INTERNATIONAL JOURNAL OF CONSERVATION SCIENCE
ISSN: 2067-533X Volume 17, Issue 2, 2026: 769-794 www.ijcs.ro
DOI: 10.36868/IJCS.2026.02.25

APPLYING THE 4R PRINCIPLES IN THE REVITALISATION OF POST-INDUSTRIAL HERITAGE AS THE METHOD OF PRESERVATION OF AUTHENTICITY AND INTEGRITY: SELECTED EXAMPLES FROM POLAND

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Abstract
This article examines the application of the 4R principles (Reduce, Reuse, Recycle, Recover) of circular economy in the revitalization of post-industrial facilities in Poland. Based on a comparative analysis of ten selected projects, the study evaluates how circular strategies were implemented in practice, with a particular focus on architectural interventions and material management. In addition, the revitalizations were analyzed in terms of authenticity and integrity, in accordance with international conservation standards. The findings reveal that although circular strategies are increasingly embedded in industrial heritage transformations, the depth of their application and consistency with conservation values varies. The study highlights the potential of the 4R framework to support sustainable reuse while preserving cultural significance, provided that both environmental and heritage criteria are consistently addressed.

Keywords*: Post-industrial heritage; Circular economy; 4R principles; Authenticity; Integrity; Adaptive reuse; Industrial architecture; Poland*

Introduction

The revitalization of post-industrial sites constitutes one of the key challenges of contemporary architecture and urban planning in Poland. This process not only restores the functionality of degraded spaces but also preserves their cultural and historical value. The revitalization of industrial buildings also supports the sustainable development of cities by repurposing land to serve the needs of urban areas and local communities. A particularly important issue in the revitalization process—especially in the case of industrial facilities with ceased production—is the management of the existing building fabric and industrial infrastructure. Adapting post-industrial buildings to new functions often requires significant alterations to the structures of buildings and entire industrial complexes, which in turn generates substantial amounts of demolition waste—an outcome that unfortunately contradicts the principles of sustainable development.

According to Eurostat, construction and demolition waste (CDW) accounts for 38% of all waste in Europe and around 12.3% in Poland [1]. The EU Waste Framework Directive introduced a 70% recycling target for CDW by 2020 [2], yet only 40% is currently reused or recycled [3].

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The European Green Deal and the Circular Economy Action Plan further emphasize circular economy (CE) principles in construction—one of the most resource-intensive sectors, consuming nearly 50% of raw materials and producing 35–40% of EU waste [3-5]. The sector is also responsible for 30–40% of energy use and ~30% of CO_2 emissions [6], making recycling and material reuse essential for lowering its carbon footprint [2], [7], [8]. Improved material management could reduce up to 80% of construction-phase emissions [9], which account for 5–12% of greenhouse gases in EU countries, compared to 37% globally [10]. European regulations now call for sustainable use of resources, including building reuse and durability [11]. With urban areas projected to grow by 60% by 2050 [12], limiting embodied carbon and CE goals [13-15] have become critical for achieving net-zero targets aligned with the Paris Agreement [7].

In response to the need for climate adaptation and sustainable development goals, developed countries began introducing selective waste collection systems and educational campaigns as early as the 1980s, aiming to raise public awareness of responsible material management. As noted by Jawahir and Bradley, this period marked the emergence of the 1R principle (reduce), particularly important in the context of lean manufacturing and resource efficiency [16]. This principle later formed the basis for the widely known 3R model (reduce, reuse, and recycle), which was adopted into waste management policies in industrialized countries such as Germany and China [17]. With the intensification of overproduction and waste accumulation, broader frameworks were introduced—extending the original model into the 4R, 6R, and even 10R strategies [17], [18]. These expanded systems incorporate additional approaches such as recovery, redesign, remanufacture, and rethink, promoting a more systemic application of circular economy principles in material and resource management.

In recent years, the revitalization of post-industrial sites has gained increasing attention not only in architectural and urban studies but also in international conservation discourse. Organizations such as UNESCO and ICOMOS have highlighted the need to protect the cultural significance, material authenticity, and spatial continuity of heritage sites undergoing adaptive transformation.

The Operational Guidelines for the Implementation of the World Heritage Convention (OG) underline the importance of preserving both the authenticity and integrity of heritage sites, especially in the context of functional adaptation or change of use [19]. These guidelines require that any interventions, including adaptive reuse, must respect the original cultural values and historical layers of a place. ICOMOS, acting as an official advisory body to UNESCO, has addressed the challenges of conserving 20th-century and industrial heritage through a series of international charters and thematic documents. The Madrid Document (2011), developed by the ICOMOS ISC-20th Century, promotes a balanced approach that integrates reuse, continuity of use, and compatible change while safeguarding architectural authenticity [20]. Moreover, the Industrial Heritage Thematic Framework provides criteria for recognizing the cultural significance of industrial sites and encourages the recovery of not only structures but also associated landscapes, infrastructures, and social narratives [21]. In addition, the publication Heritage and the Sustainable Development Goals (ICOMOS, 2019) stresses the role of heritage conservation – including industrial sites – in achieving environmental and social sustainability, aligning conservation strategies with broader policy frameworks such as the UN Agenda 2030 [22].

These international guidelines and principles provide a critical reference point for evaluating revitalization practices and support the integration of circular economy strategies – such as the 4R model – into the conservation discourse. In this context, adaptive reuse is not merely a pragmatic design solution but a conservation-oriented method that aligns with global values of sustainable management.

Literature Review

The literature review was structured around three main research areas. The first concerned the revitalization of post-industrial sites, with particular emphasis on the Polish context. This body of literature encompasses both academic publications and professional industry press. Three principal approaches can be distinguished within this field: case studies, sustainable strategies, and various models and methods of revitalization. The second area focused on the concept of the circular economy (CE), particularly the 4R/3R principles and their application in the construction sector. A growing academic interest in CE within the built environment is observable, with increasing attention given to the recovery of materials and energy as integral components of sustainable design. The third thematic area of the literature review concerned the criteria of authenticity and integrity, which constitute core aspects of the conservation of immovable heritage, as defined by ICOMOS.

A thorough characterization of the 3R principles (reuse, recycle, reduce), which form the basis for the extended 4R framework, is offered by Huang et al. The authors identify the key barriers to implementing the 3R strategy, though their analysis is primarily situated within the Chinese context [23]. A broader spectrum of "R" principles within the circular economy is discussed by Morseletto, who identifies up to ten "re-" actions, depending on the intended outcomes of their application [24]. However, in the context of the construction sector, many of these principles appear to overlap in meaning and application. Jawahir and Bradley, in turn, propose a 6R model, emphasizing the potential contributions of individual "re-" strategies throughout the full product life cycle [16]. Their model introduces the principle of "remanufacture", which in the construction context closely aligns with "recycle". Across all studies, the "reduce" principle consistently emerges as the cornerstone of the circular economy approach.

