization, and promotion activities.

This has led to the diversification of visit programs, including guided tours, educational workshops for schools, immersive reality experiences, and educational activities for children and families. Additionally, free podcasts have been created by the professionals involved in the project and the students from the University of Insubria. Besides, the collaboration with universities supported the preliminary diagnosis, and the design proposal.

3.3. Overview of the final project and verification of the obtained results

Table 6 reports a comprehensive overview of the final project, listing the strategies applied in Casa Macchi. As reported in the table, a single strategy may be correlated to more than one SDG and more than one FAI's objective.

The heritage preservation of Casa Macchi has had a central role in the urban renovation of Morazzone, as a specific attention was crucially directed toward the cultural and social project of integrating the property into the community. As an example, free access for Morazzone residents has been granted, attracting several visits. In general, its redevelopment and public opening as house-museum and grocery shop serve as driving force for a comprehensive enhancement of the cultural values of the historic center. The house-museum is the only museum in the city, and a social place for circular economy activities, and meetings. A relevant number of events and initiatives take periodically place, aiming at educating and engaging different targets of people. Furthermore, the grocery store encourages the consumption of locally-sourced products, supporting the local economy and reducing the carbon footprint associated with food transportation. Finally, the preservation of

the rural building with education purposes will create a dynamic space for hosting various activities on sustainable development.

All these actions provide an opportunity to facilitate a community-centric approach and touristic attraction, and generate economic benefits for the region and contributes to employment opportunities. Just to have an idea: in the first year of the public opening, Casa Macchi has attracted approximately 18,400 visitors from the surrounding provinces; the purchases in the grocery store are primarily made by house-museum visitors. Besides, two new commercial activities have opened in Morazzone, including a restaurant and a bed and breakfast. New events have been planned, including guided tours every weekend and evenings, workshops for children, also with the municipality and local entities.

To summarize, the principal results of the methodology application on Casa Macchi are the following:

- The appropriate approach for heritage preservation cannot be limited to the monument itself, but should consider its historical settings, natural and urban surroundings, and infrastructure, thus allowing a balance between heritage preservation and urban needs.
- Recovering traditional construction techniques and craftsmanship for heritage preservation maintains historical authenticity, raises awareness on cultural heritage, and supports local artisans. On a broader spectrum, they also remind to a wide set of sustainable and circular economic practices within the entire architectural and urban design project, from recovering territorial resources (e.g., energy, water, biodiversity) to defining new tourism, cultural, and sales activities (e.g., offering unpackaged food to reduce waste and unnecessary packaging, providing local products to support the local economy, using recycled and second-hand materials, etc.).
- Urban regeneration project can imply a higher engagement of citizens in new cultural and tourist-related businesses, economic benefits, and development of additional urban renewal projects involving various stakeholders (e.g., public and heritage authorities, universities, associations).

4. Conclusions

The Italian National Trust, FAI, has developed a methodology to preserve the heritage stock and, concurrently, reduce the carbon emissions, water footprint and soil exploitation, in accordance with the challenging 17 SDGs by the United Nations. This methodology involves a comprehensive evaluation of all SDGs goals, and indicators, adopting a holistic perspective that encompasses five macro-areas of interventions (energy, water footprint, biosphere, responsible consumption and production, and sustainable communities). The organizational structure enhances their interpretation and readability, especially considering the complexity of preserving both natural and cultural heritage within climate change issues.

The principal key points of this transdisciplinary methodology are

the following:

- Comprehensively assess the SDGs in the framework of cultural and natural heritage, integrating guidelines from ICOMOS and UNESCO with FAI's experience and practice routine on heritage preservation.
- Develop a practical design support system for deciding and evaluating the multi-objective solutions for intervention on cultural heritage, involving of a wide range of expertise and competencies in different scientific fields.
- Manage highly complex and varied processes, considering the design, management, and maintenance phases, and foster their replicability and critical adaptability to different contexts considering cultural, political, legislative, and social specificities.
- Consider heritage buildings and areas as living laboratories, to experiment continuous innovation in technologies, enhance traditional techniques and knowledge, and adapt to evolving environmental and cultural challenges.

