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Unlocking multiple potentials: a data-driven framework for adaptive reuse of industrial heritage in Changzhou, China

Jing Zhang[a,b], Nan Jiang[a,c,d], Yizhao Du[e] and Thomas Chung[b,f]

[a]School of Architecture, Southeast University, Nanjing, China; [b]School of Architecture, The Chinese University of Hong Kong, Sha Tin, Hong Kong, China; [c]Key Laboratory of Urban and Architectural Heritage Conservation of Ministry of Education, Southeast University, Nanjing, China; [d]Visual Image Research Base of Chinese Nation, Southeast University, Nanjing, China; [e]Faculty of Architecture and the Built Environment, Delft University of Technology, Delft, The Netherlands; [f]Research Centre for Sustainable Placemaking and Urban-Rural Regeneration, The Chinese University of Hong Kong, Sha Tin, Hong Kong, China

ABSTRACT

Adaptive reuse of industrial heritage can showcase industrial culture and drive urban transformation but faces issues like homogenization, secondary ruins, and long-term adaptation deficits. Research gaps include insufficient analysis of correlations between reuse potential and strategies, and limited generalizability from single-case studies. This study addresses these gaps using Changzhou, China's industrial heritage, aiming to provide a data-driven analytical framework for industrial heritage reuse potential, to reveal the network of potential indicators, to deconstruct the kernel of multidimensional potentials, to show the regional differentiation characteristics of potentials, and to construct a decision-making basis for typological governance. It draws on a consolidated dataset covering industrial heritage with multi-level protection statuses and a sample of 28 sites, identifies multidimensional indicators, explores their interrelations via Pearson correlation analysis, and extracts five primary dimensions – spatial, cultural, locational, operational, and historical potentials – through Factor Analysis, accounting for 70% of variability across 20 reuse indicators. GIS mapping highlights regional variations of these potentials, aiding targeted governance. Hierarchical Cluster Analysis categorizes industrial sites into six adaptive reuse types: unbalanced development, synergistic development, exemplary leading, canal industrial, functional continuity, and to-be-developed. The potential for adaptive reuse of industrial heritage reflects the dynamic needs of heritage governance, which requires systematic protection of heritage through top-down institutional strengthening, while bottom-up community empowerment opens up resilient renewal pathways for heritage. The framework constructed in this research helps to develop targeted regeneration strategies for industrial heritage based on different potential types to maximize its intrinsic value and enhance its long-term adaptation after adaptive reuse, while remaining generalizable to other regions and supporting policy design for adaptive reuse governance.

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Industrial heritage; adaptive reuse; multilevel potential; factor analysis; cluster analysis

1. Introduction

Western countries began focusing on the redevelopment of abandoned industrial areas as early as the 1980s, incorporating them into the concept of brownfield regeneration (Adams, De Sousa, and Tiesdell 2010; Jones and Zhang 2024; Osman et al. 2015; Wetherell 2022). The International Committee for the Conservation of the Industrial Heritage (TICCIH) defines industrial heritage as "the remains of industrial culture which are of historical, technological, social, architectural or scientific value. These remains consist of buildings and machinery, workshops, mills and factories, mines and sites for processing and refining, warehouses and stores, places where energy is generated, transmitted and used, transport and all its infrastructure, as well as places used for social activities related to industry such as housing, religious worship or education" (TICCIH 2003). The Dublin Charter emphasizes the outstanding universal value of the industrial heritage, which represents the human life of the past, the face of social life, the skills of the workers and the collective memory of the community (TICCIH 2011). However, industrial heritage has gradually become a severe problem in social and economic development due to various reasons, including the difficulty and high cost of demolition and new construction (Bullen and Love 2010) and relocation of industrial heritage (ICOMOS 1964) the gradual outward expansion of cities (Burns 2020) the low utilization rate of land (Nocca, Bosone, and Orabona 2024) and environmental pollution (Page and Berger 2006; Ye, Kweon, and He 2024).

As a result, in the face of wasted resources and value loss of industrial heritage, it is often acceptable to convert industrial land to new uses to ensure its preservation (TICCIH 2003). Industrial heritage regeneration

CONTACT Nan Jiang jnseuarch@163.com School of Architecture, Southeast University, Nanjing 210096, China
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refers to the revival and reuse of original industrial sites and structures, injecting new life and functions while preserving their historical and cultural significance (Swensen and Granberg 2024; Vizzarri et al. 2021; Yasemin Çakır and Edis 2022). ICOMOS emphasizes that this process should interpret and convey the diversity and interconnectedness of both tangible and intangible cultural values (ICOMOS 2021). At the tangible spatial level, the characteristics of industrial heritage, such as robust building structures, high ceilings, and large interior spaces, offer potential for transformation (Y. Li et al. 2018). Several authors reflected these ideas in relation with the specific characterics of industrial heritage in their studies, noting that these industrial heritage sites are planned for further sustainable regeneration and transformation, including value preservation, spatial transformation, functional upgrading, and environmental management, which can avoid the large amount of wasted resources caused by the demolition of large-scale industrial sites, with the ultimate goal of improving the efficiency of heritage utilization (Luo and Gong 2020). At the intangible cultural level, the social, historical, architectural, and technological value of industrial heritage is a catalyst for urban revitalization (Martinović and Ifko 2018).

In the past two decades, Chinese industrial transformation brought about the reuse of industrial heritage, which has become a crucial factor in promoting sustainable urban regeneration (Vardopoulos 2019). Despite being recognized as the "world's factory" in the 21st century, China quickly shifted towards post-industrialization by restricting heavy industry and encouraging the service sector to optimize the industrial structure (Mo, Wang, and Rao 2022). Since 2001, a political initiative called "tui er jin san", which means reducing the secondary industry and developing the tertiary industry, has been popularized nationwide. The shift from a production-centered to a service-centered approach highlights the growing emphasis on a service-based economy, reflecting evolving social needs and lifestyles (Hao and Cao 2019) which has directly contributed to the preservation and regeneration of industrial heritage. The year 2002 marked the first milestone for industrial heritage protection when Shanghai enacted regulations to preserve buildings considered representative of the city's industrial development, saving five industrial buildings in M50 from demolition (Zielke and Waibel 2014). From 2007 to 2020, the state council has successively promulgated regulations – they started with the development of the newly born industry, then shifted focus to the promotion of the relocation and reuse of urban former industrial areas, and finally devoted themselves to urban community revitalization and help (J. Zhang, Xu, and Aoki 2023).

However, due to the difficulties in regenerating industrial heritage, the problem of low vitality after regeneration is widespread. On the one hand, the importance, degree of degradation, ownership, and funding of industrial heritage vary, making it difficult to determine the costs and benefits of resource development in time and space (Della Lucia and Pashkevich 2023). On the other hand, the potential for industrial heritage regeneration is also constrained by challenges such as its peripheral location relative to urban centers and metropolitan areas, the extensive scale of the areas requiring intervention, and the significant environmental liabilities that must be addressed (Fernandes et al. 2020). This has led to uniform patterns of reuse and replication (Meng, Zhang, and Pang 2024). It has become common for most industrial heritage sites to deteriorate into a state of "secondary ruins" (Han and Zhang 2022) and homogenization has become a great challenge for most urban industrial heritage renewal projects (X. Zhang and Ren 2024). This is not conducive to effective industrial heritage preservation, full utilization, or effective promotion of sustainable urban regeneration (Meng, Zhi, and Pang 2023).

Facing the low vitality problem of industrial heritage regeneration, *adaptive reuse* is considered a promising strategy for heritage conservation (Bottero, D'Alpaos, and Oppio 2019) because each successful protection case is protected and updated according to its actual conditions (J. Zhang et al. 2021). According to the Nizhny Tagil Charter, "sympathetic adaptation and re-use may be an appropriate and a cost-effective way of ensuring the survival of industrial buildings (TICCIH 2003). " On the one hand, it facilitates the process of adapting structurally sound older buildings to economically viable new uses and is considered an important practice for preserving the historic architectural character of towns and eras (Vardopoulos 2022). On the other hand, this approach is either to determine conservation methods considering stakeholders, typology, existing situation, and potential problems, or to decide between adaptive reuse and new construction alternatives by preparing projects for each situation (Yasemin Çakır and Edis 2022).

