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Original article

Abandoned industrial heritage: From waste to resource. Which evaluation tools to evaluate this circular process?

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ABSTRACT

The abandonment of industrial buildings, driven by global economic changes and deindustrialization, has led to a growing interest in their adaptive reuse as a strategy for sustainable regeneration. This paper explores how disused industrial heritage can be transformed from waste into a valuable resource, aligning with circular economy principles. The main objective of the research is to propose an evaluation framework capable of assessing the multidimensional impacts (environmental, economic/financial, and socio-cultural) of adaptive reuse projects for industrial heritage across various project phases.

To achieve this, a systematic literature review was conducted following PRISMA guidelines, identifying key criteria and indicators used in previous evaluations. The review highlighted the complexity of balancing heritage conservation, community needs, and sustainability goals. While numerous studies propose multicriteria evaluation frameworks, few explicitly address the circular economy perspective. In this context, the European Commission's Level(s) tool (currently the only officially recognized framework for assessing building sustainability in a circular economy perspective) was selected as the basis for this research.

The Level(s) tool was integrated and expanded to account for the unique characteristics of industrial heritage, including historical significance and socio-cultural values. The resulting evaluation framework consists of six thematic-areas, nine macro-objectives and a comprehensive set of 48 criteria and 100+ indicators. Indicators are categorized by evaluation phase (ex-ante, ongoing, ex-post) and lifecycle status (renovation activity, in-use, future adaptation potential), ensuring relevance across the building lifecycle. They also distinguish between impacts on the building/site itself and those on its urban context.

The framework allows stakeholders, including designers, investors, policymakers, and communities, to evaluate the sustainability of adaptive reuse projects in a structured, transparent, and comparable way. It supports decision-making through multicriteria analysis and encourages stakeholder collaboration. Moreover, it emphasizes the integration of qualitative and quantitative data and accommodates varying levels of technical expertise.

This study provides a replicable, flexible, and interdisciplinary tool for evaluating the circular regeneration of industrial heritage. Future research will focus on applying this framework to real-world projects to validate and refine its components.

1. Introduction and research aim

The processes of deindustrialization and changing global economic dynamics have led to the abandonment, degradation, and even demolition of many industrial structures. However, industrial heritage represents a unique testimony to the technological, economic and social evolution of our society, comprising both tangible (infrastructure and machinery) and intangible aspects (i.e. technical skills) [1].

Adaptive reuse (AR) [2] is recognized as the most suitable strategy for "giving new life" to abandoned industrial heritage [3,4]. It enables the conservation of historical and cultural values while transforming heritage into resources aligned with contemporary community needs [5], fostering sustainability.

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This approach is consistent with circular economy principles [6], as it extends resource values, reduces waste, and supports their use by future generations, in line with the UN's sustainability goals [7,8]. The AR of industrial heritage represents a way to operationalize circular economy principles in the built environment. The circular economy provides the overarching framework aimed at extending resource values and minimizing waste, while adaptive reuse translates these principles into action by extending, for example, the life cycle of existing buildings and preserving their embodied energy and cultural value. When effectively implemented, such circular processes generate regenerative outcomes, producing social, cultural, and environmental benefits that contribute to more sustainable and inclusive urban regeneration.

This research is primarily framed within the circular economy paradigm, which provides the methodological foundation of the proposed framework. The regenerative dimension is understood as the social and environmental outcome of circular processes applied to the adaptive reuse of industrial heritage.

New uses have to respect industrial heritage significance, authenticity, and integrity while addressing evolving community needs [4]. Therefore, the reuse of abandoned industrial heritage is a complex issue linked to multiple values as well as to different needs/interests at stake [9]. It is necessary that decision-making processes should be supported by multidimensional evaluation tools, able to capture multidimensional impacts [10].

This contribution aims to propose an evaluation framework for assessing the multidimensional impacts of industrial heritage AR (a strategy able to operationalize the circular economy model) at different project phases and lifecycle status. After the introduction (Section 1), a systematic literature review on studies focused on assessing industrial heritage AR has been carried out (Section 2). Then the methodology for the development of the proposed evaluation framework is presented, based on the integration and adaptation of the Level(s) tool by the European Commission (Section 3). It is deeply detailed and discussed in Section 4. Limitations of this study and possible further research steps are then stated in **Section 5.**

2. Materials and methods

2.1. Systematic literature review

In order to investigate the different evaluation framework used and developed in the scientific literature, this study adopts the 'Preferred Reporting Items for Systematic Reviews and Meta-Analyses' (PRISMA) guidelines, using four steps: identification, screening, eligibility and inclusion [11].

It was conducted on Scopus and Web of Science databases (Fig. 1), considering the following keywords and Boolean operators: industrial heritage AND adaptive reuse AND evaluation OR assessment OR valuation. The research was carried out among "article title", "abstract" and "keywords". This first step resulted in 167 documents. After removing 20 duplicates between the two database, 147 papers remained. Applying a time filter from 2015 (start of Agenda 2030) reduced them to 138.

Papers were selected among all the subject areas excluding the following: medicine, computer science, mathematics, chemistry, physics and astronomy, pharmacology, toxicology and pharmaceutics, chemical engineering, agricultural and biological sciences, earth and planetary sciences. This resulted in 103 papers.

Filtering for English reduced them to 101, and selecting only final-stage publications brought the count to 97, becoming 91 excluding then some "source title" (papers in the International Journal of Building Pathology And Adaptation, Automation In Construction, Art Inquiry). These were reviewed in full-text for eligibility. After full-text analysis, 26 of the original 167 papers were selected for final evaluation (inclusion step).

2.2. Literature review on evaluation tools for industrial heritage adaptive reuse

Abandoned industrial heritage is both a challenge and opportunity. Its AR bridges cultural preservation and sustainable urban regeneration. Researchers propose different methodologies to evaluate reuse projects balancing heritage values and contemporary needs in the conservation vs. development conflict.

Authenticity and conservation principles are fundamental in maintaining historical integrity as also **Xiong et al.** [12] highlighted. They propose a guiding pathway for reusing industrial heritage that prioritizes authenticity, through principles like minimal intervention, interpretability, prevention, subsidiarity, and intertextuality. **Han and Zhang** [13]. elaborate a global review of industrial heritage reuse research from 2017 to 2022 identifying emerging trends, such as interdisciplinary work, sustainability, cultural value, and community involvement. **Zheng et al.** [14] introduce a weighting point method to assess cultural expression, helping (through a quantitative evaluation method) identify strengths/weaknesses of industrial heritage reuse and enhancing public-heritage connections. Furthermore, **Nocca et al**. [15] propose a multidimensional approach valuing both tangible and intangible aspects, focusing on the "intrinsic value", intended as the "in and of itself" value linked to the spirit of place. It is separated from instrumental values and plays a key role in orienting choices in this kind of project. The complexity characterizing the AR of abandoned industrial heritage is stressed by **Della Spina et al.** and **Bottero et al.** [16,17] that use multicriteria tools (A'WOT, PROMETHEE) to rank and assess AR strategies, to optimize resources allocation and reach paramount in the trade-off between preserving symbolic values and adapting to new economically viable uses. Also **Yasemin and Edis** [18] highlight the multidimensionality characterizing the AR of industrial heritage, elaborating a dataset of reuse strategies and related outcomes as guide for choosing a new function and intervention.

Vardopoulos et al. [19] propose an integrated SWOT-PESTLE-AHP model to evaluate sustainability, addressing social, environmental, technical, economic, legal, and political dimensions, and also ensuring stakeholder input. Similarly, **Liu et al.** [20] use AHP to assess industrial ruins based on different criteria such as space safety, investment, cultural, ecological, and social value.

The coexistence of different objectives, constraints, needs, interests and values at stake in the AR process is emphasized also by **Giuliani et al.** They conduct a sensitivity analysis to assess stakeholder influence on decision-making, emphasizing the importance of involving diverse stakeholders to ensure balanced and well-informed decisions. The stakeholder map helps identify different points of views. **Song et al**. [21] use social network analysis to face spatial challenges in converting industrial sites into public spaces, suggesting indicators and strategies for functional zoning and spatial organization.

User satisfaction and functional adaptability are key aspects in many studies. **Meng et al.** [22] develop a framework to assess user satisfaction with the spatial repurposing of industrial heritage, across six dimensions: functional replacement, transportation accessibility, carrying capacity, public space, boundary form, and recognition of value. Similarly, **Madani et al.** [23], by exploring user preferences, emphasize environment, technology and energy, aesthetics and sociocultural criteria in designing innovation centers in industrial heritage. **Zheng et al.** [14] integrate Maslow's Hierarchy of Needs into architectural assessments, demonstrating the importance of aligning designs with user requirements. They emphasize the importance of addressing both basic and higher-level human needs in architectural spaces.