The application of FAI's methodology on a case study, "Casa Macchi", has provided new awareness on the applicability and challenges posed by strategies for a sustainable heritage preservation. It has proved the complexity of the connections among the heritage site, the surrounding territory, the needed resources, and the socio-cultural context. Indeed, the preservation of Casa Macchi has had effects on multiple "side" aspects, ranging from the recovering of ancient systems and traditional building techniques, the planning of cultural events and initiatives, and the promotion of local economy through new job settlement. This approach contributes to the theoretical understanding of how sustainability principles can be effectively applied to heritage preservation, fostering resilience and adaptive management strategies. Furthermore, the methodology underscores the importance of considering heritage conservation as a catalyst for sustainable urban development, highlighting the interconnectedness of cultural, environmental, and social dimensions in shaping resilient and livable cities.

Given the complexity of the comprehensive study, primarily due to the need of balancing conflicting objectives (e.g., efficiency and preservation, urban development, and carbon reduction), some limitations can be pointed out. First, the current lack of common "scientific" indicators to assess sustainable development makes the estimation of the obtained benefits difficult. In literature, in fact, several indicators are found, in some cases leaving a certain margin of discretion for the adopting entities, or unsuitable to be applied in local context, like small villages or single buildings. Besides, having widespread and common indicators would also facilitate the comparison and the choice among different strategies for buildings/heritage sustainable development and retrofit. Thus, the methodology will be further expanded defining key performance indicators for the five macro-areas of intervention. The strong variability in legislative context and geographic background, even in a single country, may also represent a limitation in the replicability of this method: the features of a specific heritage could require peculiar interventions, not systematically replicable. Additionally, typical duration for the full application of this methodology, including the analysis of the current state, funding, retrofit, and assessment of the obtained outcomes, is long: the wider the area of intervention, the higher the needed time. Estimation of benefits in terms of urban regeneration can take years of monitoring. Due to these elongated periods, innovation in research and new directives and legislation coming into force may undermine the effects of this methodology application in the first years of implementation.

However, these aspects can be considered as *stimuli* for the continuous development of this procedure, aiming at a complete integration in decision-makers' tools and policies. Work is currently underway to implement this methodology in all new projects to ensure adherence to sustainable development principles. Concurrently, the level of environmental sustainability of realized project is monitored based on criteria identified by this methodology. The aim is to introduce new

measures and activities for protecting, enhancing, educating, and engaging the public in cultural and natural heritage. Furthermore, quantitative targets have been set for selected indicators, such as water consumption, energy consumption, and operational costs. Finally, actions related to education, training, and public engagement are increasingly focused on issues related to environmental and energy transition, addressing all the stakeholders (e.g., staff, schools, users).

CRedit authorship contribution statement

Elena Lucchi: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Francesca Turati:** Writing – review & editing, Writing – original draft, Visualization, Resources, Investigation, Data curation. **Benedetta Colombo:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Data curation. **Eva Schito:** Writing – review & editing, Writing – original draft, Software, Formal analysis, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

Acknowledgment

The project was financed by the Fondazione Cariplo within the call "Patrimonio per lo sviluppo", Project "Casa Macchi, Morazzone (VA): The opportunity of a restoration revitalises the historic town centre" and the Lombardy Region through the "Programme agreement for the implementation of urban regeneration and revitalisation initiatives in the historical centre of the municipality of Morazzone (VA), with the restoration of Casa Macchi for public use".