In order to assess the contribution of adaptive reuse to the community, an important component is the *adaptive reuse potential* for buildings at the end of their original service life (Langston et al. 2008). In this process, the selection criteria have been the reflection for priority of the values for industrial heritage by different heritage agents and stakeholders (Dong and Hou 2014). The ranking of heritage adaptive reuse potential helps to assist current owners or future developers in resetting the decay curve through strategic capital investments in the renewal process at a critical time in a building's life cycle (Langston 2012). Evaluating the potential for adaptive reuse of industrial heritage is a complex process that depends on numerous factors, and relying on a single evaluation metric may result in less accurate assessment

(Meng, Zhi, and Pang 2023). Therefore, the fusion of multiple indicators to find a consensus has become a common approach. In the comparison of reuse potential, multi-criteria decision analysis, such as the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), the Novel Approach to Imprecise Assessment and Decision Environments (NAIADE), and the Multi-Attribute Theory of Value (MATV), are commonly used to assess the intrinsic value of industrial heritage and to determine the best option for reuse (Bottero, D'Alpaos, and Oppio 2019; Nocca, Bosone, and Orabona 2024). In potential factor quantification, the Fuzzy Decision-making Trial and Evaluation Laboratory (DEMATEL) approach, and the Entropy weight method is often used to categorize, classify, and quantify potential factor scores (Añibarro, Andrade, and Jiménez-Morales 2023; Vardopoulos 2019). In potential classification, cluster analysis is often combined with the above methods (Špano et al. 2022; L. Xu et al. 2025) for categorization after heritage assessment for targeted reuse.

Although existing studies have established industrial heritage reuse evaluation systems and indicators from different perspectives, the following problems still exist. Firstly, there is a lack of research on the correlation between heritage potential and regeneration strategies. Identifying heritage regeneration opportunities and unlocking greater potential and benefits in relation to the characteristics and strengths of heritage remains a primary challenge (M. Li et al. 2024). Secondly, there is a lack of research on the geographical distribution of heritage regeneration potential. At the urban scale, few studies have focused on the geographic variation of industrial heritage potential in terms of spatial and functional change (Yu, Xiao, and Liu 2023). Third, Industrial heritage regeneration research suffers from case homogeneity. Most papers focus on a single case (Ravaz et al. 2024) making it difficult to draw commonalities and differences within or between regions, limiting the generalizability of results.

In conclusion, as an important urban element, heritage possesses dynamic values (Micelli and Pellegrini 2018) which are crucial to identify where the potential lies and how to activate it. The research attempts to establish an evaluation system for the reuse potential of industrial heritage and aims to answer the following questions:

- What are the indicators for the potential and what is the relationship of indicators for assessing the adaptive reuse potential of industrial heritage?
- What types of industrial heritage can be classified according to their adaptive reuse potential and what are the characteristics of each type?

This study aims to provide a data-driven analytical framework for industrial heritage adaptive reuse potential. Its novelty lies in revealing the network of potential indicators, deconstructing the kernel of multidimensional potentials, showing the regional differentiation characteristics of potentials, and constructing a decision-making basis for typological governance. The analytical framework is validated in adaptive reuse projects of industrial heritage in Changzhou, China, and provides a scientific basis and decision support for its regeneration practice, while remaining generalizable to other regions and supporting policy design for adaptive reuse governance.

2. Research design

2.1. Research framework

The research framework of this study is shown in Figure 1. The study starts by collecting information on industrial heritage recognized by different institutions to form an inventory. Based on the Architectural Design Data Collection's assessment system of building reuse potential, the indicators were selected and made comparable by a Likert 5-point scale. The correlation between the potential indicators was analyzed by Pearson correlation analysis, data reduction was achieved through Factor Analysis, and the heritage

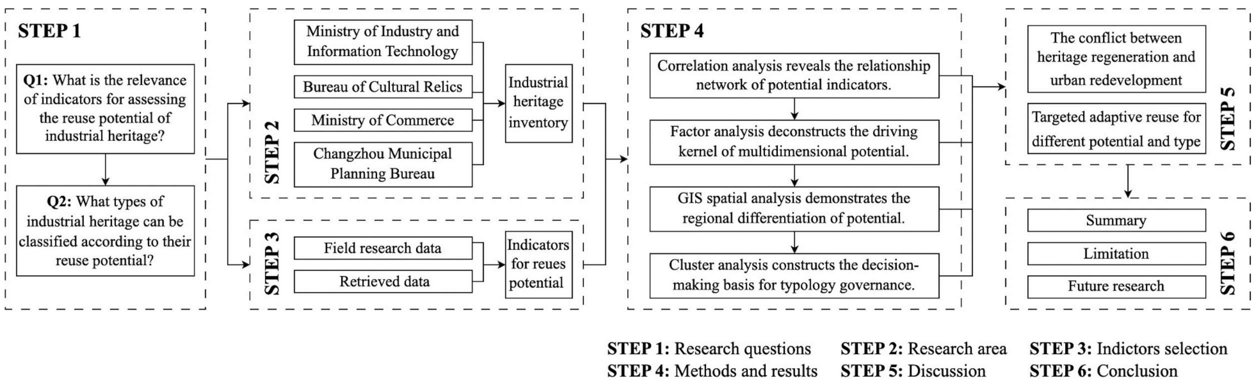


Figure 1. Research framework.

samples were aggregated according to the similarity of potential by Hierarchical Cluster Analysis.

2.2. Research area

The research takes Changzhou, China, as a case study, which represents the industrial heritage of the Yangtze River Delta region (Figures 2 and 3). First, the canal-industrial heritage corridor formed by the integration of the Grand Canal (Beijing-Hangzhou) and industrial heritage represents a distinctive feature of Changzhou's industrial heritage conservation (Zha and Wang 2019). These industrial remains have profound connections with cultural and natural environments, reflecting the characteristics of past manufacturing developments and defining today's environmental and landscape contexts (Sun and Fan 2024). Second, the prosperous traditional handicraft industry and foreign capital investment have made Changzhou the city with the highest number of national industrial heritage sites in Jiangsu Province (Y. Xu and Zhou 2015). Third, Changzhou's uniqueness lies in the integration with daily life, and gradual renewal approach (Lu 2018; Zhuang et al. 2019).

Figure 2. Jiangsu Province in China.

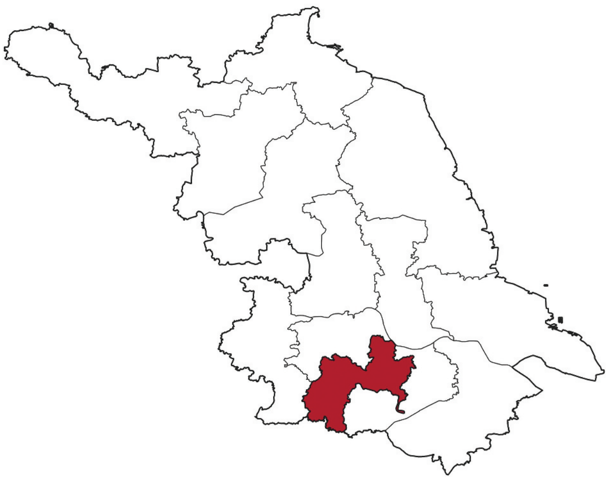


Figure 3. Changzhou in Jiangsu Province.

Figure 4. Industrial heritage in Changzhou.

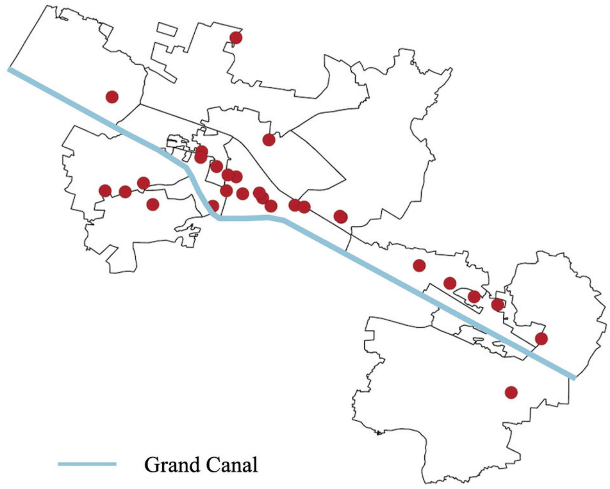
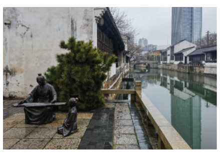


Figure 5. Industrial heritage in 11 subdistricts.

There are six districts in Changzhou (Figure 4), with Tianning, Wujin, Zhonglou, and Xinbei selected as the main research areas. On one hand, these areas have a large number and high density of industrial heritage. On the other hand, the Grand Canal passes through these areas, and the pattern of industrial heritage distribution along the canal is clear. In these four districts, industrial heritage sites are distributed across 11 continuous subdistricts (Figure 5).

The list of Changzhou's industrial heritage comes from three main sources: the industrial heritage list published by the Ministry of Industry and Information Technology, the cultural relic protection units published by the Bureau of Cultural Relics, and the long-established enterprises published by the Ministry of Commerce. On this basis, the list combines information from the Jiangsu Provincial Cultural Relics Bureau and Changzhou Municipal Planning Bureau to add other important industrial heritage, forming a data list containing 28 items of industrial heritage in 11 subdistricts from four selected districts (Table 1, Figure 6).