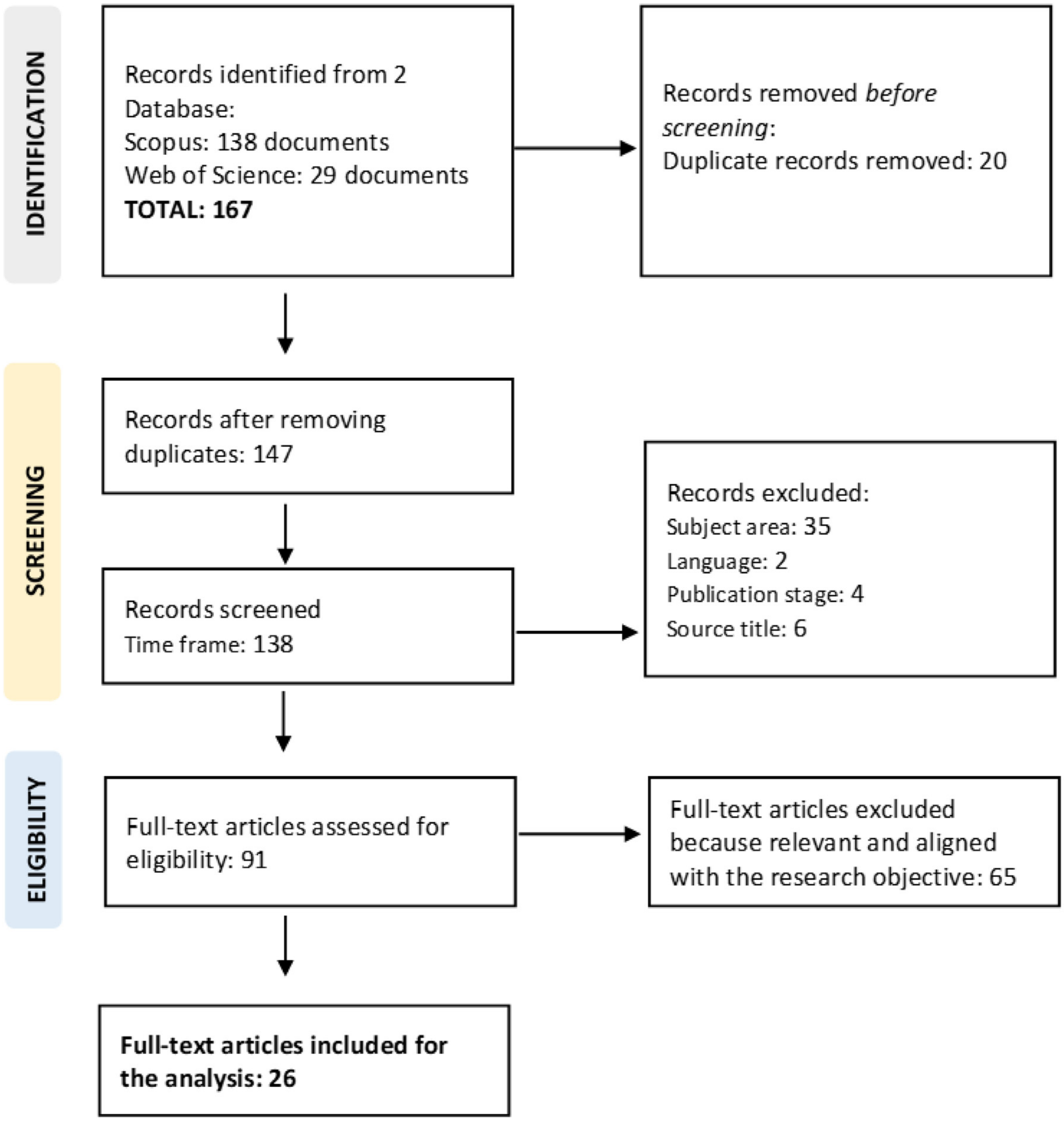

Fig. 1. PRISMA flowchart.

Han et al. [13] investigate tourist satisfaction using five criteria, finding that better environmental quality significantly enhances visitor experiences. The semantic differential method shows high satisfaction with spatial, socio-cultural, landscape, and greening elements, but low satisfaction with facilities and transport.

Case studies provide empirical insights into the socio-economic and cultural impacts of AR. **Huang et al.** [24] apply Structural Equation Modeling (SEM) and Importance-Performance Analysis (IPA) to evaluate user satisfaction with industrial heritage renewal, focusing on Dongguan Jianyuzhou Park. Their findings highlight that the historical and cultural factors boost satisfaction more than environmental or economic ones. **Farashah** [25] explores Yazd's textile heritage, highlighting its economic and social benefits and stating that multiple buildings can aid restoration phasing. **Vardopoulos** [19] examines industrial-to-museum conversions, highlighting the lack of ex-post evaluation and revealing positive effects of industrial AR on sustainability, cultural enrichment, and urban revitalization. **Vizzarri et al. (2020**) [26] propose a holistic framework for projects selection in AR, focusing on integrating tangible and intangible values, using an O-AHP-based index combining quantitative and qualitative data. **Cimadomo and Varagnoli** [27] further emphasize the role of education and research in aligning industrial heritage rehabilitation with sustainability and modern technological integration. In Turkey, **Dedekarginoğlu** [28], through the regeneration project of Ankara's CerModern art gallery, illustrates the potential of industrial spaces to serve contemporary cultural functions while preserving historical memory.

Key drivers as central for success like participation, top-down/bottom-up, genius loci are stressed by **Pulles et al.** [29] starting from the analysis of regeneration strategies across Europe and Asia. They find that AR strategies aligned with genius loci and involving multiple drivers get better evaluations than top-down ones. Their findings align with **Gharaati et al.** [30], who evaluate 12 Iranian industrial heritage sites using 7 indexes and 20 sustainability indicators derived from international charters, stressing the importance of community participation and mixed-use development.

Finally, technical and contextual challenges are explored in depth. **Xu and Aoki** [31] examine China's industrial heritage conservation systems, categorizing its values into physical, human, natural, and cultural capital, while **Walczak** [32] investigates the transformation of post-industrial buildings in Łódź from a conservation perspective. Both studies underline the need for context-sensitive approaches that consider industrial heritage's unique architectural and material features.

The scientific literature confirms that industrial heritage AR is a complex issue, demanding balance between preservation, current needs, different values and stakeholder involvement.

Recent European research initiatives further reinforce the relevance of circular models in heritage adaptive reuse. In particular, the HORIZON2020 CLIC (Circular models Leveraging Investments in Cultural heritage adaptive reuse) [33] and OpenHeritage [34] projects have demonstrated how heritage-led reuse can operationalize circular principles through innovative governance, business, financial and community-based models. Their findings encourage and support the multidimensional approach for addressing heritage adaptive reuse, highlighting its importance as a driver for multidimensional sustainability.

However, the scientific literature reveals partial approaches, often limited to a single dimension (environmental, economic, or socio-cultural), lacking the systemic and circular integration. Recurring themes include the need for robust decision-making frameworks, the role of user/community satisfaction, conservation of cultural historical values while changing uses, and the growing emphasis on environmental impact. These papers, together, emphasize the importance of interdisciplinary approaches and public engagement, while few contributions address AR from a circular economy perspective.

2.3. Level(s) tool by European Commission

To date, the only officially recognized tool for assessing projects in the circular economy perspective is the Level(s) tool [35,36]. It has been developed by the European Commission (EC) in 2018 to guide the construction sector towards greater sustainability, providing a common reference framework to evaluate the environmental, social, and economic performance of buildings throughout their entire life cycle, promoting the principles of the circular economy. This is a voluntary framework aimed at designers, builders, developers, and policymakers, with the goal of improving sustainable practices aligned with EU initiatives (e.g. European Green Deal, Circular Economy Action Plan, New European Bauhaus). The primary purpose is to support the transition towards more sustainable buildings that efficiently use natural resources, reduce their carbon emissions, and enhance the quality of life for occupants. It also aims to make decision-making processes more transparent and facilitate the monitoring of progress towards sustainability objectives.

As the name of the tool itself suggests, Level(s) is organized into levels, corresponding to different degrees of design depth and, consequently, of evaluation (www.green-forum.ec.europa.eu):

– Level 1 – Conceptual Design. This stage focuses on qualitative evaluation and selecting sustainability indicators. The framework helps communicate key concepts to clients, allowing early identification and prioritization of sustainability goals.
– Level 2 – Detailed Design and Construction. This phase involves quantitative analysis to assess design performance, compare alternatives, and monitor construction using standardized metrics.
– Level 3 – As-Built and Operational Performance. The final stage assesses construction and early building performance, offering insights to refine strategies and inform future projects.

The three levels indicate a progression in the precision and reliability of conducting a performance assessment, as well as the degree of professional expertise and skill needed to apply each level. This structure allows for the assessment of a building's impact throughout its entire life cycle. This is fundamental for reducing negative impacts from construction sectors considering buildings are responsible for 1/2 of all extracted materials, 1/2 of total energy consumption, 1/3 of water consumption, 1/3 of waste generation (www.environment.ec.europa.eu).

Level(s) is structured around three main thematic-areas:

– environmental performances of life cycle;
– health and comfort;
– cost, value and risk.

They are divided, in turn, into macro-objectives that provide an overall view of the impacts that address key sustainability aspects over the building life cycle:

– greenhouse gas and air pollutant emissions along a building's life cycle (thematic-area 1)
– resource efficient and circular material life cycles (thematic-area 1)
– efficient use of water resources (thematic-area 1)
– healthy and comfortable spaces (thematic-area 2)
– adaptation and resilience to climate change (thematic-area 3)
– optimised life cycle cost and value (thematic-area 3)

These objectives can be monitored through sixteen indicators, which illustrate how a building's performance can align with EU policy goals in areas.

Designed for residential/commercial use, Level(s) needs to be integrated in order to be tailored for the evaluation of heritage reuse, particularly industrial heritage.

The Level(s) framework is a valuable starting point for assessing the performance of AR projects due to its structured, lifecycle-based methodology. However, its focus does not fully capture the complexity of heritage AR. These kinds of projects require a broader evaluation scope, addressing environmental sustainability but also cultural significance, socio-economic impacts, and community integration. To bridge this gap, this study proposes an evaluation framework to ensure a holistic assessment that aligns with the challenges and opportunities of industrial heritage AR, balancing conservation and development, to identify a new equilibrium [37].

2.4. Methodology

This study aims to elaborate an evaluation framework for assessing the multidimensional (economic/financial, socio-cultural, environmental) impacts of AR projects of industrial heritage in the circular economy perspective, covering both buildings and their surroundings. The starting point is the Level(s) tool, the only one to date generally recognized for evaluating projects from a circular economy perspective. This tool is intended for the evaluation of projects that are not characterized by historical and cultural values. This study therefore intends to integrate and adapt this tool to industrial heritage AR characterized by particular historical and cultural values and with particular reference to decommissioned industrial heritage.

The proposed framework keeps the Level(s) structure of thematic-areas, objectives, and indicators, adding also evaluation criteria (Fig. 2). So, additionally to the Level(s) tool, the indicators are grouped into criteria. Furthermore, the indicators are also categorized by project phase (*ex-ante, ongoing, ex-post*) and lifecycle status (*renovation, in use, future adaptation*). They are explained further below. Unlike the Level(s) tool, it addresses both the building and its surrounding.