References

- Alba-Rodríguez, M.D., Machete, R., Glória Gomes, M., Paula Falcão, A., Marrero, M., 2021. Holistic model for the assessment of restoration projects of heritage housing. Case studies in Lisbon. *Sustain. Cities Soc.* 67, 102742 <https://doi.org/10.1016/j.scs.2021.102742>.
- Australia ICOMOS, 1979. Australia ICOMOS Guidelines for the Conservation of Places of Cultural Significance ("Burra Charter"), pp. 1–2. Australia ICOMOS: Burra, Australia.
- Cervesato, A., 2022. Reuse and reconversion as sustainability paradigm for marginal areas regeneration. *Sustainability* 14, 15270. <https://doi.org/10.3390/su142215270>.
- Dalla Gasperina, I., 2017. *Il Morazzone e dintorni: un libro in viaggio tra arte, natura e cultura*, Comune di Morazzone: Morazzone.
- De la Torre, M., 2013. Values and heritage conservation. *Herit. Soc.* 6, 155–166. <https://doi.org/10.1179/2159032X13Z.00000000011>.
- Department for Development and Economic Cohesion (DPS). The internal areas: which territories are we talking about? https://www.agenziacoese.gov.it/wp-content/uploads/2021/01/Nota_metodologica_Aree_interne-2-1.pdf. (Accessed 8 November 2023).
- European Commission, 2021. New European Bauhaus. https://europa.eu/new-european-bauhaus/index_en. (Accessed 26 June 2023).
- Fondo Ambiente Italiano, 2023. <https://fondoambiente.it/il-fai>. (Accessed 9 November 2023).
- Gonçalves, J., Mateus, R., Silvestre, J.D., Roders, A.P., Bragança, L., 2021. Attitudes matter: measuring the intention-behaviour gap in built heritage conservation. *Sustain. Cities Soc.* 70, 102913 <https://doi.org/10.1016/j.scs.2021.102913>.
- Ikiz Kaya, D., Dane, G., Pintossi, N., Koot, C.A.M., 2021. Subjective circularity performance analysis of adaptive heritage reuse practices in The Netherlands. *Sustain. Cities Soc.* 70, 102869 <https://doi.org/10.1016/j.scs.2021.102869>.
- International Council on Monuments and Sites (ICOMOS), 2018. Buenos Aires Declaration Marking the 70th Anniversary of the Universal Declaration of Human Rights. ICOMOS. [https://www.icomos.org/images/DOCUMENTS/Secretariat/2018/AGA_2018/AGA2018_BuenosAiresDeclaration_EN-FR-ESP_final.pdf#:~:text="](https://www.icomos.org/images/DOCUMENTS/Secretariat/2018/AGA_2018/AGA2018_BuenosAiresDeclaration_EN-FR-ESP_final.pdf#:~:text=)