One of the most significant studies concerning the application of circular economy principles in the construction sector is the work of E. Stricker *et al.* [25]. It serves as a comprehensive compendium on the reuse of building components to reduce greenhouse gas emissions, save energy, and protect the environment. A similar approach is presented in the Manual of Recycling, which, in addition to numerous examples, includes calculation methods for recycling costs and its environmental impact [26]. A particularly valuable source of knowledge is the article by B. Kapica *et al.* [27], in which the authors outline various strategies for the reuse of construction materials and building elements. They also propose a systemic, nationwide solution for implementing circular economy principles at the scale of the entire economy [27]. Another informative contribution is the case study of project K.118 in Switzerland, which highlights significant savings not only in greenhouse gas emissions but also in investment costs, with reused materials accounting for approximately 3.4% of the original material cost [28]. The K.118 case has also been analyzed by C. De Wolf *et al.* [29], who explored methodologies for evaluating the environmental impact of circular economy practices in the built environment. Similarly, in their comparative analysis of adaptive reuse versus demolition and new construction of former mining facilities in the Małopolska region, A. Ostręga *et al.* [30] demonstrate the clear economic, environmental, and social benefits of revitalization strategies based on reuse of industrial structures.

Numerous publications on revitalization highlight the significant impact of conservation measures on both economic values and the social dimension of regeneration processes [31-34]. Dudzińska-Jarmolińska emphasizes that revitalization projects in Poland are most commonly associated with the introduction of new commercial functions, while recreational or community uses—more typical in Western Europe—are still rarely implemented [35]. Researchers in the field of architecture analyzing commercial adaptive reuse projects frequently highlight the economic implications of such interventions. K. Misiuk [36], using the example of a former factory in Białystok, outlines specific guidelines that should be followed in commercially driven

conversions of post-industrial facilities [36]. A. Grzelak and I. Pielesiak [37] present a synthesis of the socio-spatial and economic conditions in their analysis of industrial zones in Ozorków, stressing that spatial conflicts and insufficient community engagement may hinder the commercialization process and reduce the financial viability of revitalization schemes. M. Pieczka and B. Wowrzeczka [38] conduct an analysis of non-commercial reuse for artistic purposes, identifying five distinct strategies applicable to Polish projects.

A particularly important publication on the revitalization of post-industrial facilities in Poland is the study by Maciejewska and Turek, which presents selected case studies from Poland and Europe realized in the 21st century, along with valuable practical guidelines for implementing such initiatives [39]. Another significant work is the article by Baborska-Narożny, in which five basic models of post-industrial regeneration are identified [40]. From the perspective of power station reuse, the study by B. Wowrzeczka [41] is particularly relevant, offering a typology of three models of transformation—conservation-based, ecological, and commercial. The author notes that regardless of the approach, such interventions represent a kind of "recycling" of space and typically generate positive social and image-related outcomes [41]. An excellent overview of the revitalization of former breweries and distilleries can be found in the publication by M. Gyurkovich *et al.* [42], which presents numerous examples from Poland and abroad, highlighting their contribution to the sustainable development of historic urban fabric.

Sustainable development remains a key focus in academic discourse on the regeneration of post-industrial buildings and areas [32]. S. Iodice and P. De Toro [43] point out that a circular economy-based revitalization model can support the preservation of the cultural identity of a place while simultaneously introducing strategies aimed at waste reduction and improving energy efficiency. S. De Gregorio *et al*. [44] underline that today's spatial and functional needs require environmentally friendly design responses. Sustainable regeneration also entails the integration of new technologies and functions that address current social demands. R. Trifa [45], however, warns that such interventions must not compromise the historical and aesthetic values of industrial heritage structures. Similar arguments are raised by O. Wei *et al*. [46], who, based on surveys and case studies, conclude that adaptive reuse strategies preserving the characteristic identity of post-industrial facilities enhance the sustainable development of urban areas at ecological, social, and economic levels. Comparable findings were made by A. Szewczyk-Świątek *et al*. [47], who investigated the reuse of post-mining areas, using the Brzeszcze mine as a case study, applying circular economy principles in both preserving and transforming such sites.

Most scholars agree that revitalization projects of former industrial facilities should preserve the aesthetic authenticity of buildings by reinforcing their historical and cultural values [33]. Such projects can serve as important catalysts for local social and economic revitalization and should aim towards multifunctional schemes that incorporate modern technologies [45], which enhance the efficiency of space use and facilitate commercial viability. However, J. Lenartowicz and A. Ostręga [48] highlight that revitalization processes that utilize and showcase industrial heritage often face significant obstacles, including legal constraints and insufficient inventory documentation of buildings and resources.

In recent years, there has been growing interest in the practical application of the concepts of authenticity and integrity in architectural conservation, particularly concerning historic buildings operating in dynamic social and functional contexts. R. Liu *et al*. [49], analyzing the case of the historic city of Yicheng, propose an elaborate interpretive framework in which authenticity is divided into three interrelated aspects: material (relating to the preservation of building fabric), intangible (covering traditions and local practices), and every day (concerning contemporary uses of the urban space). Integrity, in turn, refers to the completeness of spatial layouts, functional continuity, and harmony with the cultural landscape. A similar effort to apply these concepts to conservation practices was undertaken by X. Xiong *et al.* [50] in a study of an industrial facility. They emphasize that authenticity in industrial heritage should primarily be

understood through the preservation of structural frameworks, original spatial configurations, and modes of use [50]. Integrity refers to the holistic retention of functional and spatial systems that give the facility historical coherence and legibility. In practical conservation work, the authors advocate for principles such as minimal intervention, recognizability, and reversibility of alterations, aiming to strike a balance between safeguarding historical values and accommodating contemporary uses.

From a more theoretical perspective, E. Nakonieczna and J. Szczepański [51] offer a critical analysis of the notion of authenticity as a cultural and ideological category, pointing to its ambiguity and vulnerability to instrumentalization. They argue that mere reconstruction of a building's form does not guarantee its authenticity if it lacks original substance or contextual use. Instead, they propose moving away from the absolutization of materiality and towards recognizing authenticity as a dynamic relationship between place, its history, and social perception.

One of the key publications on the values of authenticity and integrity is the work by H. Stovel [52], in which the author seeks to define both concepts and propose their practical application to various types of heritage sites. The study is particularly relevant as it forms part of a panel discussion within ICOMOS, thereby constituting a credible source for interpreting these notions. H, Stovel attempts to clarify both attributes by juxtaposing them with ICOMOS guidelines [53] and comparing them to conservation approaches adopted in other countries [54]. In his analytical framework, H. Stovel does not draw a sharp distinction between the two conditions. Instead, he introduces additional criteria such as the following:

- Wholeness – the inclusion within the object of all components essential to its value (e.g., individual parts of a building complex),
- Intactness – good technical condition, supported by favorable economic and social conditions,
- Material genuineness – the preservation of historic materials,
- Organization of space and form – the legibility of the historical spatial layout,
- Continuity of function – the maintenance of original functions or the introduction of compatible ones,
- Continuity of setting – the surrounding environment and context should support the values of the heritage property.