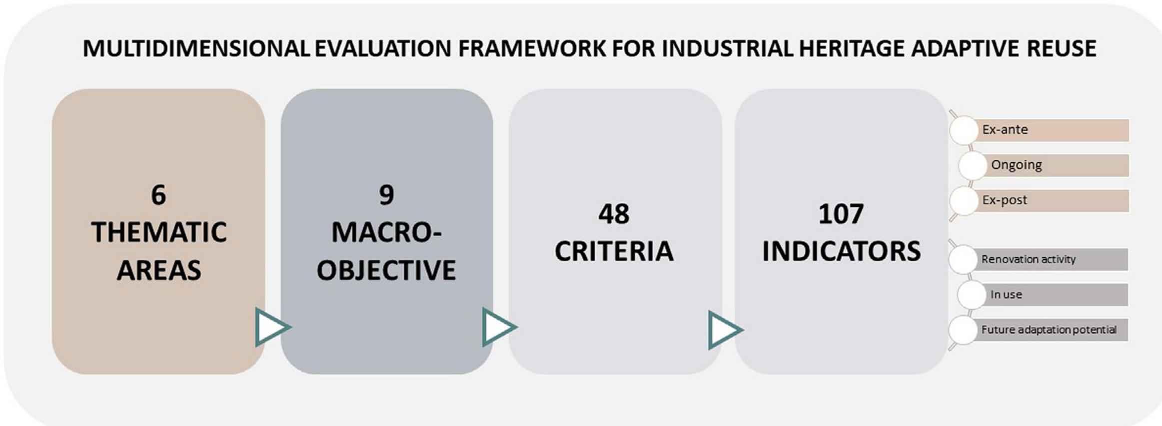

Fig. 2. The structure of the proposed evaluation framework.

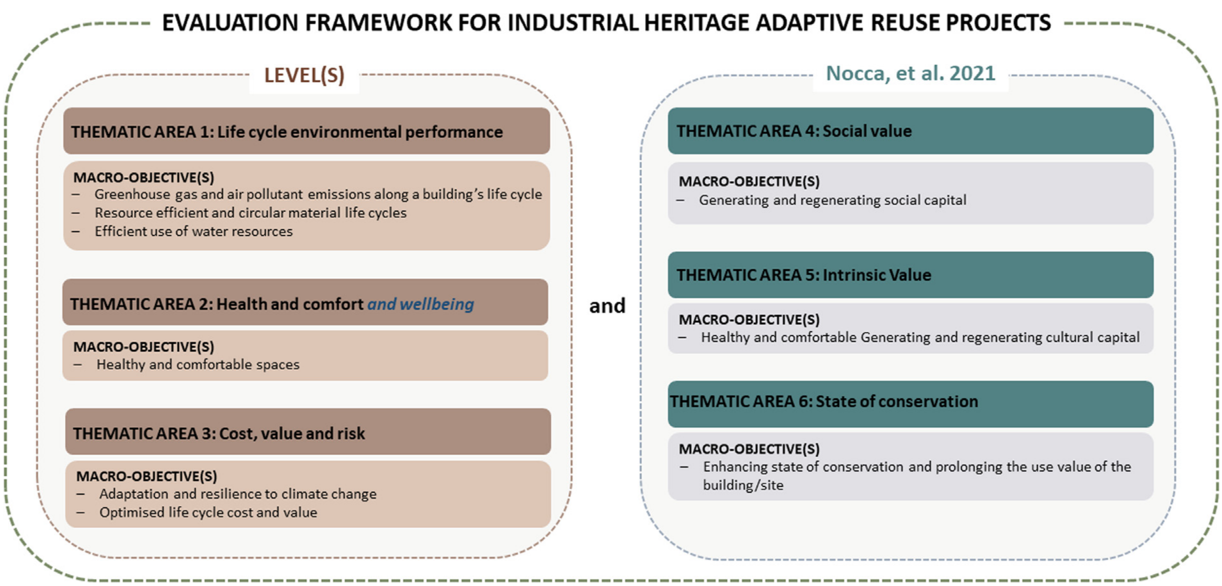

Fig. 3. Evaluation framework for industrial heritage adaptive reuse projects.

Table 1
Evaluation framework – six thematic-areas and their description.

No.	THEMATIC-AREA	DESCRIPTION
1	**Environmental performances of life cycle**	Assessing and improving the **environmental performance** of reused buildings/sites throughout their entire life cycle, from design and construction to use and end-of-life.
2	**Health and comfort and *wellbeing***	Enhancing indoor (but also outdoor) **environmental quality and wellbeing of the community.**
3	**Cost, value and risk**	Optimize **financial performance** and resilience of buildings/sites throughout their lifecycle.
4	**Social capital and value**	Enhance the **social impacts and community benefits** linked to the reused buildings/sites throughout their lifecycle.
5	**Cultural capital and value**	Preserve, enhance and hand down the **cultural significance and heritage value** of the reused buildings/sites throughout their lifecycle. Both **tangible and intangible values** are considered.
6	**State of conservation and use value**	Maintain and enhance the condition and **functional durability** of the reused buildings/sites.

The three thematic-areas of Level(s) expand to six, as proposed by Nocca et al. (2021) [15] for cultural heritage in general, and they are further refined and detailed to be more specifically tailored to disused industrial heritage characterized by cultural and historical values (Fig. 3).

Each thematic-area identifies specific aspects/issues to be monitored, evaluated and improved, linking them to key indicators that allow the macro-objectives to be translated into concrete and measurable actions. The proposed six thematic-areas are described in Table 1. They cover all sustainability dimensions (environmental, financial/economic, social, cultural), including objective and subjective factors.

Specifically, the first three thematic-areas come from Level(s) tool, while thematic-areas 4, 5, 6 extend it to cover also social and cultural dimensions. The third thematic-area (inherited from the EC) has been integrated with the aspect related to “wellbeing”, expanding its focus to encompass health conditions but also a broader perception of overall indoor and outdoor quality of life.

Each thematic-area is associated with one or more macro-objectives, which define the key goals to be achieved within that thematic scope. These objectives represent the main strategic priorities for enhancing the performance of buildings throughout their lifecycle. The detailed listing and description of these macro-objectives are provided in Table 2 below.

Table 2
Evaluation framework – nine macro-objectives and their description.

MACRO-OBJECTIVE	DESCRIPTION
Macro-objective 1 (thematic-area 1) Greenhouse gas and air pollutant emissions along a building's life cycle	**To minimise the total greenhouse gas emissions** along a building's life cycle, from cradle to grave, with a focus on emissions from building operational energy use and embodied energy.
Macro-objective 2 (thematic-area 1) Resource efficient and circular material life cycles	To optimise the building design, engineering and form in order to support lean and **circular flows,** extend long-term material utility and reduce significant environmental impacts.
Macro-objective 3 (thematic-area 1) Efficient use of water resources	To make **efficient use of water resources,** particularly in areas of identified long-term or projected water stress.
Macro-objective 4 (thematic-area 2) Healthy and comfortable spaces	To construct buildings/sites that are **comfortable, attractive and productive to live and work in**, and which protect human health.
Macro-objective 5(thematic-area 3) Adaptation and resilience to climate change	**To protect building performance against projected future changes in the climate**, in order to protect occupier health/wellbeing and comfort and to minimise **long-term risks to property values and investments**.
Macro-objective 6 (thematic-area 3) Optimised life cycle cost and value	To optimise the life cycle cost and value of buildings to reflect the potential for long- term **performance improvement, inclusive of acquisition, operation, maintenance, refurbishment, disposal and end of life.**
Macro-objective 7 (thematic-area 4) Generating and regenerating social capital	To foster **inclusiveness** and strong community networks and enhancing **trust, cooperation and collaboration** among people.
Macro-objective 8 (thematic-area 5) Generating and regenerating cultural capital	To foster the **production and sharing of knowledge**, thereby enhancing the **cultural, historic, intrinsic values** of cultural heritage within the community. To preserve cultural, historic and intrinsic values of industrial heritage in order to hand down them also to **future generations.**
Macro-objective 9 (thematic-area 6) Enhancing state of conservation and prolonging the use value of the building/site	To ensure **cultural heritage/site preservation and their functionality** for present and future generations.

Furthermore, for each macro-objective, criteria and indicators (with corresponding ID and unit of measure) are identified to monitor and evaluate the achievement (or not) of the macro-objectives within their respective thematic-areas (Table 3). The 48 criteria define the specific aspects to be evaluated and monitored in order to assess the achievement of the related macro-objective. The indicators have been assigned to each criterion based on their direct relevance to the specific sustainability factor being assessed. Meanwhile, indicators that are similar, complementary or closely related have been grouped together to provide a more comprehensive assessment. This approach allows for a holistic evaluation of each sustainability dimension, avoiding fragmentation and redundancy in the analysis. By grouping related indicators under the same criterion, data analysis becomes more straightforward, allowing for clearer interpretation of results and more informed decision-making.

The indicator ID is structured to include the thematic-area number, the corresponding macro-objective, the related criterion, and a sequential indicator number. Criteria represent a new category of the evaluation framework compared to the Level(s) structure. Many indicators can refer to more than one macro-objective. They have been included in the macro-objective considered most consistent and relevant to the indicator.

For each indicator, the evaluation phase - ex-ante, ongoing, or ex-post - is specified. Not all indicators are applicable across all phases, as their relevance and utility depend on the project's temporal and operational context. During the ex-ante phase, focused on predicting project impacts, the design level is also considered. This approach aligns with the level-based structure promoted by the EC, which stages projects through progressive level of detail.

As aforementioned, the indicators are also categorized based on lifecycle status: *renovation activity, in use, future adaptation potential*. The *renovation activity* category refers to the phase of intervention and physical transformation of the site or building. It encompasses all activities related to modifying the building/site to adapt it for new uses. The *in use* category pertains to the phase in which the building has already been adapted and is actively being utilized, focusing on assessing the project's performance during its operational stage. Finally, the *future adaptation potential* category involves anticipating how the site or building might evolve in the future. This can include potential modifications or improvements linked to future regulatory changes, evolving community needs, technological advancements, or shifts in usage trends. These categories evaluate opportunities for continuous adaptation or potential future interventions in a long-term perspective, in order to prolong the use value according to the circular economy principles.