Table 1. List of Changzhou industrial heritage.

Heng Yuan Chang Factory (HYCF) National heritage Construction: 1932 Industry: Textile Site: 37,600 m²	**Da Ming Yarn Factory (DMYF)** National heritage Construction: 1952 Industry: Textile Site: 120,600 m²	**Qishuyan Locomotive Factory (QLF)** National heritage Construction: 1938 Industry: Transportation Site: 500,000 m²	**Da Cheng No.3 Factory (DC3F)** Provincial heritage Construction: 1936 Industry: Textile Site: 148,200 m²
			
Da Cheng No.2 Factory (DC2F) Municipal heritage Construction: 1932 Industry: Textile Site: 151,300 m²	**Da Cheng No.1 Factory (DC1F)** Municipal heritage Construction: 1930 Industry: Textile Site: 102,500 m²	**Hong Zhuang Brick Kiln (HZBK)** Municipal heritage Construction: 1952 Industry: Minerals Site: NA	**Secondary Radio Factory (SRF)** Municipal heritage Construction: 1965 Industry: Electronic Site: 38,000 m²
			
Fu Yuan Rice Factory (FYRF) Municipal heritage Construction: 1931 Industry: Food Site: 800 m²	**Xian He Food Factory (XHFF)** National heritage Construction: 1869 Industry: Food Site: 31,000 m²	**Comb Factory (CF)** National heritage Construction: 1951 Industry: Furniture Site: 9,000 m²	**Qishuyan Power Factory (QPF)** Construction: 1920 Industry: Electronic Site: 1,160,000 m²
			
Nan Gang Wharf (NGW) Construction: 1957 Industry: Transportation Site: 40,000 m²	**Black Peony Factory (BPF)** Construction: 1940 Industry: Textile Site: 11,000 m²	**Synthetic Fiber Factory (SFF)** Construction: 1966 Industry: Textile Site: 47,000 m²	**Leather Machinery Factory (LMF)** Construction: 1956 Industry: Equipment Site: 64,000 m²
			
Mining Machinery Factory (MMF) Construction: 1964 Industry: Equipment Site: 73,000 m²	**Wu Jin Water Factory (WJWF)** Construction: 1958 Industry: Water Site: 18,000 m²	**San Jing Technology Factory (SJTF)** Construction: 2003 Industry: Textile Site: 91,000 m²	**Chemical and Light Factory (CLF)** Construction: 1963 Industry: Chemistry Site: 9,000 m²
			
Guang Yang Bearing Factory (GYBF) Construction: 1994 Industry: Metal Site: 20,000 m²	**Golden Lion Bicycle Factory (GLBF)** Construction: 1976 Industry: Transportation Site: 14,000 m²	**Ling Long Paint Factory (LLPF)** Construction: 1988 Industry: Chemistry Site: 12,000m²	**Dong Po Wharf (DPW)** Construction: Song Dynasty Industry: Transportation Site: 43,000 m²
			
Qing Guo Lane Wharf (QGLW) Construction: 1581 Industry: Transportation Site: 87,000 m²	**Bi Ling Yi Wharf (BLYW)** Construction: 1957 Industry: Transportation Site: 40,000 m²	**Wu Jin Furniture Factory (WJFF)** Construction: NA Industry: Furniture Site: 18,000 m²	**Iron Factory (IF)** Construction: 1958 Industry: Metal Site: 220,000 m²
			

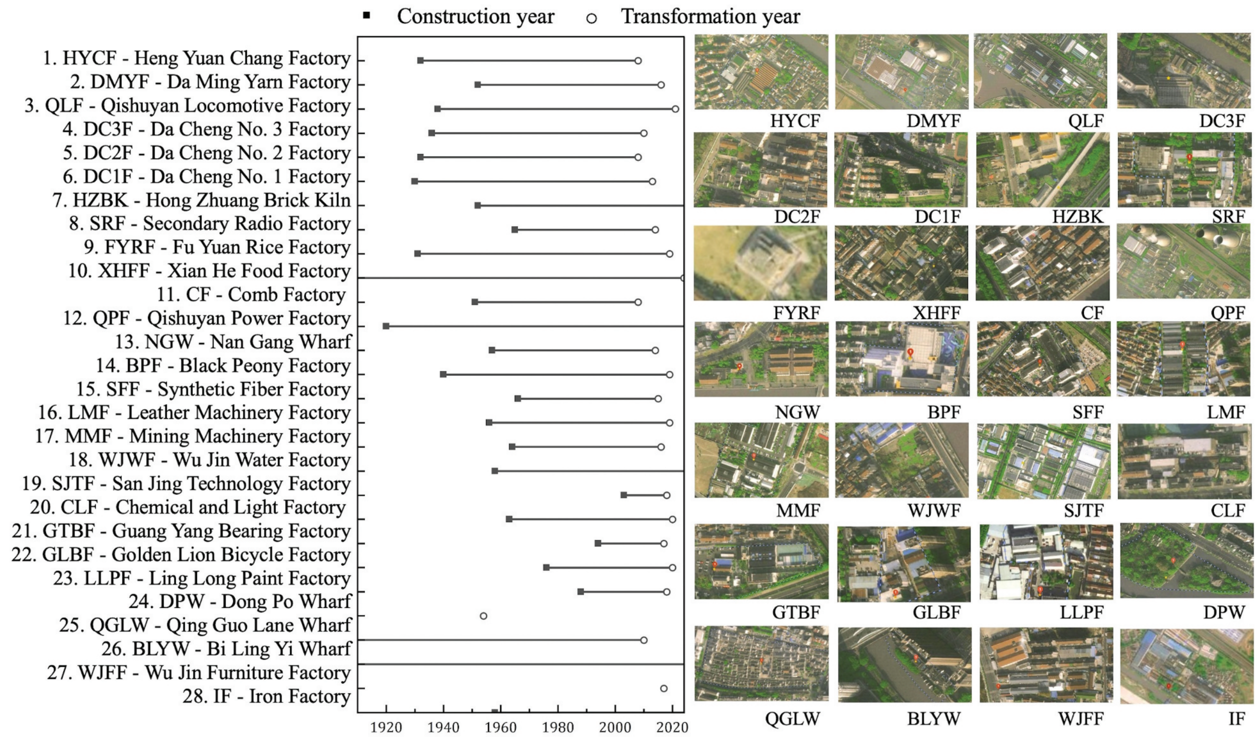


Figure 6. Construction and transformation year of industrial heritage in Changzhou.

2.3. Indicators selection

Architectural Design Data Collection is known as the "Encyclopedia" of China's architecture industry. This paper introduces a system for evaluating the reuse potential of buildings in the book, screening indicators from five dimensions: history, industry, function, economy, and use (ASC 2019). Although the screened indicators cover key aspects of the theory, the intrinsic relationship between these indicators is not clear and still needs to be empirically tested. To enhance the locality and objectivity of the assessment, the quantifiable physical attribute indicators of the multiple cases in Changzhou were selected to reflect the potential of industrial heritage reuse. The 20 indicators are derived from the retrieved data and field research data, and all the data are collected in 2024 (Table 2). Among them, the eight field research data are cultural exhibition (CE), industrial building area (IBA), typical industrial building length (IBL), typical industrial building width (IBW), industrial building percentage (IBP), industrial landscape (IL), vacancy rate (VR), public accessibility (PA). The 12 searches yielded data are construction year (CY), protection level (PL), historical documents (HD), cultural function (CF), official media (OM), social media (SM), academic paper (AP), distance to city center (DCC), factory area (FA), neighboring house price (NHP), distance to canal (DC), building density (BD). Among these, several indicators are directly referenced in prior studies, such as construction year (X. Chen et al. 2024; Ye, Kweon, and He 2024; K. Zhang et al. 2023) and public accessibility (Bottero, D'Alpaos, and Oppio 2019; Chu, Zhou, and Wu 2024; Ertaş Beşir and Çelebi Karakök 2023; Meng, Zhi, and Pang 2023; Zglobicki et al. 2023). Others are discussed indirectly under related terms. For example, historical documents appear as scientific knowledge (Zglobicki et al. 2023) document value (Ertaş Beşir and Çelebi Karakök 2023) or document contribution (Layuno Rosas and Magaz-Molina 2023). Typical industrial building length, width, and related size metrics correspond to concepts such as special layout (Ye, Kweon, and He 2024) building volume (K. Zhang et al. 2023) constructive span (Milošević, Milošević, and Simjanović 2020) and minimal building depth (Milošević, Milošević, and Simjanović 2020).