Further attempts to define the concepts employed in the Operational Guidelines for the Implementation of the World Heritage Convention (OG) are undertaken by J. H. Khalaf [55], K. H. Khalaf[56]. He notes that Paragraph 88 [19], which refers to integrity, remains an ambiguous requirement, and, like Stovel, Xiong, and Liu, he explores the interconnection between authenticity and integrity. J. H. Khalaf [55] engages in a discussion on the implications of interventions within heritage structures and their influence on the condition of integrity. He argues that continuity—such as expansion—under the condition of compatibility constitutes a key element of the integrity of cultural heritage [55].

Although adaptive reuse may interfere with the continuity of function, which is often considered a component of authenticity, scholars highlight that it is frequently the only viable strategy for preserving the cultural value of heritage sites [57], [58]. At the same time, it is acknowledged that preserving the historic fabric while introducing new elements often yields measurable and sustainable benefits [59]. This view is consistent with that of one of the leading conservation theorists of the 20th century, G. Giovannoni [60] and Ş. Ertaş Beşir and M. E. Çelebi Karakök [61], that a building must be used to survive. H. Oevermann [62] highlights that the criteria set by UNESCO can present valuable opportunities for industrial heritage projects.

M. T. Witwicki [63] also points out the considerable challenges involved in defining the value of authenticity for architectural objects within the framework of Poland's monument register. Quoting M Sołtysik [64], he identifies three principal aspects of authenticity: that of material and structure, function, and form. In relation to the authenticity of industrial heritage buildings,M. T. Witwicki [63] underscores the importance of technological equipment in

evaluating heritage value. However, he observes that due to the numerous technological transformations such equipment has undergone, it is often extremely difficult to preserve it in its original form [63].

Experimental part

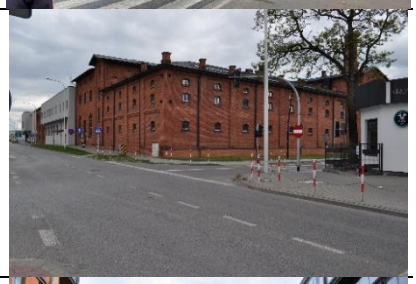
Methods and Materials

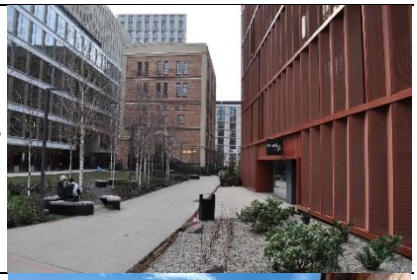
The study employed traditional architectural research methods. Firstly, a literature review was conducted, focusing on professional journals in order to identify case study sites. This was followed by a literature survey covering three key areas: the revitalization of post-industrial facilities, the concept of the circular economy (CE) in the context of the construction industry, and the interpretation of ICOMOS guidelines with respect to the principles of authenticity and integrity. Subsequently, in situ field research was carried out to verify the implementation of 4R principles in the selected case studies. Photographic documentation of the analyzed sites was also conducted. The collected materials were then subjected to a comparative analysis with regard to the application of CE principles and the degree to which authenticity and integrity were preserved after revitalization. Each site was critically assessed based on the gathered data in terms of the conscious or unconscious application of the 4R principles during the revitalization process and their potential impact on the cultural heritage values of the site.

The study focused on former industrial facilities whose revitalization projects had been completed within the last ten years. Only projects located in Poland were included, regardless of their specific region or setting. A key selection criterion was the publication of information about the revitalization process in architectural industry media—both print and digital. This criterion was adopted due to the opinion-forming nature of such projects and their role in setting trends in industrial redevelopment. The study was conducted as a case study analysis of ten revitalized post-industrial facilities in Poland (Table 1). All of the examined sites were under heritage protection in accordance with national legislation and legal regulations.

Table. 1. Selected Case Study Facilities and Their Characteristics

Revitalized Post-industrial Complex	Construction	Production Shutdown	Revitalization Completion	Adaptive Reuse - function	Photo
Wrocław Brewery	1893	2004	2024	Multifunctional – housing, offices, foodcourt	
"Mamut" Bakery in Wrocław	1880	2006	2022	Hotel, housing	

Old Coal Mine in Wałbrzych	1770	1996	2014	Cultural Center, museum	
Goetz Brewery in Kraków	1840	2001	2016	Multifunctional – housing, offices, hotel, restaurants	
Brewery in Ostrowiec Świętokrzyski	1908	1970	2019	Cultural center – library, gallery, cinema	
Powiśle Power Plant in Warsaw	1904	2003	2021	Multifunctional – shopping center, gastronomy, offices, housing	
Norblin Factory in Warsaw	1854	1981	2021	Multifunctional – museum, shopping center, food court, offices	
"Koneser" Vodka Distillery in Warsaw	1897	2007	2018	Multifunctional – cultural (galleries), shopping, offices, housing	

Warsaw Brewery	1846	2004	2021	Multifunctional – housing, offices, food court	
Żnin Sugar Factory	1894	2004	2020	Hotel with conference center and recreation	

Due to the transfer of the 4R principles from the waste management sector to the field of construction, it was necessary to refine the definitions of each principle in the context of revitalization strategies. For the purposes of this study, the following definitions of the 4R principles were adopted:

- Reduce – refers to the reduction of construction waste, including the minimization of demolitions, replacement of building components, and other structural interventions that require adaptation of the facility to new functions, e.g., through functional transformations;
- Reuse – refers to the reuse of materials or building components in a conventional manner while maintaining their original function, or in a new way [25], without requiring significant processing or additional energy input;
- Recycle – refers to the reuse of materials or building components by processing them [25]. Unlike reuse, recycling requires the input of energy to transform the material into a reusable form [29];
- Recover – refers to the recovery of building or economic value from materials, facilities, or components that no longer fulfill their original purpose or function.

An important aspect of the study was also the attempt to interpret the criteria of authenticity and integrity, which were developed based on the Operational Guidelines for the Implementation of the World Heritage Convention (OG) [19] and relevant academic literature [52], [54], [55]. Although these criteria relate to the Outstanding Universal Value (OUV) of World Heritage sites, their application may also be critical for the evaluation of heritage assets on a regional scale. In order to assess conservation-related phenomena, an analysis was conducted based on the fundamental characteristics that a site should meet with regard to the criterion of authenticity, as defined in paragraph 82 of the OG, and the criterion of integrity, as defined in paragraph 88 of the OG [19].

Results and discussion

Authenticity

The study involved field research and literature review, accompanied by the analysis of archival materials – including iconography and historical plans – aimed at assessing the condition of authenticity features of individual sites after revitalization, in accordance with paragraph 82 of the Operational Guidelines (OG). The summary of the results is presented in Table 2. The column titled “other factors” indicates the presence of additional circumstances that may not necessarily have a positive influence on the assessment of authenticity, such as a limited degree of

preservation of the original structure or the very poor technical condition of the building prior to revitalization.