The categorization into *ex-ante, ongoing*, or *ex-post* phases is anchored in a temporal perspective, while the classification into *renovation activity, in use, future adaptation potential* focuses on the building/site's life cycle. However, the two classifications are closely related and, in some stages, overlap (Fig. 4).

The indicators were deduced both from the literature review and from critical considerations; in some cases, they were adopted directly as found in the sources, while in others they were reinterpreted or reformulated by the authors to better fit the specific evaluative framework. In particular, indicators marked as "Authors' elaboration" have been developed by the authors through synthesis of methodologies drawn from Level(s) and scientific literature on industrial heritage evaluation. A reference to the main relevant sources has been added in the corresponding column of the table.

As shown in Table 3, some indicators need specialized expertise, while others rely on common knowledge and allow community engagement. Some are complex and require specific disciplinary skills.

The unit of measure may vary depending on whether we are evaluating scenarios at Level 1, 2, or 3. However, to facilitate comparisons across the ex-ante, ongoing, and ex-post phases, it is important to identify a common unit of measure that can be applied to all three (if possible).

The indicators from the EC are marked with an asterisk in the evaluation framework. The remaining indicators, as aforementioned, have been derived from the comprehensive scientific literature review, while some of them have been developed by the authors based on a critical analysis of this literature.

3. Discussion

Adapting the Level(s) framework for abandoned industrial heritage requires expanding its thematic-areas, macro-objectives, criteria, and indicators. These include aspects such as the recovery of existing materials, the preservation of historical memory, the social management of urban transformation, and integration into the surrounding urban context. The proposed structure of thematic areas ensures the comprehensive inclusion of all values characteriz-

Table 3
The overall evaluation framework.

THEMATIC-AREA	MACRO-OBJECTIVE	CRITERIA	ID	INDICATOR	UNIT OF MEASURE	SOURCE	EVALUATION PHASE					OPERATIONAL PHASE		
							EX-ANTE			ONGOING	EX-POST	Renovation activity	In use	Future Adaptation potential
							PROJECT LEVEL (ex-ante)							
							1	2	3					
1. Environmental performances of life cycle	**Macro-objective 1:** Greenhouse gas and air pollutant emissions along a building's life cycle	a.ENERGY EFFICIENCY	1.1.a.1	Use stage energy performance*	Kilowatt hours per square meter per year (kWh/sqm/yr)	[38]	•	•	•		•		•	
			1.1.a.2	Life cycle Global Warming Potential*	kg CO_2 equivalents per square meter per year (kg CO_2 eq./sqm/yr)	[38]	•	•	•		•	•	•	•
			1.1.a.3	Annual embodied energy saved per square meter of reused space	kWh/sqm/yr	[33,41,42]	•	•	•		•		•	
			1.1.a.4	Adopted energy efficient measures	No. or Binary (Yes/Not) or checklist	[20,54]	•	•	•	•	•	•	•	
			1.1.a.5	Amount of GHG emissions per year (for the different pollutant typologies: CO2, Pm10, Pm5, Pm,2.5, etc.)	kg CO_2 eq. per year (linked to 1.1.a.2)	[41]	•	•	•	•	•	•	•	•
		b.ENERGY PRODUCTION	1.1.b.1	Annual amount of energy self-produced	kilowatt hours per square meter per year (kWh/sqm /yr) or %	Authors' elaboration	•	•	•		•		•	
		c.CLEAN ENERGY CONSUMPTION	1.1.c.1	Annual amount of energy consumed coming from renewable energy sources	kilowatt hours per square meter per year (kWh/sqm /yr) or %	[9]	•	•	•		•		•	
	Macro-objective 2: Resource efficient and circular material life cycles	a. MATERIAL USE	1.2.a.1	Bill of quantities, materials and lifespans*	Unit quantities, mass and years	[43]	•	•	•	•	•	•		
		b. WASTE PRODUCTION	1.2.b.1	Construction and demolition waste and materials*	kg of waste and materials per sqm total useful floor area	[43]	•	•	•	•	•	•		
		c. ADAPTABILITY	1.2.c.1	Design for adaptability and renovation*	Adaptability score	[43]	•	•	•		•		•	•
		d.MATERIAL REUSE	1.2.d.1	Design for deconstruction, reuse and recycling*	Deconstruction score (by European Commission [43])	[43]	•	•	•		•		•	•
			1.2.d.2	Amount of demolished material reused on site	Kg	Authors' elaboration	•	•	•	•	•	•		
			1.2.d.3	Amount of recycled material used in the construction process	Kg	Authors' elaboration	•	•	•	•	•	•		
		e.MATERIAL DURABILITY	1.2.e.1	Number of years until first major repair	No.	Authors' elaboration					•		•	
			1.2.e.2	Material lifespan in years	No. of year	[45]					•		•	
		f.WASTE PRODUCTION	1.2.f.1	Percentage of waste recycled or reused during construction phase	% in a year	Authors' elaboration	•	•	•	•		•		
			1.2.f.2	Percentage of waste recycled or reused in maintenance process	% in a year	Authors' elaboration					•		•	
			1.2.f.3	Percentage of waste recycled or reused coming from activities taking place at the building/site	% in a year	Authors' elaboration					•		•	
		g.GREENERY AND NATURE-BASED SOLUTIONS	1.2.g.1	Number of adopted nature-based solutions	No. in a year	[33]	•	•	•	•	•	•	•	
			1.2.g.2	Percentage of surface of green area on the total surface	%	[9,13]	•	•	•	•	•		•	

(continued on next page)

Table 3 (*continued*)

THEMATIC-AREA	MACRO-OBJECTIVE	CRITERIA	ID	INDICATOR	UNIT OF MEASURE	SOURCE	EVALUATION PHASE					OPERATIONAL PHASE		
							EX-ANTE PROJECT LEVEL (ex-ante)			ONGOING	EX-POST	Renovation activity	In use	Future Adaptation potential
							1	2	3					
	Macro-objective 3: Efficient use of water resources	a.WATER CONSUMPTION	1.3.a.1	Use stage water consumption*	m^3/yr of water per occupant	[46]					•		•	
		b.WATER EFFICIENCY	1.3.b.1	Presence of water reuse systems	Binary (Yes/Not)	[20,33]	•	•	•	•	•	•	•	
			1.3.b.2	Annually percentage of water coming from in-site reused water processes	% per year	Authors' elaboration	•	•	•		•		•	
			1.3.b.3	Annually amount of water supply from outside on the total water amount required	%	Authors' elaboration	•	•	•		•		•	
2. Health and comfort and wellbeing	**Macro-objective 4:** Healthy and comfortable spaces	a.AIR QUALITY COMFORT	2.4.a.1	Indoor air quality*	Ventilation rate (air flow) CO_2 Particulates Relative humidity	[19,23,47,56]	•	•	•		•		•	
		b.THERMAL COMFORT	2.4.b.1	Time outside of thermal comfort range*	% of the time out of range during the heating and cooling seasons	[47]					•		•	
			2.4.b.2	Percentage of people declaring to be in thermal comfort (indoor/outdoor depending on whether it relates to the building or the site)	Percentage of interviewees declaring to be in thermal comfort during a reference period	[15,22,23]					•		•	
		c.LIGHT COMFORT	2.4.c.1	Lighting and visual comfort*	Level 1 checklist (by European Commission [47]) or Useful Daylight Illuminance (UDI)	[47]	•	•	•		•		•	
			2.4.c.2	Percentage of people declaring to be in light comfort during a reference period	%	[22]					•		•	
			2.4.c.3	Ratio of transparent surface area to usable floor area	%	Authors' elaboration	•	•	•	•	•		•	
		d.ACOUSTIC COMFORT	2.4.d.1	Acoustics and protection against noise*	Level 1 checklist (by European Commission[47])	[47]	•	•	•	•	•		•	
			2.4.d.2	Percentage of people declaring to be in acoustic comfort indoor	%	[22]					•		•	
			2.4.d.3	Percentage of people declaring to be in acoustic comfort outdoor	%	[22]					•		•	
		e.COMMUNITY SATISFACTION	2.4.e.5	Level of the capacity of the reused industrial heritage to meet needs/ requirement of the local community	Likert scale	[30]	•	•	•		•		•	
		f.SAFETY/SECURITY	2.4.f.6	Percentage of citizens feeling safe in the site and its surrounding	%	[14,33]	•	•	•		•		•	
		g.LAND RECLAMATION	2.4.g.7	Minimum amount of reclaimed land required to activate the reuse process	Sqm	Authors' elaboration	•	•	•			•		
			2.4.g.8	Amount of reclaimed land	Sqm	Authors' elaboration				•	•		•	

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Table 3 (*continued*)