Prior to the analysis, each of the 20 indicators was scored on a Likert 5-point scale, which facilitates the handling of non-numerical data and makes the indicators comparable with each other (Table 3). In order to reduce subjective bias, each indicator is operated according to clear, rule-based standards, and qualitative attributes are converted into quantitative scores as much as possible.

2.4. Methods

2.4.1. Pearson correlation analysis

Pearson's correlation coefficient analysis was used to investigate the relationship between indicators in industrial heritage reuse. This statistical method quantifies the linear relationship between two continuous

Table 2. 20 indicators of the reuse potential of industrial heritage.

Abbr.	Description	Potential	Range	Mean	Source	Reference
CY	Construction year	Reveal historical context	1519–2003	1919	Factory website	X. Chen et al. (2024), Ye, Kweon, and He (2024), K. Zhang et al. (2023)
PL	Protection level	Show government support	2–5	2.79	Industrial heritage inventory	Ye, Kweon, and He (2024)
HD	Historical documents	Provide original information	0–18	2.25	National Library of China	Ertaş Beşir and Çelebi Karakök (2023,) Ye, Kweon, and He (2024), Zglobicki et al. (2023)
CF	Cultural function	Education and leisure capacity	0–16	2.14	Baidu map POI	Chu, Zhou, and Wu (2024), Ertaş Beşir and Çelebi Karakök (2023,) Nocca, Bosone, and Orabona (2024)
CE	Cultural exhibition	Education and leisure capacity	0–3	0.71	Field research	Chu, Zhou, and Wu (2024), Daldanise and Clemente (2022)
OM	Official media	Official attention level	1–450	82	China Changzhou Website	Zglobicki et al. (2023)
SM	Social media	Reflect public concern	0–2437	118	Weibo	X. Chen et al. (2024), Ye, Kweon, and He (2024)
AP	Academic paper	Embody academic value	0–153	15.1	CNKI	Zglobicki et al. (2023)
IBA	Typical IB area	Indicate available space	0–13350	2552	Field research	Dong and Hou (2014), Wetherell (2022)
IBL	Typical IB length	Indicate available space	0–27	11.3	Field research	Dong and Hou (2014), M. Li et al. (2024), Wetherell (2022)
IBW	Typical IB width	Indicate available space	0–267	55.6	Field research	Dong and Hou (2014), M. Li et al. (2024), Wetherell (2022)
IBP	IB percentage	Show industrial characteristics	0–100%	46	Field research	Huang et al. (2023)
IL	Industrial landscape	Shape visual aesthetics	0–3	1	Field research	Andrade et al. (2024), K. Zhang et al. (2023)
DCC	Distance to city center	Transportation convenience	0.51–13.2	4.49	Baidu map	Andrade et al. (2024) Meng, Zhi, and Pang (2023), Ye, Kweon, and He (2024)
FA	Factory area	Developable size	0.02–116	10.5	Factory website	Bottero, D'Alpaos, and Oppio (2019,) Milošević, Milošević, and Simjanović (2020)
NHP	Neighboring house price	Market prospects	6832–28914	18100	Fang.com	Bottero, D'Alpaos, and Oppio (2019,) Chu, Zhou, and Wu (2024), Meng, Zhi, and Pang (2023)
DC	Distance to canal	Transportation and landscape	0.06–5.24	1.13	Baidu map	Meng, Zhi, and Pang (2023)
VR	Vacancy rate	Exposure underutilization	0–100%	31	Field research	X. Chen et al. (2024), Daldanise and Clemente (2022)
BD	Building density	Developable size	0–80%	56	Baidu map	Chu, Zhou, and Wu (2024)
PA	Public accessibility	Possibility of public access	1–5	4.43	Field research	Bottero, D'Alpaos, and Oppio (2019,) Chu, Zhou, and Wu (2024), Ertaş Beşir and Çelebi Karakök (2023,) Meng, Zhi, and Pang (2023), Zglobicki et al. (2023)

Table 3. Likert 5-point scale for 20 indicators.

	5	4	3	2	1
Construction year	<1911	1911–1948	1949–1978	1979–2000	>2000
Protection level	National level	Provincial level	Municipal level	Media report	–
Historical documents	>3	3	2	1	0
Cultural function	>3	3	2	1	0
Cultural exhibition	>3	3	2	1	0
Official media	>100	51–100	11–50	1–10	0
Social media	>100	51–100	11–50	1–10	0
Academic paper	>10	7–10	4–6	1–3	0
Typical IB area	>3000	2001–3000	1001 - 2000	500 - 1000	<500
Typical IB length	>12	10–12	7–9	4–6	<4
Typical IB width	>45	31–45	16–30	5–15	<5
IB percentage	>60%	41%-60%	21%-40%	10%-20%	<10%
Industrial landscape	>2	2	1	–	0
Distance to city center	<1.0	1.0–4.0	4.1–7.0	7.1–10.0	>10.0
Factory area	>50	21–50	6–20	1–5	<1
Neighboring house price	>20000	16001–20000	13001–16000	10000–13000	<10000
Distance to canal	<0.5	0.5–1.0	1.1–2.0	2.1–3.0	>3.0
Vacancy rate	<5%	5%-10%	11%-20%	21%-30%	>30%
Building density	>70%	61%-70%	51%-60%	40%-50%	<40%
Public accessibility	Open	–	Reservation	–	Close

variables in terms of direction and strength (Xia et al. 2024). This method has already been applied in heritage assessment. Merciu utilized the Bravais-Pearson linear correlation coefficient to demonstrate that the demand for cultural heritage sites is inversely proportional to travel costs and distance (Merciu, Petrişor, and Merciu 2021). Similarly, Chen employed this method to establish significant correlations among the artistic, historical, cultural, and scientific values of architectural heritage (D. Chen 2023).

Therefore, this method is used in this paper to evaluate the correlation relationship between the indicators of industrial heritage potential. The r in this method measures the linear relationship between two variables, ranging from −1 (perfect negative correlation) to + 1 (perfect positive correlation). Cohen states that $r = 0.50$ is a strong correlation (Cohen 2013). Due to the large number of indicators in this paper, values with $r > 0.6$ and $p < 0.01$ were taken for analysis.

2.4.2. Factor analysis

Industrial heritage assessment still faces the challenge of quantifying qualitative indicators (Zhao, Liu, and Qiao 2024). On the one hand, the Analytic Hierarchy Process is subjective, and the fuzzy evaluation method is prone to being influenced by individual factors (K. Zhang et al. 2023). On the other hand, the social sciences contain many latent variables that cannot be measured directly and need to be reflected through observed variables (Guo et al. 2021). Factor Analysis responds to this problem through data reduction. Zhong uses the method to explore industrial heritage renewal strategies based on the theory of locality (Zhong et al. 2024). Cao uses it to analyze the importance and performance of architectural heritage preservation in historic cities (Cao, Mustafa, and Mohd Isa 2024). Chan analyzed the views of different stakeholders on the revitalization of industrial buildings in Hong Kong (Chan, Cheung, and Wong 2015). However, the data sources in these studies are generally expert opinions and questionnaires rather than physical attribute data based on multiple cases, which may affect the locality of the assessment system.

The 20 indicators were reduced to a small number of canonical variables using Factor Analysis. The general purpose of this method is to describe the covariance structure among many variables in terms of a few underlying (but not directly observable) quantities, which are called "factors" (Riitters et al. 1995). The number of factors to retain can be determined through methods such as the Kaiser criterion (K1 rule) or scree plot (Knight 2000). After factor extraction, it is crucial to select an appropriate method for factor rotation based on the nature of the data and research objectives (Matsunaga 2010). Once factors are extracted and rotated, the factor loadings are examined to understand how each observed variable contributes to the latent factors (O'Brien 2007).

2.4.3. Hierarchical Cluster Analysis (HCA)

Cluster analysis is a useful tool for finding the similarity or uniqueness of a case (Špano et al. 2022). As a bottom-up clustering method that aggregates samples based on their similarity, it ultimately forming a hierarchically structured clustering result. This approach has been applied in the field of heritage classification. Ikiz Kaya used HCA on 53 adaptive reuse architectural heritage sites to investigate the correlations between certain characteristics, individual cases, and active circularity variables (Ikiz Kaya, Pintossi, and Dane 2021). Hofmann used HCA to analyze 24 photographs and generate five different types of urban green spaces that were used to study the relationship between parks and abandoned urban land

Table 4. Total variance explained.