Table. 2. Authenticity according to the paragraph 82 of OG [19] (authors)

Revitalized Post-industrial Complex	*Authenticity Factors*								Assessment
	Form and design	*Material and substance*	*Use and function*	*Traditions, techniques*	*Location and setting*	*Intangible heritage*	*Spirit and feelings*	*Other factors*	
Wrocław Brewery	●●	●●	—	●●	●●	—	●●	—	Medium high
"Mamut" Bakery in Wrocław	●●	●●	—	●	●●	—	●●	—	Medium high
Old Coal Mine in Wałbrzych	●●	●●●	●●	●●	●●●	●●	●●●	—	High
Goetz Brewery in Kraków	●	●	●	●	—	—	●	●	Low
Brewery in Ostrowiec Świętokrzyski	●	●	—	●	●	—	●	—	Low
Powiśle Power Plant in Warsaw	●	●●	—	●	●	—	●●	●	Medium
Norblin Factory in Warsaw	●	●●	●	●●	●●	●	●●	—	High
"Koneser" Vodka Distillery in Warsaw	●	●	●	●●	●	●	●	—	Medium
Warsaw Brewery	●	●	●	●	—	—	●	●	Low
Żnin Sugar Factory	●●●	●●●	●	●●	●●●	●	●●●	—	High

Legend: — not present; ● present; ●● commonly present; ●●● significantly present; —— negative factors;

The analysis based on Table 2 enabled the assessment of the degree of authenticity preservation in selected post-industrial facilities following their revitalization, in accordance with the definitions set out in paragraph 82 of the Operational Guidelines (OG). The table included seven key attributes of authenticity: form and design, material and substance, use and function, traditions and techniques, location and setting, intangible heritage, and spirit and feelings. Additionally, the presence of other factors indirectly affecting the assessment of authenticity was also examined.

Most of the analyzed facilities moderately fulfill the authenticity criteria applicable to heritage structures. In the majority of cases, five out of the seven core attributes were identified. The least frequently observed attributes were "use and function" and "intangible heritage," which is unsurprising in the context of the adaptive reuse of tangible industrial heritage. In some instances, a partial continuation of function was noted – primarily in cases where ~~there was an~~ exhibition or

museum uses were introduced, presenting the historical context (e.g., the Żnin Sugar Factory, the Old Mine in Wałbrzych, and “Koneser” in Warsaw). In the case of the Goetz and Warsaw Breweries, partial continuation of original function was observed through the conversion of administrative buildings into office spaces, maintaining a link with former uses.

The findings indicate that three facilities achieved the highest level of authenticity: the Old Mine in Wałbrzych, the Żnin Sugar Factory, and the Norblin Factory in Warsaw. In all three cases, nearly all authenticity criteria were met, resulting in a final assessment of "high." The Old Mine is particularly noteworthy for preserving both spatial and material structures, introducing museum functions, and engaging former employees as guides – all of which significantly contributed to the retention of intangible heritage and the authentic spirit of the place.

One of the most commonly preserved attributes was form and design – six facilities received a rating of “widely present," indicating a strong effort to maintain the historic architectural character. High scores in this category were noted in Wrocław (the Breweries and the Mamut Bakery) and in Żnin, where historical massing was largely preserved.

The material and substance attribute, related to the preservation of original building materials, was also frequently observed. The highest ratings were given to the Żnin Sugar Factory and the Old Mine, where a significant portion of the original substance survived the revitalization. In other cases, original materials were partially reconstructed or supplemented.

Use and function – the compatibility of the new function with the original purpose – was the least frequently fulfilled attribute. In most cases, the original function was entirely changed, which is a natural consequence of adapting industrial spaces to contemporary needs. Only in facilities serving museum functions were elements of the original narrative of use retained.

The attribute of intangible heritage is equally ambiguous when applied to post-industrial heritage. In most revitalized sites, only brief and superficial historical references are present, offering little insight into the deeper traditions of the place. Exceptions include museum-type facilities such as the Norblin Factory, "Koneser," and the Old Mine, where exhibitions highlight aspects of the everyday lives of former employees. Particularly noteworthy are the initiatives at the Żnin Sugar Factory and the Wałbrzych mine, where guided tours are conducted by former workers—their narratives serving as a unique source of intangible heritage.

The traditions and techniques attribute received positive assessments in facilities where original technical elements were preserved or prominently displayed—such as cast iron columns, ceramic flooring, and historic ventilation systems. High ratings were awarded to Żnin, Norblin, and the Wrocław Breweries in this respect.

The location and setting attributes proved to be significant where the spatial context remained largely intact. The Żnin Sugar Factory and the Norblin Factory in Warsaw received the highest scores due to the preservation of the readable urban structure and the limited intrusion of new development. In contrast, sites such as the Warsaw Breweries saw their original context partially obscured by extensive new construction.

The spirit and feelings attribute, although difficult to measure objectively, were rated highly in projects that preserved the atmosphere of the site. This encompassed not only physical relics but also the ambient character of the space, conveyed through preserved damage, raw materials, and industrial detailing. Żnin, Norblin, and the Old Mine were particularly notable in this regard. The analysis also considered the design of contemporary additions, in which architects incorporated stylistic or material references to the post-industrial context.

Finally, other factors potentially influencing the perception of authenticity were included. In some cases—such as the Goetz Brewery, Ostrowiec Świętokrzyski, and the Warsaw Breweries—extensive new construction, limited exposure of historical remnants, or inadequate integration with the historical narrative resulted in lower overall assessments.

Synthesizing the data from Table 2, it can be concluded that although most sites fulfill several core authenticity criteria, the full spectrum is preserved in only a few cases. The analysis reveals a clear relationship between the degree of authenticity and factors such as the post-revitalization function and the scale of conservation interventions. These correlations will be further explored in the following section dedicated to the interpretation of results.

Integrity

As part of the research, an assessment of the integrity condition was also conducted for the analyzed facilities, primarily in relation to the presence of elements expressing Outstanding Universal Value (OUV). In the context of this study, these elements referred to both the built fabric and the machinery or components of former production systems. Regarding the criterion of adequate size in relation to the characteristics and processes that convey the significance of a site, particular attention was paid to the extent to which production processes could be interpreted or illustrated through preserved structures. When analyzing the factors associated with integrity, it should be noted that the presence of the third component—negative effects of development or neglect—had an adverse impact on the evaluation in the majority of cases.

Table. 3. Integrity according to the paragraph 88 of OG [19] (authors)

Revitalized Post-industrial Complex	***Wholeness***	***Intactness***	***Inclusion of all elements to express OUV***	***Representation of features and processes***	***Suffer from adverse effect of development or neglect***	***Assessment***
Wrocław Brewery	●	●	—	—	●	Medium low
"Mamut" Bakery in Wrocław	●●	●	—	—	●	Medium low
Old Coal Mine in Wałbrzych	●●	●●	●●●	●●●	●	High
Goetz Brewery in Kraków	—	—	—	—	●	Low/none
Brewery in Ostrowiec Świętokrzyski	●	●	—	—	●	Low
Powiśle Power Plant in Warsaw	—	●	—	●●	●	Low
Norblin Factory in Warsaw	●	●	●	●●	●	Medium
"Koneser" Vodka Distillery in Warsaw	—	●	●	●●	●	Medium low
Warsaw Brewery	—	—	—	—	●●●	None
Żnin Sugar Factory	●●●	●	●●	●●	—	High

The degree of integrity in the analyzed sites was, in most cases, assessed as low. This primarily resulted from the condition of the facilities prior to revitalization. In many instances, industrial activity had ceased several decades earlier, leading to the technical degradation of both the buildings and the machinery. Furthermore, in some cases, adaptive interventions required demolition, replacement of structural elements, or reconstruction of the building fabric, which limited the potential for maintaining integrity in the sense defined by the Operational Guidelines (OG).