THEMATIC-AREA	MACRO-OBJECTIVE	CRITERIA	ID	INDICATOR	UNIT OF MEASURE	SOURCE	EVALUATION PHASE					OPERATIONAL PHASE		
							EX-ANTE PROJECT LEVEL (ex-ante)			ONGOING	EX-POST	Renovation activity	In use	Future Adaptation potential
							1	2	3					
3. Cost, value and risk	**Macro-objective 5:** Adaptation and resilience to climate change	a.COMMUNITY VULNERABILITY	3.5.a.1	Protection of occupier health and thermal comfort*	Projected % time out of range in the years 2030 and 2050	[23,49]	•	•	•		•		•	
			3.5.a.2	Increased risk of extreme weather events*	Checklist (by European Commission [49])	[49]	•	•	•		•		•	•
			3.5.a.3	Increased risk of flood events*	Checklist (by European Commission [49])	[49]	•	•	•		•		•	•
	Macro-objective 6: Optimised life cycle cost and value	a.FINANCIAL SUSTAINABILITY	3.6.a.1	Life cycle costs*	Euros per square meter per year (€/ sqm/yr)	[51]	•	•	•	•	•		•	
			3.6.a.2	Value creation and risk factors*	Checklist (by European Commission [51])	[51]	•	•	•	•	•		•	
			3.6.a.3	Cost of project implementation	€	[5,20]	•	•	•	•	•	•		
			3.6.a.4	Annual costs required for maintaining the reused industrial heritage	€ per year	[9]	•	•	•	•	•		•	
			3.6.a.5	Annual operating costs associated with activities provided through the reused industrial heritage	€ per year	[9]	•	•	•		•	•	•	
			3.6.a.6	Extent of economic diversification	Likert scale	[25]	•	•	•	•	•	•	•	
		b.REVENUE AND EARNINGS	3.6.b.1	Annually amount of revenue from new activities established (beneficiary-dependent)	€ per year	[19]	•	•	•		•		•	
		c.FINANCIAL SELF-SUSTAINABILITY	3.6.c.1	Level of capacity of activities located in the reused industrial heritage to be financially self-sustaining	Likert scale	[9]					•		•	
		d.REAL ESTATE MARKET VALUE	3.6.d.1	Real estate market value of the surrounding buildings (comparing before and after the implementation of the project)	€ in a year	[15,57]	•	•	•	•	•	•	•	•
			3.6.d.2	Number of real estate buying and selling transactions in the surrounding area (comparing before and after the implementation of the project)	No. in a year	Authors' elaboration	•	•	•	•	•	•	•	•
		e.TAX REVENUE	3.6.e.1	Annually tax revenue from new businesses/activities established (beneficiary-dependent)	€ per year	[58]	•	•	•		•		•	
		f.INVESTMENT ATTRACTIVENESS	3.6.f.1	Amount of private investments in the industrial heritage	€ in a year	[9]	•	•	•	•	•	•	•	•
			3.6.f.2	Amount of new public investments in the industrial heritage	€ in a year	[9]	•	•	•	•	•	•	•	•
			3.6.f.3	Amount of new investment in the industrial heritage after the implementation of the project	€ in a year	[9]					•		•	•
		g.ENTREPRENEURSHIP ATTRACTIVENESS	3.6.g.1	Number of creative and innovative enterprises localized in the building/site	No. in a year	[27]	•	•	•		•		•	•
			3.6.g.2	New start-ups born as a result of (and related to) the industrial heritage reuse project	No. in a year	[27]					•	•	•	•

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Table 3 (*continued*)

THEMATIC-AREA	MACRO-OBJECTIVE	CRITERIA	ID	INDICATOR	UNIT OF MEASURE	SOURCE	EVALUATION PHASE					OPERATIONAL PHASE		
							EX-ANTE			ONGOING	EX-POST	Renovation activity	In use	Future Adaptation potential
							PROJECT LEVEL (ex-ante)							
							1	2	3					
4. Social capital and value	**Macro-objective 7:** Generating and regenerating social capital	a.EMPLOYMENT	4.7.a.1	Number of (short and long-term) jobs directly generated from adaptive reuse project	No. in a year	[9,24,25]	•	•	•	•	•	•	•	•
			4.7.a.2	Number of different job categories generated from adaptive reuse project	No. in a year	[9]	•	•	•	•	•	•	•	•
		b.SOCIAL COHESION	4.7.b.1	Number of third sector subjects involved in activities located in the reused building/site	No. in a year	[33,57]				•	•	•	•	
			4.7.b.2	Number of third sector subjects involved in activities related to the reused building/site (but external)	No. in a year	Authors' elaboration				•	•	•	•	
			4.7.b.3	Number of associations born in relation to the reused industrial heritage	No. in a year	Authors' elaboration				•	•	•	•	
			4.7.b.4	Percentage of surface of reused industrial heritage intended to host third sector	%	Authors' elaboration	•	•	•	•	•		•	
		c.COOPERATION	4.7.c.1	Number of Public-Private-Partnership activated in relation to the reused industrial heritage	No. in a year	[5,54]	•	•	•	•	•		•	
		d.PARTICIPATION	4.7.d.1	Number of stakeholder categories participating in decision-making process of industrial heritage adaptive reuse	No.	[24,30,54]	•	•	•			•		
			4.7.d.2	Percentage of community declaring a willingness to be involved in the organization of activities located in the reused industrial heritage	%	Authors' elaboration	•	•	•	•	•	•	•	•
		e.INCLUSIVENESS	4.7.e.1	Number of volunteers involved in activities located in the reused industrial heritage	No.	[9]					•		•	
			4.7.e.2	Number of stakeholders categories involved in activities located in the reused industrial heritage	No.	[54]	•	•	•	•	•		•	
		f.PEOPLE ATTRACTIVENESS	4.7.f.1	Average length of site visit	Hours per day	Authors' elaboration					•		•	
			4.7.f.2	Frequency of site visitation	Days per month	[25]					•		•	
			4.7.f.3	Number of visitors to the reused building/site	No. per year	[33]	•	•	•		•		•	
		g.ACCESSIBILITY	4.7.g.1	Level of accessibility for different groups of population (e.g., the elderly, children, people with disabilities)	Likert scale	Authors' elaboration	•	•	•		•		•	
			4.7.g.2	Frequency of use of the site by the local community	Days per months	Authors' elaboration	•	•	•		•		•	
			4.7.g.3	Level of physical accessibility of the reused industrial site/building	Likert scale	[23]	•	•	•		•		•	

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THEMATIC-AREA	MACRO-OBJECTIVE	CRITERIA	ID	INDICATOR	UNIT OF MEASURE	SOURCE	EVALUATION PHASE					OPERATIONAL PHASE		
							EX-ANTE			ONGOING	EX-POST	Renovation activity	In use	Future Adaptation potential
							PROJECT LEVEL (ex-ante)							
							1	2	3					
5. Cultural capital and value	**Macro-objective 8:** Generating and regenerating cultural capital	a.KNOWLEDGE PRODUCTION	5.8.a.1	Number of activities aimed at knowledge production	No. per year	Authors' elaboration	•	•	•	•	•		•	
			5.8.a.2	Annual number of events aimed at knowledge production	No. per year	Authors' elaboration					•		•	
			5.8.a.3	Annual number of participants in events aimed at knowledge production	No. per year	Authors' elaboration					•		•	
			5.8.a.4	Number of community members involved in the organization of events aimed at knowledge production	No. in a year	Authors' elaboration					•		•	
			5.8.a.5	Surface intended to activities aimed at knowledge production	Sqm or %	Authors' elaboration	•	•	•	•	•		•	
		b.TRADITIONAL SKILLS SHARING (related also to old industrial processes)	5.8.b.1	Number of activities aimed at transmission of traditional tangible and intangible industrial culture	No. in a year	[9]	•	•	•	•	•		•	
			5.8.b.2	Annual number of events aimed at transmission of traditional tangible and intangible industrial culture	No. per year	[56]					•		•	
			5.8.b.3	Annual number of participants in events aimed at transmission of traditional tangible and intangible industrial culture	No. per year	[9,56]					•		•	
			5.8.b.4	Number of community members involved in the organization of events aimed at transmission of traditional tangible and intangible industrial culture	No. in a year	[56]					•		•	
			5.8.b.5	Surface intended to activities aimed at transmission of traditional tangible and intangible industrial culture	Sqm or %	[14]	•	•	•	•	•		•	
			5.8.b.6	Number of training courses and programs for transmission of traditional skills	No. in a year	[9]	•	•	•	•	•		•	
		c.ATTACHMENT TO PLACE	5.8.c.1	Percentage of community declaring to feel emotionally attached to the place	%	[15,25,57]	•	•	•		•		•	
			5.8.c.2	Percentage of community declaring they would recommend other people to visit the place	%	Authors' elaboration					•		•	
		d.LOCAL IDENTITY	5.8.d.1	Community perception of the industrial site as an integral part of their identity	Likert scale	Authors' elaboration	•	•	•	•	•	•	•	
		e.CULTURAL VIBRANCY	5.8.e.1	Annually number of cultural events organized in the building/site	No. per year	[56]					•		•	
			5.8.e.2	Annually number of participants to cultural events organized in the building/site	No. per year	[33]					•		•	

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Table 3 (*continued*)

THEMATIC-AREA	MACRO-OBJECTIVE	CRITERIA	ID	INDICATOR	UNIT OF MEASURE	SOURCE	EVALUATION PHASE					OPERATIONAL PHASE		
							EX-ANTE			ONGOING	EX-POST	Renovation activity	In use	Future Adaptation potential
							PROJECT LEVEL (ex-ante)							
							1	2	3					
		f.COMMUNITY PERCEPTION	5.8.f.1	Level of intensity of attributes that the community associates with the building/site	Likert scale	Authors' elaboration	•	•	•	•	•	•	•	
			5.8.f.2	Level of intensity of feelings that the community associates with the building/site	Likert scale	Authors' elaboration	•	•	•	•	•	•	•	
6. State of conservation and use value	**Macro-objective 9:** Enhancing state of conservation and prolonging the use value of the building/site	a.ADAPTABILITY	6.9.a.1	Level of reversibility of actions for adaptive reuse of industrial heritage	Likert scale	[5,30]	•	•	•	•	•	•	•	•
		b.“INVASIVITY”/ SEVERITY OF CHANGE	6.9.b.1	Capacity of the project to meet the “minimum interventum” strategy	Likert scale	[59]	•	•	•	•	•	•		•
		c.FLEXIBILITY/ ADAPTABILITY	6.9.c.1	Presence of removable spatial elements	Binary (Yes/Not)	[5]	•	•	•	•	•	•	•	•
			6.9.c.2	Capacity of the space to be adapted to different functions over time	Likert scale	[5,60]	•	•	•	•	•	•	•	•
			6.9.c.3	Percentage of multi-functional spaces on the total spaces	%	[5,12]	•	•	•	•	•	•	•	
		d.INTEGRITY AND AUTHENTICITY	6.9.d.1	Level of conservation of original features	Likert scale	[14,24,31,61]	•	•	•	•	•	•		
		e.RECOGNIZIBILITY	6.9.e.1	Level of recognizability of the transformations	Likert scale	[14,15,24,31,62]	•	•	•	•	•	•		
		f.CONSERVATION OF THE ORIGINAL DIMENSIONS OF THE BUILDING	6.9.f.1	Level of conservation of the original dimensions of the building	Likert scale	[56]	•	•	•	•	•	•		
			6.9.f.2	Pre-existing volume conserved	m^3	[5,22]				•	•	•		
		g.COMPATABILITY	6.9.g.1	Level of compatibility of new use(s) with previous use(s)	Likert scale	[15,30]	•	•	•	•	•	•	•	
			6.9.g.2	Level of compatibility of new use(s) with the characteristics of the building	Likert scale	[5,16,24]	•	•	•	•	•	•	•	
			6.9.g.3	Level of aesthetic relationship (visual compatibility) with the surrounding landscape (conservation of morphological-dimensional relationship between the site and its context)	Likert scale	[9,27]	•	•	•	•	•	•	•	
		h.TEMPORARY USE	6.9.h.1	Surface intended for temporary use on the total of surface in use phase	%	Authors' elaboration	•	•	•	•	•	•	•	•
			6.9.h.2	Surface intended for temporary use on the total of surface during the renovation phase	%	Authors' elaboration	•	•	•	•	•	•		
			6.9.h.3	Number of third sector subjects involved in temporary use implementation	No. in a year	Authors' elaboration	•	•	•	•	•	•	•	•
			6.9.h.4	Number of activities taking place in spaces intended for temporary use	No. in a year	Authors' elaboration	•	•	•	•	•	•	•	•