Factor	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	5.518	27.589	27.589	4.399	21.993	21.993	4.486	22.428	22.428
2	3.714	18.572	46.161	3.642	18.208	40.201	3.001	15.007	37.435
3	2.671	13.355	59.516	2.624	13.118	53.319	2.786	13.932	51.367
4	1.848	9.239	68.755	1.906	9.531	62.851	2.103	10.516	61.883
5	1.676	8.380	77.135	1.361	6.803	69.653	1.554	7.770	69.653
6	0.969	4.844	81.979						
7	0.721	3.603	85.582						
8	0.656	3.282	88.865						
9	0.423	2.113	90.978						
10	0.403	2.017	92.995						
11	0.340	1.700	94.695						
12	0.266	1.329	96.025						
13	0.222	1.109	97.134						
14	0.178	0.890	98.024						
15	0.132	0.658	98.683						
16	0.100	0.498	99.181						
17	0.064	0.319	99.500						
18	0.048	0.240	99.740						
19	0.037	0.186	99.927						
20	0.015	0.073	100.000						

(Hofmann et al. 2012). Preston used K-Means to classify 2,197 brownfield sites to develop a hierarchical system of brownfield types to reveal their physical characteristics and distribution patterns (Preston et al. 2023).

Overall, HCA appears to be more suitable for the classification needs of industrial heritage in this study. Industrial heritage exhibits significant variations in historical context, architectural features, and reuse potential. HCA can effectively capture non-spherical or uneven clusters, better reflecting this heterogeneity, whereas other clustering methods such as K-means may oversimplify the structure by assuming regular cluster shapes. Additionally, for small to medium-sized datasets (ranging from tens to hundreds of samples), HCA maintains manageable computational costs. Therefore, this study employed HCA to categorize 28 heritage sites. By observing the changes in the dendrogram and clustering coefficients during the clustering process, they were ultimately divided into six categories.

3. Results

3.1. *Indicator correlation of regeneration potential*

Pearson analysis of 20 indicators revealed 12 pairs with a correlation greater than 0.6, including 11 positive correlations and 1 negative correlation (Figure 7). The most significant correlations were found between industrial building area and building width (0.809), distance to city center and neighboring house price (0.730), and building width and vacancy rate (0.719). Cultural function, protection level, and media attention indicators (official media, social media, academic papers) showed strong positive correlations ranging from 0.623 to 0.687. Building characteristics (width, length, area) and spatial indicators (vacancy rate, building density) demonstrated consistent positive correlations between 0.616 and 0.690. Notably, distance to the city center negatively correlated with factory area (−0.607) (Figure 8).

The social correlations reveal the interactive mechanism between social cognition and cultural value of industrial heritage. The positive correlation among official websites, social media, and academic papers (0.623, 0.653, 0.687) aligns with Zglobicki's finding that the internet, tourist guides, and interpersonal communication serve as primary information sources (Zglobicki et al. 2023) indicating that multi-media synergy is a crucial pathway for public access to industrial heritage knowledge. His observation that cultural tourism development depends on the rank and importance of tourist attractions (Zglobicki et al. 2023) further validates the consistency between cultural function and protection level (0.687).

Regarding architectural characteristics, the large spans of industrial heritage facilitate space utilization. There are strong positive correlations between building area, length, and width of typical industrial buildings (0.616, 0.809), reflecting overall architectural scale coherence. This validates Milosevic's emphasis on physical indicators (spatial attributes and qualities of the physical structure) and location-related indicators (Milošević, Milošević, and Simjanović 2020). Notably, the strong positive correlations among building width, vacancy rate, and building density (0.617, 0.690, 0.719) show the contribution of the spatial specificity of industrial buildings to reuse.

For the location, downtown and suburban heritage have different advantages. The distance from the city center shows a strong positive correlation with surrounding house prices (0.730) and a negative correlation with factory areas (−0.607),

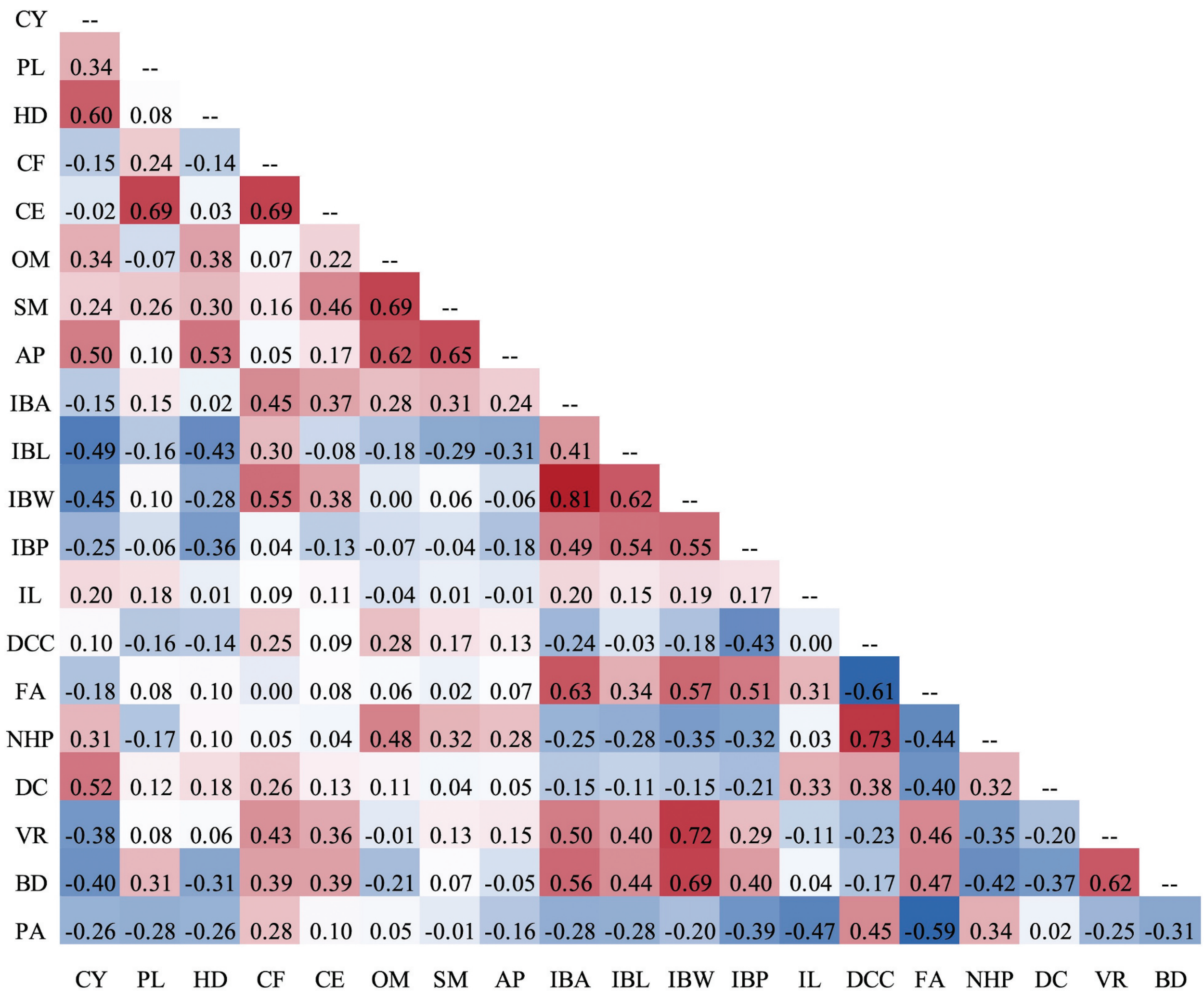


Figure 7. Pearson correlation analysis between 20 indicators.

indicating that industrial heritage sites closer to the city center are smaller but have higher economic value.

3.2. Latent factors on regeneration potential

Common factors were extracted when their eigenvalues exceeded 1 (Table 4). Combining the scree plot (Figure 9), five public factors were extracted, and the cumulative explained variance was 69.653 %, which exceeded the criterion of 60 % (Zhong et al. 2024).

To further clarify the structure of each common factor, orthogonal rotation of the indicators was carried out using the maximum variance method (Table 5).

Table 5. Rotated Factor matrix.