The analysis applied five main criteria as outlined in paragraph 88 of the OG: wholeness, intactness, presence of elements expressing Outstanding Universal Value (OUV), representativeness of features and processes, and adverse effects of development or neglect. The final assessment was based on a synthetic interpretation of the occurrence and intensity of these factors.

The highest integrity rating ("high") was achieved by three sites: Old Coal Mine in Wałbrzych, the Żnin Sugar Factory, and Norblin Factory in Warsaw. In all these cases, a significant portion of the original building fabric, industrial equipment, and spatial relationships between components of the complexes were preserved. These revitalizations were particularly positively assessed not only for maintaining the material structure but also for enabling visitors to experience former technological processes through the exhibition of machines and installations, as well as preserved spatial layouts.

The criterion of wholeness was significantly present only in three cases: Żnin, Wałbrzych, and partially "Mamut" in Wrocław. In the remaining sites, only fragments of the original industrial complexes were preserved, which limited the possibility of interpreting the full functional structure of the facilities.

Intactness, understood as the undisturbed technical condition, was found mainly in sites that were in good condition prior to revitalization or where conservation works were undertaken without replacement of key structural components. The best examples here were Old Coal Mine and, to a lesser extent, Żnin and Norblin. In other cases, such as Goetz Brewery or Warsaw Brewery, the level of intactness was minimal or non-existent, mainly due to the limited preservation of original fabric.

The criterion concerning the presence of elements expressing OUV—i.e., the existence of representative, distinctive components such as industrial machinery, transport systems, or structural details—was both highly rated and difficult to meet. This criterion was fully met only in Old Coal Mine in Wałbrzych, where the majority of original mining installations were preserved and made accessible. Żnin and Norblin were rated moderately—some elements were integrated into the new function, while others serve as exhibition pieces.

Similar patterns were observed in the category of representativeness of processes, referring to the ability of users and visitors to understand the site's historical function. High ratings were given to those sites where the functional layout and spatial relationships were retained or where clear interpretive narratives were created (Wałbrzych, Żnin, Norblin). In other cases—especially commercial redevelopments such as Goetz Brewery, Ostrowiec, or Powiśle—functional legibility was diminished by new development and altered spatial arrangements.

The final factor analyzed was the adverse effect of development or neglect, referring to the negative impact of either on-site development or previous disrepair on the site's integrity. This was observed in the majority of cases—typically in the form of intensive new construction (Warsaw Brewery, Goetz Brewery), prior conservation neglect (Ostrowiec, Powiśle), or radical spatial transformations. Only in the case of Żnin Sugar Factory was no such threat recorded.

4R Principles

Among the group of projects in which the principles of the circular economy (4R) were applied to a limited extent—or almost entirely omitted—are four developments: the brewery in

Ostrowiec Świętokrzyski, the Goetz Brewery in Kraków, the “Koneser” complex in Warsaw, and the Warsaw Brewery.

The revitalization of the former brewery in Ostrowiec Świętokrzyski represents a public-purpose investment in which the facility was adapted for use as a cultural center. Although production ceased as early as 1970, the site had been used as a warehouse [65] and, later—until 1995—as the seat of the Municipal Cultural Centre [66]. The current adaptation fits within a basic model of post-industrial redevelopment and demonstrates only traces of the “reuse” and “recover” principles. It is worth noting the limited extent of demolition works, which may serve as an indirect example of the “reduce” strategy.

A completely different character is seen in the redevelopment of the Goetz Brewery on Lubicz Street in Kraków—a commercial revitalization project where six historic buildings listed in the heritage register were preserved prior to intervention [67], [68]. Although the adaptation of these buildings was carried out with considerable care, and the new architecture stylistically refers to the industrial heritage, the project does not directly implement solutions aligned with the 4R principles. Individual technical elements such as barrels, vats, or fragments of piping now serve purely decorative functions, symbolically referencing the industrial past [42]. There were no documented examples of material reuse. As a result, this revitalization is limited to the most basic aspects of “recover” and partial "reuse."

Similarly, in the “Koneser” complex in Warsaw, there was no observed application of circular economy principles. Although this investment is significant from a social and urban perspective—having contributed to the regeneration of the Praga district and an increase in surrounding land values—it lacked a material approach characteristic of 4R. A substantial portion of post-war twentieth-century buildings was demolished and replaced with new constructions stylized as industrial. Public spaces were enriched with elements of industrial aesthetics; however, these are entirely new creations, not authentic remnants of the former factory [69]. Thus, as in the case of the Goetz Brewery, the revitalization was limited to “recover” of the urban area and “reuse” of selected historic buildings (Fig. 1).

(a) (b)

Fig. 1. Example of limited application of 4R principles: (a) Goetz Brewery in Kraków: reuse of industrial machinery as decorative elements; (b) Warsaw Brewery: recycling of former industrial installations as public space features (Source: Photos by authors; a – May 2025, b – January 2025)

In the case of the Warsaw Brewery, the revitalization process—initiated in the early 2000s—led to the near-total loss of industrial fabric. The remnants are limited to the brewhouse, the Schiele House, and the former laboratory [70], while the majority of new development was built from scratch [42]. Although the architecture formally references the industrial style, actual elements preserved from the former brewery are scarce. These include a vaulted cellar adapted into a food court, former industrial pipelines repurposed to define public space, and cast-iron columns reused as street lamps. Nonetheless, this site constitutes a compelling example of the “recover” principle through the reclamation of valuable central-city spaces.

One example where the 4R principles were implemented in a limited but noticeable scope is the adaptive reuse of the Wrocław Brewery complex, completed in 2023 [71]. All existing buildings of the former brewery were preserved, and intervention in the historic building fabric was kept to a minimum, which significantly reduced the amount of construction waste. Former equipment elements, such as air vents, floor plates, and cast-iron girders and columns, were reused either as display pieces or incorporated into the site landscaping and interior furnishings. Some new buildings were constructed in a reconstructed form, referencing previously existing industrial structures that no longer survive [72].

The application of the 4R principles was moderate in the case of the "Mamut" bakery in Wrocław, whose transformation posed a challenge related to adapting post-industrial buildings for a new function—a private dormitory and hotel [73], [74]. Despite numerous alterations, the basic layout of the buildings and their distinctive ceramic decoration were preserved [73], [75]. The functional program was adapted to the structure of the existing buildings: lower, less well-lit floors were allocated for communal spaces, while the upper floors were used for residential rooms [73]. The building's structural system was largely retained and locally reinforced, as were interior finishes such as terrazzo flooring and glazed tiles (Fig. 2) [75]. These measures minimized construction waste and limited the extent of demolition. Individual elements of former equipment—such as an exhaust fan motor and cast-iron columns—were preserved as relics of the building's industrial past.