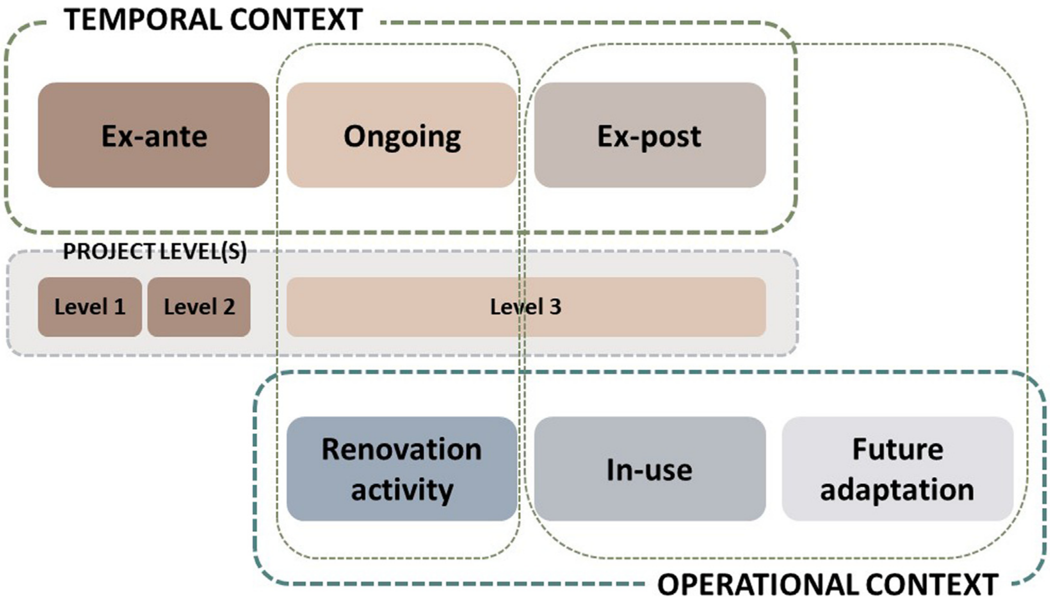

Fig. 4. Categorization of indicators: temporal and operational categories.

ing this type of resource within the evaluation process, encompassing both tangible and intangible dimensions.

Industrial heritage AR contributes to the macro-objectives of each thematic-area as follows. In reference to the first macro-objective, "**Greenhouse gas and air pollutant emissions along a building's life cycle" (1)** [38]**,** industrial heritage AR helps cut emissions by avoiding new construction and preserving existing materials and embodied energy [39,40]. This approach reduces energy-intensive processes like material extraction and assembly, offering significant environmental benefits and supporting a low-carbon economy [41,42].

Industrial heritage AR aligns with the objective **"Resource-Efficient and Circular Material Life Cycles" (2)** [43] by prioritizing the preservation of existing materials, minimizing the need for new raw materials, and reducing demolition waste, in order to preserve authenticity and integrity of the heritage. When demolition is necessary, materials can be repurposed within a circular economy process [44,45]. This approach extends the life cycle of resources, but also prevents land consumption associated with new construction.

The **"Efficient water use of water resource" (3)** objective [46] aims to minimize water consumption throughout a building's life cycle. Industrial heritage AR contributes to this goal by reducing water use during demolition and construction compared to new builds. Additionally, water-saving strategies and self-sufficiency measures can be integrated into reuse projects, optimizing water consumption and promoting more sustainable use of this critical resource.

The **"healthy and comfortable spaces" (4)** objective [47] focuses on realizing spaces that enhance comfort, attractiveness, and productivity while safeguarding human health. Health is closely linked to wellbeing, a broader concept encompassing different factors as also highlighted by the Italian National Institute of Statistics (ISTAT) [48]. These two concepts are interconnected - good health fosters wellbeing, and "not-wellbeing" can negatively affect health. In addition, as highlighted in ISTAT's 12 domains of Equitable and Sustainable Wellbeing Framework [48], there are several studies showing that cultural heritage contributes to people's wellbeing and in improving their quality of life. Industrial heritage AR supports this goal for example through thoughtful design: historical industrial buildings often feature structural characteristics, such as thick walls or strategic orientation, which improve microclimates, contributing to occupant comfort and health. Industrial heritage AR also provides new opportunities for social and economic enrichment, offering spaces for activities and employment, further enhancing overall wellbeing.

The "**Adaptation and resilience to climate change" (5)** objective [49] focuses on ensuring buildings can withstand future climate changes to safeguard health/wellbeing, comfort, and property values. Industrial heritage reuse aligns with this goal by offering sustainable land-use and consumption models refined over time through adaptation between communities and their environments. The potential of heritage investment to mitigate climate change by preserving the significant embodied energy in historic industrial buildings is highlighted [39]. AR reduces greenhouse gas emissions, waste, and resource consumption, directly addressing environmental challenges. Such practices minimize negative impacts and contribute to climate resilience. Reusing industrial heritage can help reduce global temperatures, contributing also to Paris Agreement's goals [50]. Although Macro-objective 5 is positioned under thematic-area 3 – Cost, value and risk, following the structure of the European Commission's Level(s) tool, its scope extends beyond purely financial or technical resilience. In fact, adaptation to climate change directly affects occupants' wellbeing and the environmental quality of both indoor and outdoor spaces, establishing strong conceptual links with thematic-area 2 – Health, comfort and wellbeing. For this reason, its inclusion within thematic-area 3 is maintained for consistency with the Level(s) structure, but acknowledging its cross-cutting relevance across the two thematic areas.

The **"Optimise the life cycle cost and value" (6)** objective focuses on life cycle cost and value of buildings to enable long-term performance improvements [51]. It highlights that while achieving better environmental performance may require higher initial investments, these often lead to reduced running costs, increased property values, and greater productivity over time. When applied to industrial heritage AR, this approach emphasizes cost efficiency over the building's lifecycle, incorporating intangible benefits like enhanced user wellbeing and productivity. Reusing industrial structures revitalizes their functionality, but also raises their real estate value and that of neighbouring areas, providing economic benefits for the broader community. By integrating sustainable consumption models, such as energy and water efficiency, reuse projects reduce long-term operational costs, ensuring that both financial and environmental goals are achieved, making AR a viable and impactful strategy.

In reference to the objective **"Generating and Regenerating Social Capital" (7),** industrial heritage AR can foster social cohesion by creating connections within communities and preserving collective memory. These sites serve as "connective infrastructure" [52], linking diverse groups through shared heritage and fostering participation, collaboration, and innovative economic models such as social enterprises and cooperatives. Job creation tied to reuse enhances inclusion and wellbeing, providing avenues for social engagement and integration.

Industrial heritage embodies a unique cultural identity as well as historical and technological significance. AR preserves material but also the intangible factors (i.e., traditional know-how, specialized skills, collective memory) that define community identity. For instance, preserving machinery or original production layouts offers tangible links to historical innovation. It bridges past and future, ensuring cultural continuity while allowing for innovation.

By integrating contemporary functions within authentic frameworks, AR maintains historical integrity, supports community identity, and revitalizes areas while fostering cultural innovation. This approach highlights the transformation of heritage sites into dynamic spaces that bridge historical and contemporary society needs. By maintaining the sites' authenticity, AR strengthens place identity and fosters a sense of belonging, contributing to **"Generating and Regenerating Cultural Capital" (8)**.

AR preserves industrial heritage by maintaining or adapting structures to meet contemporary needs without compromising authenticity. This approach extends the life-cycle of the buildings, preventing degradation due to abandonment, contributing to the objective **9 "Enhancing state of conservation and prolonging the use value of the building/site"**. It aligns with circular economy principles by minimizing waste, maintaining physical integrity, and supporting long-term sustainability. A well-preserved site boosts local pride, economic vitality, and the intergenerational transfer of cultural assets.

As stressed in the previous paragraph, the proposed indicators were selected through the in-depth scientific literature review, which helped identify the most appropriate parameters for monitoring the impact of each aspect of sustainability in industrial heritage AR. The distinction of indicators into *ex-ante, ongoing, and ex-post* enables a comprehensive evaluation that covers all phases of the project, from initial planning to implementation and operational management. Specifically, identifying ex-ante indicators for the early stages of the project, such as assessing the potential reusability of materials or the expected environmental impact, is fundamental for guiding more sustainable design choices. Ongoing and ex-post indicators instead help monitor compliance with design commitments during and after implementation, ensuring that sustainability objectives are effectively achieved.

The linkage of indicators to the design levels (see §3) addresses practical constraints, ensuring evaluations are grounded in available data. For example, in the early stages, much information will still be uncertain or undefined, making it impossible to "populate" certain indicators that require more specific details. In contrast, as the project progresses and technical and operational aspects are defined, increasingly accurate and complete data can be collected. This approach allows the framework to be adapted to the life cycle of the project, avoiding waste of time and resources.