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Typical IB width	**0.926**	−0.065	−0.081	0.143	0.009
Typical IB area	**0.800**	0.291	−0.156	0.121	0.096
Vacancy rate	**0.712**	0.085	−0.186	0.172	−0.161
Typical IB length	**0.696**	−0.395	−0.006	−0.226	0.162
Building density	**0.667**	−0.168	−0.253	0.320	−0.054
IB percentage	**0.564**	−0.148	−0.345	−0.216	0.160
Cultural function	**0.563**	−0.006	0.491	0.479	0.061
Official media	0.089	**0.817**	0.245	−0.063	−0.020
Academic paper	0.001	**0.793**	0.018	0.035	0.106
Social media	0.104	**0.716**	0.108	0.280	−0.096
Historical documents	−0.254	**0.650**	−0.188	0.018	0.172
Distance to city center	−0.112	0.072	**0.819**	−0.043	0.062
Neighboring house price	−0.266	0.350	**0.637**	−0.100	0.068
Public accessibility	−0.203	−0.114	**0.660**	0.049	−0.522
Factory area	0.565	0.151	**−0.612**	−0.040	0.055
Cultural exhibition	0.312	0.207	0.188	**0.867**	−0.067
Protection level	−0.046	0.048	−0.227	**0.855**	0.300
Construction year	−0.483	0.505	−0.004	0.102	**0.628**
Distance to canal	−0.170	0.078	0.460	0.111	**0.576**
Industrial landscape	0.172	−0.020	−0.058	0.059	**0.552**

Table 6. The loading of the five factors (the three strongest indices are shown in bold for defining factor names).

Factor	Positive indicators	Negative indicators	Explained variance (%)	Cumulative (%)
Factor 1: Spatial potential	CF (0.563), **IBA (0.800)**, IBL (0.696), **IBW (0.926)**, IBP (0.564), **VR (0.712)**, BD (0.667)		22.428	22.428
Factor 2: Cultural potential	HD (0.650), **OM (0.817), SM (0.716), AP (0.793)**		15.007	37.435
Factor 3: Locational potential	**DCC (0.819), NHP (0.637), PA (0.660)**	FA (−0.612)	13.932	51.367
Factor 4: Operational potential	**PL (0.855), CE (0.867)**		10.516	61.883
Factor 5: Historical potential	**CY (0.628), IL (0.552), DC (0.576)**		7.770	69.653

Cultural function (CF), Typical IB area (IBA), Typical IB length (IBL), Typical IB width (IBW), IB percentage (IBP), Vacancy rate (VR), Building density (BD); Historical documents (HD), Official media (OM), Social media (SM), Academic paper (AP); Distance to city center (DCC), Neighboring house price (NHP), Public accessibility (PA), Factory area (FA); Protection level (PL), Cultural exhibition (CE); Construction year (CY), Industrial landscape (IL), Distance to canal (DC).

The names of five factors are determined by both the characteristics of industrial heritage and the meaning of the indicators. Prior studies have used factor analysis to categorize indicators for industrial heritage. For example, Albert Chan grouped indicators into land use, local situation, integrated planning with urban revitalization, individual district study, market-led design, and owner participation to learn stakeholder views on revitalizing industrial buildings (Chan, Cheung, and Wong 2015). Abantika Mukherjee categorized indicators into environmental, economic, social, historical, architectural, and technological values to examine alignments and tensions between expert and community perceptions (Mukherjee and Banerji 2025). Research questions shape indicators and factors, which means prior factor schemes do not fully capture reuse potential, so factors are summarized and named from the perspective of industrial heritage reuse potential. Although all relevant indicators were considered, the three strongest indicators were used to define the name of each factor (Shaker 2015). These five factors were named as spatial potential (factor 1), cultural influence (factor 2), locational potential (factor 3), operational potential (factor 4), and historical potential (factor 5). Indicators were associated with multiple factors; however, each indicator was assigned to the factor with the strongest correlation (Table 6).

The scores of industrial heritage on these five factors (Figure 10) help to analyze its reuse potential and help to build on its strengths and avoid its weaknesses to choose the proper approach in the subsequent adaptive reuse process.

Factor 1 (22% of variance) correlates positively (-0.563–0.926) with cultural function, industrial building area, typical industrial building length and width, industrial building percentage, vacancy rate, and building density. Industrial building area, typical industrial building width, and vacancy rate show strong positive loadings (> 0.70), indicating the important role of spatial scale in adaptive reuse. Therefore, this axis is defined as *spatial potential*, which is theoretically supported by Milosevic, who emphasizes that the preservation of existing built heritage should include the reuse of existing spatial capacity (Milošević, Milošević, and Simjanović 2020). In the specific case studies, the

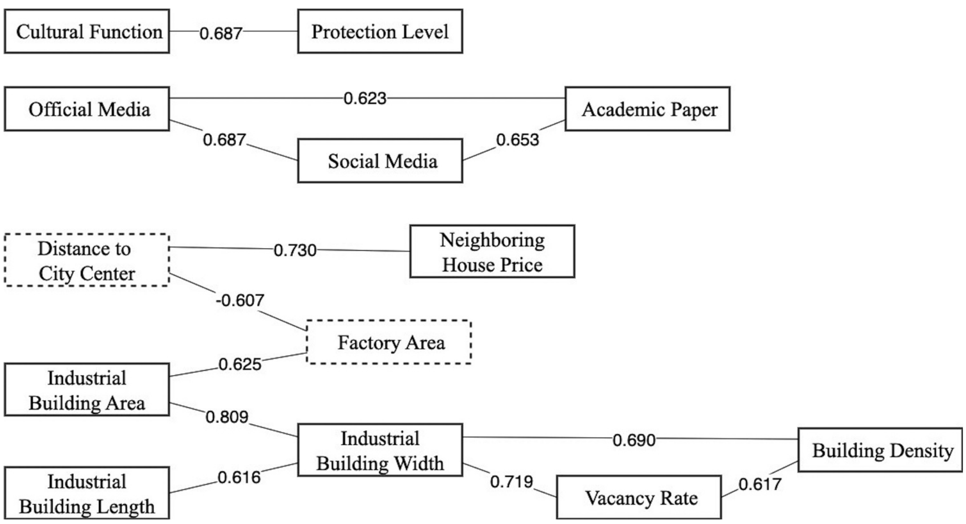
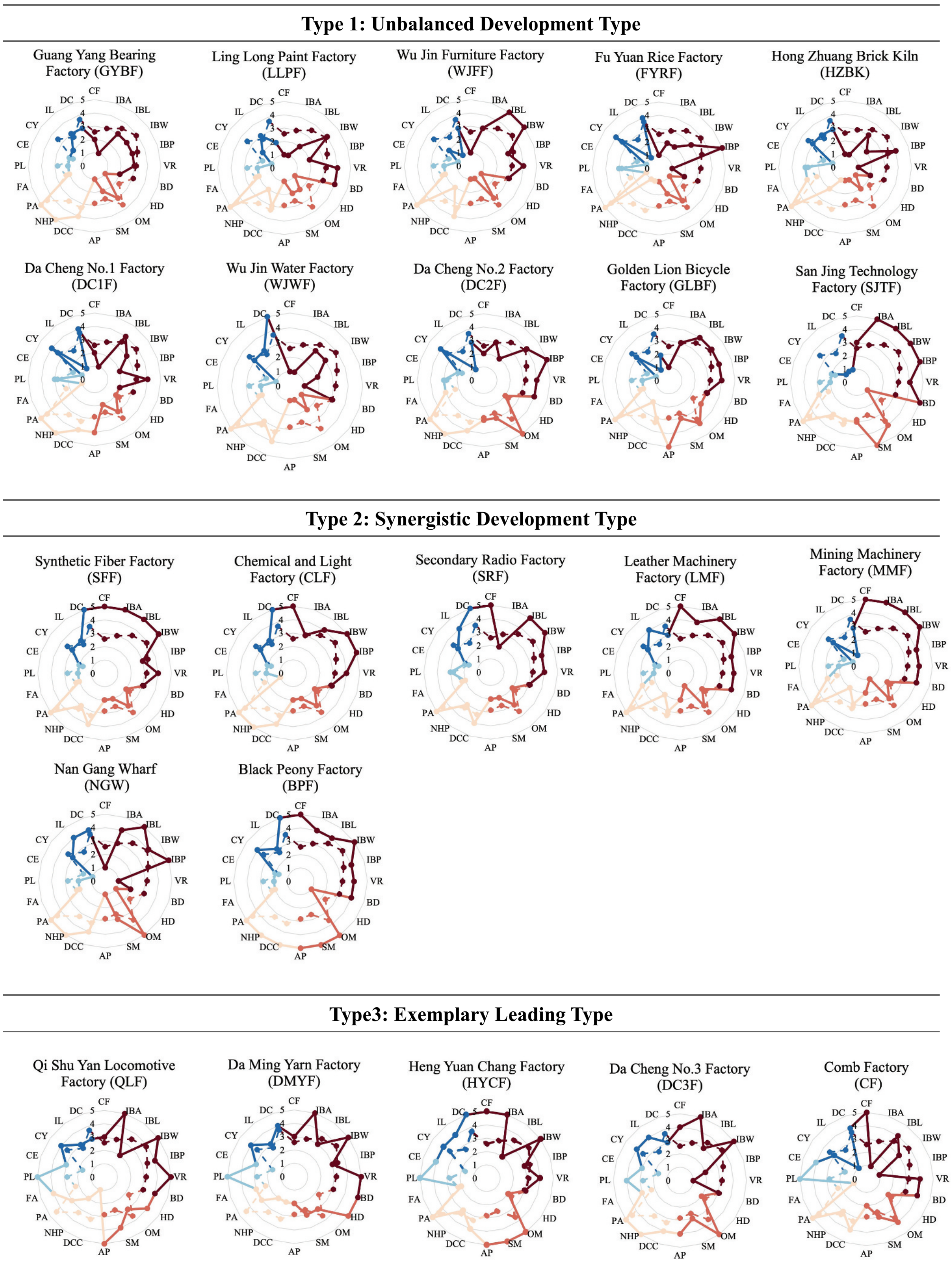


Figure 8. Indicators with correlation greater than 0.60.

variability of the spatial potential is particularly evident in the different types of industrial heritage. Large industrial heritage sites such as San Jing Technology Factory and Iron Factory exhibit high spatial potential due to their expansive floor areas and large-span structures, which are suitable for mixed-use development to enhance reuse value. In contrast, sites such as three wharves, although having open space may provide some advantages for landscaping or recreational functions, the small number of industrial buildings and their dispersed layout result in lower spatial potential.