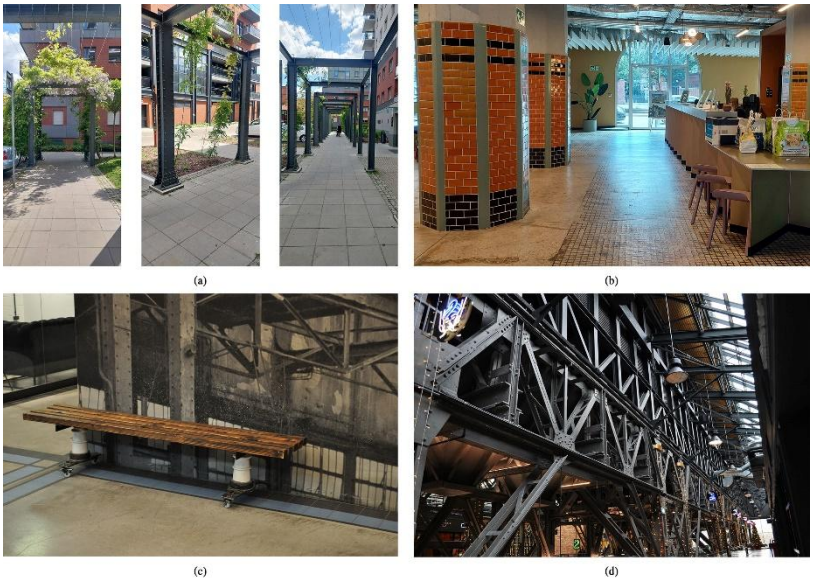


Fig. 2. Example of 4R principle implementation in projects with a moderate degree of application: (a) Wrocław Brewery – recycling of cast-iron structures as trellises; (b) "Mamut" Bakery – reuse of existing interior finishes to reduce construction waste; (c) Powiśle Power Plant – recycled materials used as urban furniture; (d) Powiśle Power Plant – recovery and reuse of the boiler hall structure
(Source: Phot. by authors; a, b – May 2025, c, d – January 2025)

Another example of partial implementation of 4R principles is the revitalization of the Powiśle Power Plant, completed in 2020 [41]. This project involved the adaptation of preserved industrial buildings—including the boiler hall, engine room, caisson, and transformer station—for new commercial and service functions [76]. However, the introduction of new residential and office buildings in the immediate surroundings of the historic structures significantly disrupted their perception and spatial coherence [77]. Due to the severe damage to the steel structures—

resulting from degradation after the power plant ceased operation and the shift in thermal and humidity conditions—it was necessary to fully dismantle, regenerate, and reassemble the components, which allowed the preservation of the original structural layout [78]. The interiors of the preserved buildings were complemented with artifacts of the former technical infrastructure—control panels, switch cabinets, and meters—which now serve as decorative features. Ceramic insulators were repurposed in interior design projects as lighting fixtures, furniture, and equipment elements [79]. At the same time, many decorative details were newly created industrial-style components, formally referencing the historical character of the site but not originating from the original infrastructure.

Among the revitalization case studies, the Old Coal Mine in Wałbrzych occupies a distinctive position as a publicly funded project demonstrating how the 4R principles can be implemented within the framework of a cultural institution (Fig. 3). In the adaptation of the former coal mine into the Center of Science and Art, the idea of sustainable development was consistently applied by minimizing demolition works and maximizing the reuse of existing technical infrastructure. Only two structures—the former cooling tower and canteen—were demolished, and their sites were redeveloped with new, functionally integrated spatial elements [80]. The revitalization process relied heavily on the principle of reuse—numerous preserved technical devices now constitute a core part of the museum exhibition. Particularly significant were machines associated with coal extraction, including the shaft hoist engine and lifting mechanism. The project also incorporated the idea of recovery by highlighting the site's social and cultural value, while selected recycled aspects were evident in the secondary use of elements for exhibition purposes [81].

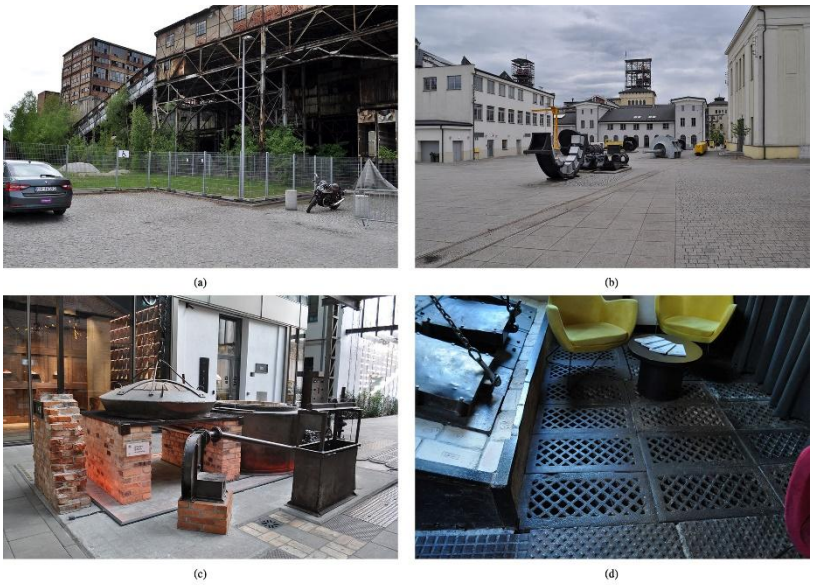


Fig. 3. Examples of the application of 4R principles in projects with a significant degree of implementation: (a) Old Coal Mine in Wałbrzych – reduce through the preservation of non-adapted structures; (b) Old Coal Mine in Wałbrzych – reuse of former machinery as exhibits within the industrial site; (c) Norblin Factory – reuse of equipment as spatial artefacts; (d) Norblin Factory – reduce through the incorporation of historical finishing elements in new interiors; (Source: Phot. by authors; a, b – May 2025, c, d – January 2025)

Another example of industrial revitalization applying various strategies derived from the circular economy is the Norblin Factory in Warsaw. Located in the city center, this development had to respond both to commercial investment requirements and industrial heritage protection

standards. The project aimed to create a multifunctional space combining retail, services, office, and cultural functions. The principle of "reduce" was fundamental—large parts of the historic fabric were retained, with visible traces of wear and damage intentionally preserved to reinforce the narrative of authenticity. Within the reuse strategy, original industrial equipment—such as rail tracks, cranes, steel structures, and manufacturing tools—was consciously incorporated as heritage relics. The recycle principle was applied through the transformation of components from trolleys, beams, and technical installations into benches, display cases, and canopies. The recover strategy was realized by establishing a new identity for the site that does not erase its past but rather integrates it with a contemporary functional program [82], [83].