Adapting Level(s) to the industrial heritage also highlighted the need for a holistic and multidisciplinary approach. The sustainability of these projects cannot be limited to environmental or economic factors, but has to also consider social and cultural dimensions. The adoption of these targeted indicators, divided across time phases, allows for monitoring each dimension of sustainability ensuring that projects adhere to environmental sustainability principles and also contribute to improving community wellbeing.

Industrial heritage, but more in general cultural heritage, is strictly linked to its context [53] and thus the evaluation framework needs to reflect this condition. Therefore, the indicators can be referred to two scale-categories:

- **Impacts on** the industrial heritage/site;
- **Impacts of** the industrial heritage/site on the context.

The first category refers to the impacts that the project has specifically on the building/site, while the second category is related to the "reverberation" of the project on the surrounding. The proposed indicator system considers the building/site and its context as an ecosystem in which different components enter into a relationship, in a symbiotic process.

Some of the indicators are explicitly referred to the impacts that the implementation of circular process (related to the AR) produces both on the building/site and on the context, while some of them are expressions of the circularity level of the process (as material reuse).

The proposed framework can provide a **structured foundation for multicriteria evaluations,** serving as a key input for comparing alternative scenarios. This connection to multicriteria evaluation is important because the reuse of abandoned industrial sites involves complex and often conflicting factors. By integrating this framework into decision-making processes, stakeholders can analyse different scenarios based on measurable and comparable criteria, leading to more informed and transparent choices. Additionally, it enhances comparability across projects, ensuring that sustainability and heritage conservation objectives are consistently addressed throughout the evaluation process.

The proposed framework aims to establish a shared language by adopting a unified framework of indicators. It is intended for a variety of stakeholders engaged at different project stages. For example, it is aimed at **design teams,** including architects, engineers, surveyors, and specialized consultants, who can use the framework to integrate sustainability principles into their projects, ensuring a comprehensive assessment of the impacts of AR. It also supports **clients and investors**, such as real estate developers, property managers, and owners of disused industrial buildings, by providing a clear system for evaluating the economic and social value of interventions, ensuring transparency in performance data, and enabling more effective risk and opportunity management. Additionally, it is designed for **policy makers and public authorities** at local, regional, and national levels, helping them develop urban regeneration and circular economy strategies. The framework provides a standardized basis for performance evaluation, improving environmental quality and achieving sustainability goals while preserving cultural heritage. Lastly (unlike the Level(s) tool), the proposed framework involves the **local community,** including citizens and associations, who benefit from greater inclusion in the adaptive reuse projects. By actively contributing to defining new uses and monitoring the social and cultural impacts of interventions, the community plays a key role in ensuring the long-term success of AR projects. The involvement of the aforementioned different stakeholder categories can represent a success factor for AR processes [54].

To ensure its effectiveness, the framework has to be easy to understand, applicable across diverse experiences, and, at least partially, accessible both to non-experts as well as professionals. Given the wide range of stakeholders involved, the need for a common language becomes even more fundamental. Therefore, developing clear guidelines for using this framework - similar to those elaborated for the Level(s) tool - is essential. Additionally, investing in training programs is necessary to equip all participants with the skills needed to effectively use and integrate these tools into their processes.

An important feature of this tool is related to transparency and comparability. In fact, through the identified indicators, it facilitates comparison between projects and provides a comparable database for making more informed decisions. Therefore, these indicators can represent the input data for integrated evaluation [55] comparing different scenarios. Specifically, based on the established functions and the specificities of the contexts, additional indicators may be identified.

4. Conclusions

The adaptive reuse of industrial heritage illustrates how circular economy principles can be effectively implemented within the built environment, generating regenerative outcomes through circular processes. By extending the lifecycle of existing buildings, preserving embodied energy and material capital, and preventing demolition waste, adaptive reuse reduces environmental pressures and supports resource efficiency. At the same time, the reactivation of disused industrial assets generates new opportunities for social interaction, cultural production, and local economic development, fostering inclusive and place-based regeneration. In this perspective, adaptive reuse functions as a catalyst that translates the methodological foundation of the circular economy into tangible social and environmental benefits.

In this context, this study adapts and integrates the European Commission's Level(s) tool for application to industrial heritage AR. The primary necessity was to integrate the thematic-areas, macro-objectives, and indicators, making the tool more suitable and tailored to assess environmental, socio-cultural, and economic sustainability, fostering more aware, equitable, and sustainable urban regeneration. This adjustment provides a significant contribution to sustainability in the construction sector - given the large amount of built capital that is currently abandoned or underutilized - transforming such spaces from "waste" into resources for cities (in line with the circular economy principles), improving their urban and social contexts. The proposed integrated approach allows for a more detailed and targeted evaluation, supporting the project from design to post-occupancy management, with clear and specific indicators for each phase of the building's life cycle. The phase-specific indicators support a robust methodology for monitoring the achievement of sustainability goals at each stage of the project, enabling an adaptive approach that allows for in-progress modifications and adjustments.

The framework can also be applied at the conceptual design stage, relying solely on qualitative assessments as the basis for design development. In all project levels not all the indicators require the same level of complexity. So, core indicators that are most relevant can be identified each time, according to the Pareto Principle.

The proposed framework also provides practical value as a tool for governance and informed decision-making among the different stakeholders involved in circular regeneration. For policymakers, it serves as a structured monitoring and evaluation tool that can be incorporated into public programmes to align urban regeneration strategies with European circular economy and climate adaptation goals. By adopting the proposed indicators, public administrations can assess the multidimensional impacts of interventions in a transparent and comparable way, fostering evidence-based policies and accountability. For professionals and developers, the framework acts as a design and management support system, helping to balance environmental performance with socio-cultural value preservation and economic sustainability. Its multidimensional structure encourages dialogue among technical experts, heritage authorities, and planners, thereby enhancing interdisciplinary collaboration. Communities and civic organizations also play a central role within the framework: the inclusion of participatory and perception-based indicators allows them to engage in monitoring and co-assessing the social and cultural outcomes of projects. This participatory dimension ensures that adaptive reuse processes are inclusive, equitable, and responsive to local needs.

In this perspective, the framework is not merely an analytical tool but a shared language that facilitates cooperation and mutual understanding among actors operating at different levels of the adaptive reuse projects. It contributes to the establishment of a more integrated, transparent, and circular governance model, where environmental, economic, and socio-cultural objectives reinforce each other rather than compete.

As already highlighted, many of the indicators included in the framework require advanced technical expertise to populate, as well as the need for close interdisciplinary collaboration. This poses the challenge of ensuring that the various stakeholders involved have access to the necessary resources and skills to understand and effectively use the tool. The effective use of the framework might depend on significant investments in training and awareness-raising, for technical professionals but also for policymakers and communities, to ensure a shared and integrated approach.

Future research will focus on applying and testing the framework in real-world adaptive reuse projects, defining the weighting of indicators and validating its effectiveness as a decision-support and policy-monitoring tool for industrial heritage adaptive reuse projects.

Attributions

Conceptualization: Francesca Nocca, Hilde Remøy; **Methodology:** Francesca Nocca, Hilde Remøy; **Formal analysis:** Francesca Nocca; **Writing – original draft**: Francesca Nocca; **Writing – review & editing:** Francesca Nocca, Hilde Remøy. All authors have read and approved the final version of the manuscript.

References

[1] TICCIH, The Nizhny Tagil Charter for the industrial heritage, Nizhny Tagil Chart. Ind. Herit. (2003) 1–6.
[2] M.R. Chertow, Industrial symbiosis: literature and taxonomy, Annu. Rev. Energy Environ. 25 (2000) 313–337.
[3] ICOMOS; TICCIH, The "Dublin Principles". Joint ICOMOS – TICCIH principles for the conservation of industrial heritage sites, structures, Areas Landsc. (2011).
[4] TICCIHIndustrial Heritage Re-Tooled. The TICCIH Guide to Industrial Heritage Conservation, J. Douet (Ed.), Routledge, 2013 ISBN 9781315426525.
[5] M.B. Hamida, H. Remøy, V. Gruis, B. van Laar, Towards promoting circular building adaptability in adaptive reuse projects: a co-developed framework, Smart Sustain. Built Environ. (2024), doi:10.1108/SASBE-03-2024-0087.
[6] Ellen MacArthur Foundation, Growth within: A Circular Economy Vision for a Competitive Europe, 2015. www.ellenmacarthurfoundation.org.
[7] United Nations *Transforming our world: the 2030 agenda for sustainable development*; United Nations: New York, NY, USA, 2015.
[8] United Nations (Habitat III) Habitat III New Urban Agenda, Quito declaration on sustainable cities and human settlements for allHabitat III Conf., 2016.
[9] F. Nocca, M. Bosone, M. Orabona, Multicriteria evaluation framework for industrial heritage adaptive reuse: the role of the 'intrinsic value, Land (2024) 13, doi:10.3390/land13081266.
[10] P. Cucco, G. Maselli, A. Nesticò, F. Ribera, An evaluation model for adaptive reuse of cultural heritage in accordance with 2030 SDGs and European Quality Principles, J. Cult. Herit. 59 (2023) 202–216, doi:10.1016/j.culher.2022.12.002.
[11] D. Moher, A. Liberati, J. Tetzlaff, D.G. Altman, Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement, Int. J. Surg. 8 (2010) 336–341, doi:10.1016/j.ijsu.2010.02.007.
[12] X. Xiong, Y. Wang, C. Ma, Y. Chi, Ensuring the authenticity of the conservation and reuse of modern industrial heritage architecture: a case study of the large machine factory, China, Buildings (2023) 13, doi:10.3390/buildings13020534.
[13] S.H. Han, H. Zhang, Progress and prospects in industrial heritage reconstruction and reuse research during the past five years: review and outlook, Land (2022) 11.
[14] X. Zheng, T. Chen, C. Zheng, T. Heath, Unlocking public engagement in reused industrial heritage: weighting point evaluation method for cultural expression, Buildings 14 (2024), doi:10.3390/buildings14092695.