Factor 2 (15% of variance) correlates positively (0.650–0.817) with historical documents, official media, social media, and academic papers, identifying this axis as *cultural potential*. The core of cultural potential lies in assessing the cultural value and social recognition of industrial heritage through extensive attention from media and the in-depth engagement of academic research. In specific case studies, industrial heritage sites such as wharves, which maintain close ties with urban culture and citizens' daily lives, serve as widely recognized and promoted venues for cultural tourism and educational activities. In contrast, while protected structures like the Wu Jin Water Factory and Xian He Food Factory possess historical significance, their limited documentation in historical records and low media exposure have hindered the full exploration

Table 7. Case scores and average scores for 6 types and 28 industrial heritage.

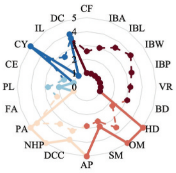


(*Continued*)

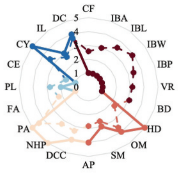
Table 7. (Continued).

Type 4: Canal Industrial Type

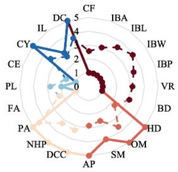
Dong Po Wharf (DPW)



Bi Ling Yi Wharf (BLYW)

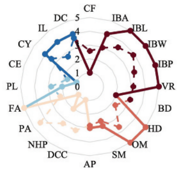


Qing Guo Lane Wharf (QGLW)

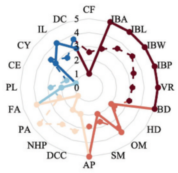


Type 5: Functional Continuity Type

Qi Shu Yan Power Factory (QPF)

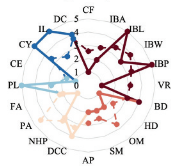


Iron Factory (IF)



Type 6: To-be-developed Type

Xian He Food Factory (XHFF)



	Factor 1: Space potential	Factor 2: Cultural potential	Factor 3: Location potential	Factor 4: Operational potential	Factor 5: Historical potential
Case score	●—●	●—●	●—●	●—●	●—●
Average score	●- - -●	●- - -●	●- - -●	●- - -●	●- - -●

and dissemination of their cultural value to the public.

Factor 3 (14% of variance) correlates positively (0.637––0.819) with distance to city center, neighboring house price, and public accessibility, but negatively with factory area (–0.612). Therefore this study defines it as *locational potential*. In specific cases, the Black Peony Factory and Chemical Light Factory show high locational potential due to their proximity to the city center, higher surrounding housing prices, and high public accessibility. These sites have strong economic vitality and civic access potential and are suitable for development as commercial, cultural or mixed-use spaces. Conversely, if it is not in a central location with well-developed urban functions or a commercial environment, the urban dimension's inherent value prior to adaptive use is low (Meng, Zhi, and Pang 2023). For example, the Qishuyan Power Factory and the Qishuyan Locomotive Factory, which are located in the industrial area on the edge of the city, have poor location potential because their industrial attributes are in conflict with the high-density functional needs of the city center.

Factor 4 (11% of variance) correlates positively (0.855, 0.867) with protection level and cultural exhibition. This axis, named *operational potential*, reflects the ability of urban heritage sites to balance conservation and utilization and their potential operational effectiveness. Specifically, the level of protection has a direct impact on the ability of heritage sites to integrate resources and operate in a sustainable manner, while cultural exhibitions, as a means of revitalization, are able to attract public participation and economic input through the demonstration of the cultural value of heritage. In specific cases, the Comb Factory and Heng Yuan Chang Factory leverage their status as nationally protected heritage sites, combined with unique traditional craftsmanship and abundant industrial historical materials, to significantly enhance their ability to attract tourists and community engagement through industrial exhibitions, interactive experiences, and cultural display activities, resulting in the highest scores in operational potential. In contrast, despite its locational advantage, Nan Gang Wharf lacks the designation as a protected heritage site and suffers from an absence of public cultural attributes, leading to limited public appeal and lower operational potential.

Factor 5 (8% of variance) correlates positively (-0.552–0.628) with construction year, industrial landscape, and distance to canal. Older construction years reflect deeper historical significance, unique industrial landscapes embody historical identity, and closer canal proximity highlights past economic roles. Therefore, this axis is defined as the *historical*

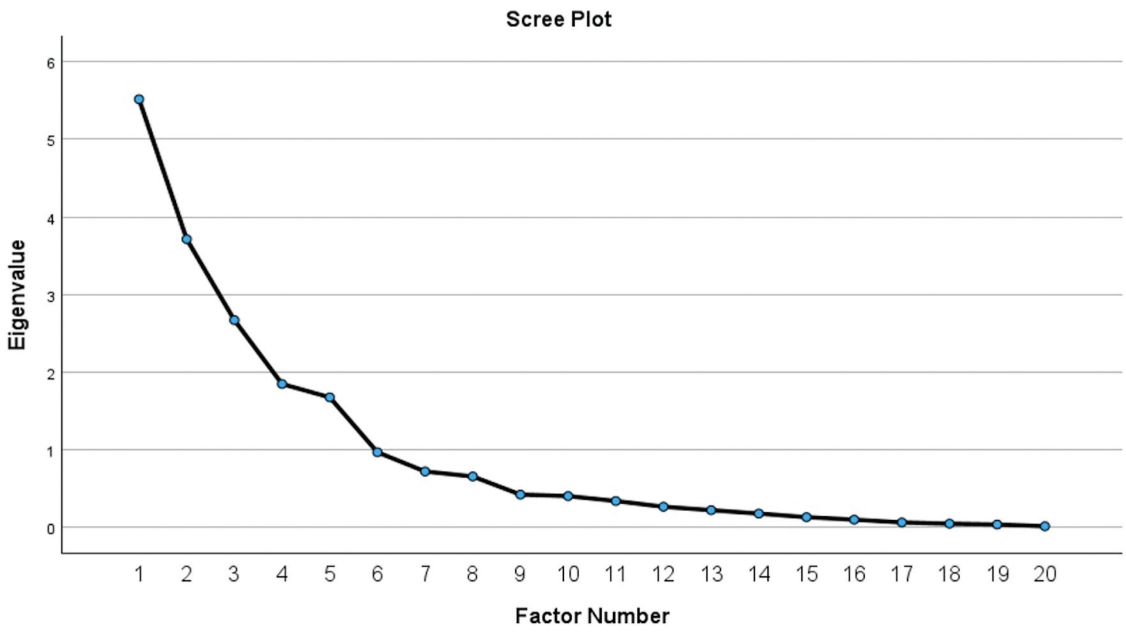


Figure 9. Scree plot for factor analysis.