The most comprehensive and advanced example of 4R implementation among the analyzed revitalizations is the adaptive reuse project of the Żnin Sugar Factory (Fig 4). The transformation of this extensive industrial complex into a multifunctional hotel and conference center with a recreational component demonstrates how a conscious approach to industrial heritage can successfully combine conservation values with the requirements of contemporary use. Not a single structure was demolished—regardless of its date of construction—which reflects the consistent application of the reduce principle [84]. Interventions in the existing built fabric were kept to a minimum, and new components—such as hotel structures—were introduced with respect for the original architecture. As part of reuse, both structural and functional elements were retained and repurposed, ranging from formwork panels to landscape and infrastructure components. A high degree of recycling was achieved through the transformation of former technical devices and equipment into new interior features, such as counters, lighting fixtures, planters, and bar fittings. The process is completed by the recover principle, as the former industrial site has gained new significance and function while retaining a rich narrative layer associated with the site's industrial past [84-86].

Fig. 4. Żnin Sugar Factory, an example of the application of 4R principles in a project with a high level of implementation: (a) reduce through the preservation of post-production imperfections in the building fabric; (b) reduce by retaining former structural elements and installations in their original state; (c) reuse former structural components as permanent formwork; (d) recycle through the transformation of former ceramic insulators into interior design elements; (e) reuse by incorporating former office equipment as exhibition displays; and (f) reduce through the absence of demolition of non-adapted buildings, reuse of former lighting poles, and recycling of post-production tanks repurposed as planters (2023)

Among the analyzed examples of post-industrial revitalization, the most frequently identified principle of sustainable development was "reuse," involving the reuse of former elements—mainly as decorative details or small architectural features. The "reduce" principle,

i.e., the reduction of waste through the preservation of existing fabric, was observed in most cases, particularly in non-commercial projects and in smaller towns. The "recycle" principle, which requires processing elements and assigning them new functional uses, occurred much less frequently. Comprehensive implementation of all four 4R principles was recorded only in the case of the Żnin Sugar Factory. A noteworthy factor is also the time-based correlation—more recent projects show a clearly higher degree of circular economy implementation.

Comparative Analysis

The compilation of results presented in Table 4 enables a comparative analysis of two key categories for assessing heritage value—authenticity and integrity—in relation to the examined cases of post-industrial site revitalization. At the same time, their evaluation was linked to the presence of circular economy 4R principles (reduce, reuse, recycle, and recover), which allows for a better understanding of the relationship between heritage value preservation and CE characteristics.

Table. 4. Comparison of 4R principles and authenticity and integrity [A] (authors)

Revitalized Post-industrial Complex	***Type***	***Adaptive reuse function***	***4R Principles levels***	***Authenticity level***	***Integrity level***
Wrocław Brewery	Commercial	Multifunctional: residential, offices, commerce	Reduce: medium Reuse: low Recycle: low Recover: medium	Medium high	Medium low
"Mamut" Bakery in Wrocław	Commercial	Residential, hotel	Reduce: medium Reuse: low Recycle: none Recover: medium	Medium high	Medium low
Old Coal Mine in Wałbrzych	Public	Cultural center, museum	Reduce: medium Reuse: medium Recycle: none Recover: medium	High	High
Goetz Brewery in Kraków	Commercial	Multifunctional: residential, offices, commerce	Reduce: none Reuse: low Recycle: none Recover: low	Low	None
Brewery in Ostrowiec Świętokrzyski	Public	Cultural center/Cinema	Reduce: low Reuse: low Recycle: none Recover: low	Low	Low
Powiśle Power Plant in Warsaw	Commercial	Multifunctional: residential, offices, commerce	Reduce: low Reuse: low Recycle: low Recover: medium	Medium	Low
Norblin Factory in Warsaw	Commercial	Multifunctional: offices, commerce	Reduce: low Reuse: medium Recycle: medium Recover: medium	High	Medium
"Koneser" Vodka Distillery in Warsaw	Public/ Commercial	Multifunctional: residential, offices, commerce, cultural	Reduce: none Reuse: none Recycle: none Recover: medium	Medium	Medium
Warsaw Brewery	Commercial	Multifunctional: residential, offices, commerce	Reduce: none Reuse: low Recycle: low Recover: medium	Low	None
Żnin Sugar Factory	Commercial	Conference Center, hotel, recreation	Reduce: high Reuse: medium Recycle: high Recover: medium	High	High

The results of the analysis indicate that there is no full correlation between authenticity and integrity. It can be observed that, primarily in sites with a high degree of preserved authenticity, there is no significant decline in the value of the integrity condition (Old Coal Mine in Wałbrzych, Żnin Sugar Factory). In these cases, all four 4R principles were also applied to a high or moderate degree. The diagram highlights the relationships between the conditions of authenticity, integrity, and the extent to which the 4R principles were implemented in the analyzed examples (Fig. 5).

The Norblin Factory in Warsaw, which achieved a high authenticity rating (due to the exposure of material values, preservation of form, and historical narrative), demonstrates a moderate level of integrity resulting from structural alterations and the partial loss of the industrial layout. At the same time, the facility shows a medium implementation of 4R principles, particularly ‘reuse’, ‘recycle’, and ‘recover’.

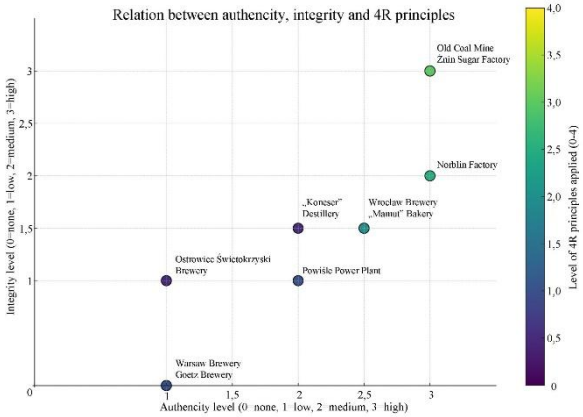


Fig. 5. Relation between authenticity, integrity, and 4R principles

The lowest authenticity and integrity values were recorded in the cases of Warsaw Breweries and Goetz Brewery. In both instances, authenticity was rated as "low," while integrity was assessed as "none." Similarly, the indicators for the application of 4R principles were low. A comparable outcome was observed for the brewery in Ostrowiec Świętokrzyski, where authenticity and integrity were rated as "low," and the implementation of the 4R principles was also limited.

Among the group of sites characterized by low integrity but higher authenticity is the Powiśle Power Plant, which was rated as “medium” in terms of authenticity and “low” for integrity, with a low level of implementation of the 4R principles. Similar results were obtained for the “Koneser” Distillery, where authenticity was assessed as "medium," integrity as "medium-low," and the application of 4R principles was limited.

Discussion

The concept of adaptive reuse represents one of the key approaches in the revitalization of post-industrial buildings. Its essence lies in assigning a new function to disused structures while preserving their material substance and historical integrity. Increasingly present in heritage conservation practices, this approach is grounded in the idea of functional and spatial continuity as the foundation for shaping a renewed identity of place without losing its cultural value. In this context, the principles of “Reuse” and “Recover”, derived from the 4R model associated with waste management, find natural application within revitalization strategies. “Reuse” refers not only to the re-employment of materials and building components but also to the conscious maintenance and adaptation of historic architectural structures. In turn, “Recover” encompasses

not only the recovery of materials but also the retrieval of intangible values—narratives, symbolism, *genius loci*, and the cultural significance related to a site's industrial past.