[15] F. Nocca, P. De Toro, V. Voysekhovska, Circular economy and cultural heritage conservation: a proposal for integrating level(s) evaluation tool, Aestimum 78 (2021) 105–143, doi:10.36253/aestim-10119.
[16] L. Della Spina, S. Carbonara, D. Stefano, A. Viglianisi, Circular evaluation for ranking adaptive reuse strategies for abandoned industrial heritage in vulnerable contexts, Buildings 13 (2023) 1–17, doi:10.3390/buildings13020458.
[17] M. Bottero, C. D'Alpaos, A. Oppio, Ranking of adaptive reuse strategies for abandoned industrial heritage in vulnerable contexts: a multiple criteria decision aiding approach, Sustainability 11 (2019) 1–18, doi:10.3390/su11030785.
[18] H. Yasemin Çakır, E. Edis, A database approach to examine the relation between function and interventions in the adaptive reuse of industrial heritage, J. Cult. Herit. 58 (2022) 74–90, doi:10.1016/j.culher.2022.09.015.
[19] I. Vardopoulos, E. Tsilika, E. Sarantakou, A.A. Zorpas, L. Salvati, P. Tsartas, An integrated swot-pestle-ahp model assessing sustainability in adaptive reuse projects, Appl. Sci. (2021) 11, doi:10.3390/app11157134.
[20] Y. Liu, H. Li, W. Li, Q. Li, X. Hu, Value assessment for the restoration of industrial relics based on analytic hierarchy process: a case study of Shaanxi Steel Factory in Xi'an, China, Environ. Sci. Pollut. Res 28 (2021) 69129–69148, doi:10.1007/s11356-021-14897-0.
[21] J. Song, J. Chen, X. Yang, Y. Zhu, Research on adaptive reuse strategy of industrial heritage based on the method of social network, Land (2024) 13, doi:10.3390/land13030383.
[22] F. Meng, X. Zhang, Y. Pang, Evaluation of satisfaction with spatial reuse of industrial heritage in high-density urban areas: a case study of the core area of Beijing's Central City, Buildings 14 (2024), doi:10.3390/buildings14051473.
[23] S.S. Madani, H. Kamelnia, A. Ghalehnovi, Assessing user's satisfaction in innovation centers with industrial heritage renovation, Int. J. Hum. Cap. Urban Manag. 9 (2024) 279–298, doi:10.22034/IJHCUM.2024.02.07.
[24] W. Huang, G. Xiong, N. Talebian, Research into satisfaction with industrial heritage renewal based on the SEM-IPA model : a case study of the Dongguan Jianyuzhou Park, Land (2022) 403.
[25] M.D.P. Farashah, Evaluation of social and economic values in textile manufacturing heritage sites: the case of Yazd, Ge-Conservacion 24 (2023) 228–237, doi:10.37558/GEC.V24I1.1266.
[26] C. Vizzarri, V. Sangiorgio, F. Fatiguso, A. Calderazzi, A holistic approach for the adaptive reuse project selection: the case of the former Enel power station in Bari, Land Use Policy (2021) 111, doi:10.1016/j.landusepol.2021.105709.
[27] G. Cimadomo, C. Varagnoli, Industrial heritage in Malaga (Spain): research and education via four key design concepts, Heritage 6 (2023) 7624–7639, doi:10.3390/heritage6120401.
[28] E. Dedekarginoğlu, Adaptive reuse in industrial buildings - an architectural evaluation of Ankara's CerModern Art Gallery, in: Proc. 14th Int. Docomomo Conf. - Adapt. Reuse Mod. Mov. Towar. Futur., 2016, pp. 251–256.
[29] K. Pulles, I.A.M. Conti, M.B.d. Kleijn, B. Kusters, T. Rous, L.C. Havinga, D. Ikiz Kaya, Emerging strategies for regeneration of historic urban sites: a systematic literature review, City, Cult. Soc. 35 (2023) 100539, doi:10.1016/j.ccs.2023.100539.
[30] F. Gharaati, M. Mahdavinejad, A. Nadolny, H. Bazazzadeh, Sustainable assessment of built heritage adaptive reuse practice: Iranian industrial heritage in the light of international charters, Hist. Environ. Policy Pract. 14 (2023) 498–532, doi:10.1080/17567505.2023.2261328.
[31] S. Xu, N. Aoki, Introduction to a major project of the National Social Science Fund: research on China's industrial heritage conservation system, Built Herit. 2 (2018) 3–18, doi:10.1186/BF03545699.
[32] B.M. Walczak, A. Kepczynska-Walczap, Adaptive re-use of industrial heritage in Lodz, Poland, Int. J. Conserv. Sci. 15 (2024) 955–966, doi:10.2307/2752507.
[33] CLIC Project *Circular models leveraging investments in cultural heritage adaptive reuse (CLIC) 2017-2021*; https://www.clicproject.eu, 2021;
[34] OpenHeritage Project *OpenHeritage: organising, promoting and enabling heritage Re-use through inclusion, technology, access, governance and empowerment. 2018-2022*; https://openheritage.eu, 2022;
[35] Dodd, N.; Donatello, S.; Cordella, M. Level(s) – a common EU framework of core sustainability indicators for office and residential buildings. User manual 2: setting up a project to use the level(s) common framework. *Available online:* https://susproc.jrc.ec.europa.eu/Efficient_Buildings/documents.html 2021, 1–68.
[36] Dodd, N.; Cordella, M.; Traverso, M.; Donatello, S. JRC Technical reports: level(s) – a common EU framework of core sustainability indicators for office and residential buildings. User manual 1: introduction to the level(s) common framework. 2021, 1–68, doi:10.2760/827838.
[37] M. Zeleny, Entering the age of accelerated change: in search of equilibrium, Hum. Syst. Manag. 40 (2021) 3–14.
[38] European CommissionLevel(s) – Macro-Objective 1: Greenhouse Gas Emissions Along a Building's Life Cycle, Directorate-General for Environment, 2020.
[39] CHCfE Consortium *Cultural Heritage Counts for Europe*, 2015.
[40] G. Foster, Circular economy strategies for adaptive reuse of cultural heritage buildings to reduce environmental impacts, Resour. Conserv. Recycl. (2020) 152.
[41] D. Fiorani, L. Kealy, S.F. Musso, Adaptive reuse of industrial heritage for carbon-neutral cities: life cycle assessment of embodied energy in European cases, J. Clean. Prod. 418 (2023) 138154.
[42] S. Wang, T. Heath, Low-carbon adaptive reuse of industrial heritage in post-industrial cities: comparative analysis of UK and Chinese cases, Sustain. Cities Soc. 87 (2022) 104251.
[43] European CommissionLevel(s) – Macro-Objective 2: Resource Efficient and Circular Material Life Cycles, Directorate-General for Environment, 2020.
[44] S.B. Hosseini, Circular economy Indicators for adaptive reuse of industrial heritage: a taxonomy based on 50 European cases, Resour. Conserv. Recycl. 198 (2023) 107178.
[45] E. Durmisevic, Transformable Building structures: design for disassembly and circular material reuse in industrial heritage, Smart Sustain. Built Environ. 8 (2019) 188–209.
[46] European CommissionLevel(s) – Macro-Objective 3: Efficient Use of Water Resources, Directorate-General for Environment, 2020.
[47] European CommissionLevel(s) – Macro-Objective 4: Healthy and Comfortable Spaces, Directorate-General for Environment, 2020.
[48] Italian National Institute of Statistic (ISTAT)Il Benessere Equo e Sostenibile in Italia. BES Report 2023, 2023.
[49] European CommissionLevel(s) – Macro-Objective 5: Adaptation and Resilience to Climate Change, Directorate-General for Environment, 2020.
[50] ICOMOS Climate Change and Heritage Working GroupThe Future of Our Pasts: Engaging Cultural Heritage in Climate Action, Outline of Climate Change and Cultural Heritage, 2019.
[51] European CommissionLevel(s) – Macro-Objective 6: Optimised Life Cycle Cost and Value, Directorate-General for Environment, 2020.
[52] L. Fusco Girard, M. Vecco, The "intrinsic value" of cultural heritage as driver for circular human-centered adaptive reuse, Sustainability 13 (2021) 3231.
[53] UNESCORecommendation on the Historic Urban Landscape, UNESCO World Heritage Centre, Paris, 2011.
[54] F. Vafaie, H. Remøy, V. Gruis, Adaptive reuse of heritage buildings; a systematic literature review of success factors, Habitat Int. (2023) 142, doi:10.1016/j.habitatint.2023.102926.
[55] N. Lichfield, Economics in Urban Conservation, Cambridge University Press, Cambridge, United Kingdom, 1989.
[56] C. Han, Y. Song, Y. Zhao, An evaluation study on tourists' environmental satisfaction after re-use of industrial heritage buildings, Sustainability 16 (2024) 3032, doi:10.3390/su16073032.
[57] L. Fusco Girard, F. Nocca, Moving towards the circular economy/city model: which tools for operationalizing this model? Sustainability 11 (2019) 6253, doi:10.3390/su11226253.
[58] F. Nocca, The role of cultural heritage in sustainable development: multidimensional indicators as decision-making tool, Sustainability (2017) 9, doi:10.3390/su9101882.
[59] X. Xiong, Y. Wang, C. Ma, Y. Chi, Ensuring the authenticity of the conservation and reuse of modern industrial heritage architecture: a case study of the large machine factory, China, Buildings 13 (2023) 534, doi:10.3390/buildings13020534.
[60] M. Bottero, C. D'Alpaos, A. Oppio, Multicriteria evaluation of urban regeneration processes: an application of PROMETHEE method in Northern Italy, Adv. Oper. Res. 2 (2018) 1–12, doi:10.1155/2018/9276075.
[61] L. Marcato, Culturally digital, digitally cultural. Towards a digital cultural heritage?, in: S. Pinton, L. Zagato (Eds.) Cultural Heritage Scenarios 2015-2017, Edizioni Cà Foscari, Venezia, 2017, pp. 507–520. ISBN 2611-0040.
[62] M.R. Pinto, S. De Medici, C. Senia, K. Fabbricatti, P. De Toro, Building reuse: multi-criteria assessment for compatible design, Int. J. Des. Sci. Technol. 22 (2017) 165–193.