- =The%20ICOMOS%20Advisory%20Committee%2C%20meeting%20in%20Buenos%20Aires,to%20supporting%20Rights%20Based%20Approaches%20to%20World%20Heritage. (Accessed 1 August 2023).
- International Council on Monuments and Sites (ICOMOS), 1999. Charter on the Built Vernacular Heritage. ICOMOS. https://www.icomos.org/images/DOCUMENTS/Charters/vernacular_e.pdf. (Accessed 9 August 2023).
- International Council on Monuments and Sites (ICOMOS), 2002. International Cultural Tourism Charter. ICOMOS. <https://www.icomos.no/wp-content/uploads/2014/04/ICTC-Charter.pdf>. (Accessed 1 August 2023).
- International Council on Monuments and Sites (ICOMOS), 2013. The Burra Charter, ICOMOS. <https://australia.icomos.org/wp-content/uploads/The-Burra-Charter-2013-Adopted-31.10.2013.pdf>. (Accessed 9 August 2023).
- International Council on Monuments and Sites (ICOMOS), 2011a. The Paris declaration on Heritage as a Driver of Development. ICOMOS, Paris.
- International Council on Monuments and Sites (ICOMOS), 2011b. The Valletta Principles for the safeguarding and management of historic cities, towns and urban. Areas, ICOMOS 18. https://civih.icomos.org/wp-content/uploads/2022/03/Valletta-Principles-GA-EN_FR_28_11_2011.pdf. (Accessed 1 August 2023).
- Jiang, L., Lucchi, E., Del, Curto D., 2023. Adaptive reuse and energy transition of built heritage and historic gardens: the sustainable conservation of Casa Jelinek in Trieste (Italy). *Sustain. Cities Soc.* 97, 104767 <https://doi.org/10.1016/j.scs.2023.104767>.
- Labadi, S., Giliberto, F., Rosetti, I., Shetabi, L., Yildirim, E., 2021. Heritage and the Sustainable Development Goals: Policy Guidance for Heritage and Development Actors. ICOMOS. <https://openarchive.icomos.org/id/eprint/2453>. (Accessed 1 August 2023).
- Lerario, A., 2022. The role of built heritage for sustainable development goals: from statement to action. *Heritage* 5, 2444–2463. <https://doi.org/10.3390/heritage5030127>.
- Lucchi, E., Agliata, R., 2023. HBIM-based workflow for the integration of advanced photovoltaic systems in historical buildings. *J. Cult. Herit.* 64, 301–314. <https://doi.org/10.1016/j.culher.2023.10.015>.
- Lucchi, E., 2023a. Renewable energies and architectural heritage: Advanced solutions and future perspectives. *Buildings* 13, 631. <https://doi.org/10.3390/buildings13030631>.
- Lucchi, E., 2023b. Digital twins for the automation of the heritage construction sector. *Autom. Constr.* 156, 105073. <https://doi.org/10.1016/j.autcon.2023.105073>.
- Lucchi, E., 2023c. Regenerative design of archaeological sites: a pedagogical approach to boost environmental sustainability and social engagement. *Sustainability* 15, 3783. <https://doi.org/10.3390/su15043783>.
- Lucchi, E., Schito, E., 2023a. Challenges and opportunities for the integration of photovoltaic modules in heritage buildings through dynamic building energy simulations. *Lecture Notes in Mechanical Engineering*. Springer, Cham, pp. 180–194. https://doi.org/10.1007/978-3-031-17594-7_14.
- Lucchi, E., Schito, E., 2023b. Integrating different PV roofs on a heritage building considering aesthetic, technical, energy, and environmental aspects: a multi-perspective approach. In: Sayigh, A. (Ed.), *Mediterranean Architecture and the Green-Digital Transition*. Innovative Renewable Energy. Springer, Cham.
- Misirlişoy, D., Günçe, K., 2016. Adaptive reuse strategies for heritage buildings: a holistic approach. *Sustain. Cities Soc.* 26, 91–98. <https://doi.org/10.1016/j.scs.2016.05.017>.
- Peregalli, S., 2022. *I luoghi e la polvere. Sulla bellezza dell'imperfezione*, La Nave di Teso: Milano.
- Potts, A., 2021. Executive summary. In: *European Cultural Heritage Green Paper Executive Summary*. Europa Nostra: The Hague - Brussels.
- Seduikyte, L., Grazuleviciute-Vileniske, I., Kvasova, O., Strasińskaite, E., 2018. Knowledge transfer in sustainable management of heritage buildings. Case of Lithuania and Cyprus. *Sustain. Cities Soc.* 40, 66–74. <https://doi.org/10.1016/j.scs.2018.03.013>.
- Shetabi, L., 2015. Heritage conservation and environmental sustainability: revisiting the evaluation criteria for built heritage. In: *Proceedings of Fabric: the Threats of Conservation*, ICOMOS: Adelaide.
- Stephenson, J., 2008. The cultural values model: an integrated approach to values in landscapes. *Landscape Urban Plann.* 84 (2), 127–139. <https://doi.org/10.1016/j.landurbplan.2007.07.003>.
- United Nations Educational, Scientific and Cultural Organization (UNESCO), 2013. *Hangzhou Declaration: Placing Culture at the Heart of Sustainable Development Policies*.
- United Nations Educational, Scientific and Cultural Organization (UNESCO), 2015. *World Heritage Policy Compendium – Policies Regarding Conservation of World Heritage Properties*. https://whc.unesco.org/en/compendium/action=list&id_faq_themes=1312.
- United Nations Educational, Scientific and Cultural Organization (UNESCO), 2021. *UNESCO Culture 2030 Indicators*. <https://whc.unesco.org/en/culture2030indicators> (Accessed 9 December 2023).
- United Nations (UN), 2015a. *Paris Climate Agreement*. UN, Paris.
- United Nations (UN), 2015b. *UN SDGs*. <https://sdgs.un.org/goals>. (Accessed 1 August 2023).
- United Nations (UN), 2017. *General Assembly, Resolution 72/229, Culture and Sustainable Development, A/RES/72/229*. <https://undocs.org/en/A/RES/72/229>. (Accessed 1 August 2023).
- World Commission on Environment and Development, Report, 1984. *Our common future*. <https://digitallibrary.un.org/record/139811?ln=en#record-files-collapse-header>. (Accessed 31 July 2023).
- Yıldız, S., Kivrak, S., Gultekin, A.B., Arslan, G., 2020. Built environment design – social sustainability relation in urban renewal. *Sustain. Cities Soc.* 60, 102173 <https://doi.org/10.1016/j.scs.2020.102173>.