The analysis of the case studies reveals that the "Reduce" principle—understood as the limitation of demolitions and reduction of generated waste—has the greatest impact on preserving authenticity and integrity in revitalized sites. Minimizing physical interventions allows for the retention of original structures, building fabric, and technical equipment, which constitute the foundation of industrial heritage value. A high level of adherence to this principle was observed particularly in projects intended for museum and educational use (e.g., the Old Coal Mine in Wałbrzych and the Żnin Sugar Factory), where the preservation of authenticity was one of the central project assumptions.

The principle of "Reuse" also plays a significant role, though its impact is often limited to decorative elements such as industrial artifacts incorporated into public space. Only in selected examples did the reuse of structural components or technical devices serve a functional purpose that reinforced the integrity of the site. In such cases—such as Żnin or Norblin—"Reuse" contributed both to the preservation of material technical heritage and the creation of a coherent spatial narrative.

The "Recycle" principle was the least frequently observed and appeared almost exclusively in the form of material recycling, transforming post-industrial elements into small architectural forms—benches, planters, or lighting fixtures. This limited use may result from the technological and energy demands of the recycling process, as well as constrained investment resources, particularly in publicly funded projects. Nevertheless, even these examples confirm the potential of this principle as a tool for retaining the industrial character and visual identity of revitalized facilities.

It is also important to highlight the symbolic and identity-related dimension of materials recovered on site, as noted by B. Kapica *et al*. [27]. The use of original infrastructural elements as carriers of memory and history not only contributes to reducing the carbon footprint but also fosters the construction of local spatial identity [27]. The use and display of former technological equipment supports the preservation of industrial heritage in revitalized facilities [87].

From the perspective of conservation theory, the application of the 4R principles aligns with global trends in heritage protection, as emphasized in key documents such as The Valletta Principles for the Safeguarding and Management of Historic Cities, Towns and Urban Areas (ICOMOS, 2011) [88], which stress the importance of identity and historical continuity when changing the function of a place, or the New Urban Agenda (UN-Habitat, 2016) [89], which encourages the use of existing infrastructure and fabric for new purposes. Revitalization projects aligned with 4R principles, thus, support not only environmental and economic goals but also conservation objectives – enabling the preservation of authenticity, integrity, and long-term sustainability of cultural heritage.

It should be emphasized that spatial and functional design decisions are key to the effective implementation of the 4R principles. Projects in which new functions were adapted to the historical spatial layout (e.g., by preserving circulation axes or the functional division of industrial halls) were more likely to apply the ideas of "Reduce" and "Reuse" in a consistent and comprehensive manner. Conversely, commercial developments in major city centers, such as Warsaw Breweries or "Koneser," where design was driven primarily by functional maximization and investor returns, often applied circular economy principles in a limited or merely symbolic way.

Finally, the analysis confirms that the most recent revitalization projects, realized after 2020, tend to demonstrate a more conscious application of the 4R principles as part of broader sustainable development strategies. This reflects the growing importance of environmental concerns, evolving public awareness, and the increasing role of heritage in urban and regional development policies.

Although the 4R model – originally developed within the circular economy framework – demonstrates significant potential in revitalization processes, its application in conservation practice faces a range of technical and systemic barriers. In the context of industrial heritage

protection, such limitations directly impact the ability to preserve the authenticity and integrity of post-industrial sites.

One of the most frequent challenges is the poor condition of materials and post-production equipment. These elements – which often constitute key carriers of historical and technological value – have frequently suffered significant degradation due to long-term neglect, lack of regular maintenance, or exposure to aggressive industrial environments. This particularly affects steel and concrete components, which, due to corrosion or carbonation, lose their mechanical and aesthetic properties, making safe reuse impossible. From a conservation perspective, this poses a challenge to implementing the "Reuse" principle in a manner consistent with heritage protection standards without resorting to reconstruction.

Another barrier is the overall technical condition of buildings, as well as the technical requirements and legal constraints imposed by new functional uses. In such cases, revitalization often necessitates significant structural interventions—reinforcement of foundations, replacement of floors, and structural additions—which not only hinder the implementation of the "Reduce" principle but may also result in the loss of integrity and disruption of the legibility of the original spatial arrangement. Consequently, even when the external architectural form is retained, the building may lose the features that identify it as part of industrial heritage.

An important factor determining the scope of application of the 4R principles is also the economic and investment context. In locations with high commercial potential, such as major city centers, design decisions are typically driven by profitability, short development cycles, and marketing appeal. In such contexts, time-consuming and costly conservation work is often abandoned in favor of new buildings styled to resemble industrial architecture. Although such approaches may appear consistent with the aesthetic of industrial heritage, they neither achieve the actual goals of heritage conservation nor take full advantage of the potential offered by the 4R model.

From a conservation theory perspective, the effective implementation of 4R principles requires not only favorable technical and financial conditions but also a conscious and integrated design approach involving conservators, architects, and investors. This approach must take into account not only the material values of heritage assets but also their intangible dimensions—local narratives, community identity, and cultural memory.

In the long term, the 4R principles, when treated as a complement to established conservation methodologies, may become an important tool for sustainable heritage management. Their application not only supports the reduction of carbon footprint and resource consumption but also increases the likelihood of preserving heritage fabric in an authentic and durable manner. Actions based on the 4R model are consistent with the guidelines of the International Charter for the Conservation and Restoration of Monuments and Sites (Venice Charter, 1964) [90] by promoting limited intervention ("reduce") and long-term retention and reuse of historic fabric, as well as with the Principles for the Conservation of Industrial Heritage Sites, Structures, Areas, and Landscapes (TICCIH/ICOMOS, 2011), by encouraging the use and display of industrial heritage [91].

Conclusions

The conducted analysis of ten case studies of post-industrial facilities revitalization in Poland demonstrates that the principles of the circular economy—particularly the 4R model (reduce, reuse, recycle, and recover)—can serve as a valuable tool supporting both design and conservation processes aimed at preserving the authenticity and integrity of heritage sites. While most of the examined projects implemented at least some elements of this approach, the full application of all four 4R principles was found to be rare.

The most commonly observed practice was the reuse of selected building elements, often for decorative or symbolic purposes. The principle of waste reduction (reduce) was also evident, especially in cases where demolition and intervention in the existing fabric were minimized. Material recycling (recycle) was applied far less frequently due to high costs and technological complexity. The recovery of spatial functions (recover) can be regarded as achieved in all cases, as this is a fundamental aspect of revitalization as a process of restoring value to urban space.

Although originally derived from waste management, the 4R principles align closely with contemporary conservation theories. They promote the protection of heritage fabric, minimal intervention, and the preservation of place identity, all of which correspond with the guidelines of international heritage organizations.

The presented examples illustrate that the effective implementation of the 4R principles requires not only suitable technical and financial conditions but also a conscious design approach that respects cultural and spatial values. As such, the 4R model can serve as a complementary tool for the protection of industrial heritage, integrating environmental, economic, and conservation-related dimensions.

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Received: December 11, 2025
Accepted: April 28, 2026