	HYC	DC3	BPF	QLF	DMYF	SRF	DC2	QPF	NGW	SFF	SJTF	CF	CLF	LMF
F1	0.491	0.334	1.063	0.352	0.386	0.649	0.03	0.906	0.246	1.026	1.341	-0.4	0.742	1.039
F2	1.195	0.864	1.038	0.926	0.303	-0.92	0.965	1.258	-0.03	-0.48	0.178	-0.43	-0.58	-0.64
F3	0.691	0.631	1.565	-1.82	-1.27	0.939	0.011	-1.8	0.636	1.084	-0.31	0.721	1.319	0.319
F4	2.101	1.011	-0.4	1.648	1.673	0.262	0.109	-1.27	-1.14	-0.17	-0.23	2.526	-0.13	-0.08
F5	0.177	0.288	0.578	0.021	0.533	0.662	-0.42	0.953	0.238	0.423	-2.26	-0.72	0.379	0.128

	IF	MMF	DC1	QGLW	XHFF	GLBF	DPW	GYBF	BLYW	WJFF	WJWF	FYRF	LLPF	HZBK
F1	1.243	1.046	-0.74	-1.74	-0.71	0.087	-1.85	-0.42	-1.88	0.429	-0.86	-1.17	-0.39	-1.25
F2	0.438	-0.58	-0.28	1.503	-1.3	0.553	1.486	-0.79	1	-1.07	-1.41	-0.7	-1.14	-1.36
F3	-1.62	0.148	0.473	0.839	-0.91	-0.56	0.422	0.491	0.41	-0.01	0.309	-0.89	-0.64	-1.17
F4	-1.12	-0.71	-0.29	-0.72	0.303	-0.83	-0.65	0.055	-0.56	-0.76	-0.42	-0.01	-0.25	0.052
F5	0.482	0.074	0.297	0.274	2.929	-1.06	-0.16	-1.24	0.176	-0.83	0.078	-0.04	-1.5	-0.45

Figure 10. Factor scores for 28 industrial heritage.

potential. In the specific case, the Xian He Food Factory, built more than 150 years ago, has the highest historical potential, with its proximity to the canal for logistical transportation and its preservation of sauce barrels, a 26-meter chimney, and the "Guan Fang Yan" (Official Salt) plaque. On the contrary, the San Jing Technology Factory has the lowest historical potential, having been built in the 21st century, far away from the canal as it is more dependent on developed land transportation.

The Factor Analysis summarized five core dimensions that influence the potential for adaptive reuse of industrial heritage: spatial potential, cultural potential, locational potential, operational potential, and historical potential. Its rationality is validated by the case data and analysis, which provides a simplified and clear analytical basis for the subsequent spatial distribution of heritage reuse potential and heritage classification.

3.3. *Spatial variation of regeneration potential*

The spatial distribution of reuse potential in different subdistricts was visualized using GIS based on the average factor scores of each industrial heritage (Figure 11). Spatial potential (Factor 1) peaks in Xinzha and Sanjing while reaching its lowest in Yaoguan. Cultural influence (Factor 2) shows the highest value in Qishuyan and the lowest in Yaoguan and Yonghong. Locational potential (Factor 3) reaches its maximum in Tianning but drops to its minimum in Qishuyan. Operational potential (Factor 4) scores highest in Hehuachi and Qinglong while showing the lowest values in Xinzha and Yonghong. Historical potential (Factor 5) demonstrates its peak in Nandajie and its lowest point in Sanjing.

The contrasting spatial distribution between special potential and historical potential reflects the historical evolution of industrial development. Heritage sites with high spatial potential are primarily located in areas far from the city center. This distribution pattern is closely tied to historical industrial land use planning, as large industrial enterprises were typically located at the urban periphery, where abundant land resources could accommodate large-scale factories. Especially during the "12th five-year plan" (2011–2015), the secondary industry were moved out from main urban area to promote the development of tertiary industries and to advance the proportion of the services sector (Wu et al. 2018). This confirms Nocca's observation that commercial services are primarily located in brownfield sites near the city center, while manufacturing and investment activities are situated in more distant areas (Nocca, Bosone, and Orabona 2024). Notably, despite its

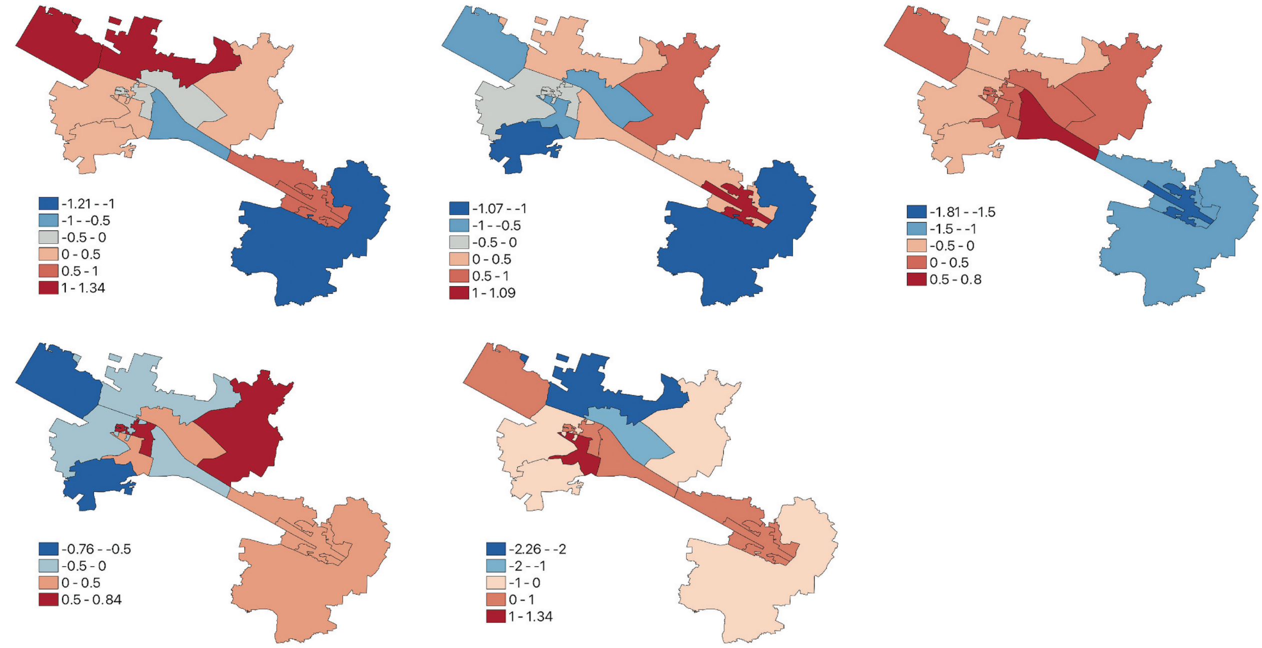


Figure 11. Factor score distribution in different subdistricts.

suburban location, Yaoguan Town shows the lowest spatial potential due to its scattered small-scale township enterprises lacking concentrated industrial spaces.

The added-value conditions of the industrial heritage location are essential in determining the reuse strategy (Meng, Zhi, and Pang 2023). Although relatively remote, Qishuyan district has received significant social attention due to its unique industrial and cultural heritage (including textiles, locomotives, and power factories), demonstrating that cultural value isn't solely dependent on location. Interestingly, while Tianning district shows overall lower operational potential, this doesn't indicate absolute governance inadequacy but rather reflects significant internal variations. The district contains both well-protected sites with excellent cultural presentations and poorly maintained sites with inadequate utilization. This phenomenon suggests current industrial heritage protection policies and resource allocation may follow a pattern of emphasizing key sites while neglecting ordinary ones.

3.4. Heritage types affected by regeneration potential

The Hierarchical Cluster Analysis is based on the scores of the 28 industrial heritage sites in 5 factors, which can be divided into 6 categories (Figure 12). This classification maximizes similarity within clusters and difference between clusters, and it strikes a balance between heritage feature differentiation and classification tractability.

Unbalanced Development Type (10 sites) is the largest category, which reflects industrial heritage reuse, showing significant advantages in some aspects while having obvious deficiencies in others. This type is characterized by clear locational potential but low cultural and historical potential. The indicator scores vary greatly, with only a few indicators scoring above the average. Among these heritage sites, Da Cheng No. 1 Factory, Da Cheng No. 2 Factory, Fu Yuan Rice Mill, and Hong Zhuang Brick Kiln are all municipally protected heritage sites, yet they particularly demonstrate the characteristic of widely varying indicator scores. In contrast, San Jing Technology Factory is an exception, with spatial and operational potential far exceeding the average values, but its historical potential is too low, so a significant imbalance still exists.

Synergistic Development Type (7 sites) demonstrates relatively balanced potential across categories, reflecting a balance between protection and regeneration of industrial heritage. The characteristics of this type include generally higher spatial potential, with other aspects at average levels. The scores of various indicators are relatively balanced, with half of the indicators scoring above average values. Notably, 6 sites in this category lack official protection status, which on one hand reflects possible coverage gaps in the cultural heritage protection system, and on the other hand demonstrates that unregulated heritage may have greater flexibility in the regeneration process.

Exemplary Leading Type (5 sites) represents high-level models of protection and reuse, providing valuable experience for transforming other industrial heritage sites. These sites have high cultural, operational, and historical potential, with medium spatial and locational potential. Most indicators score are above average values. Except for Da Cheng No. 3 Factory, which is a provincial-level industrial heritage site, the others are all national-level industrial heritage sites. This reflects the close association between industrial heritage protection levels and their reuse potential, and the

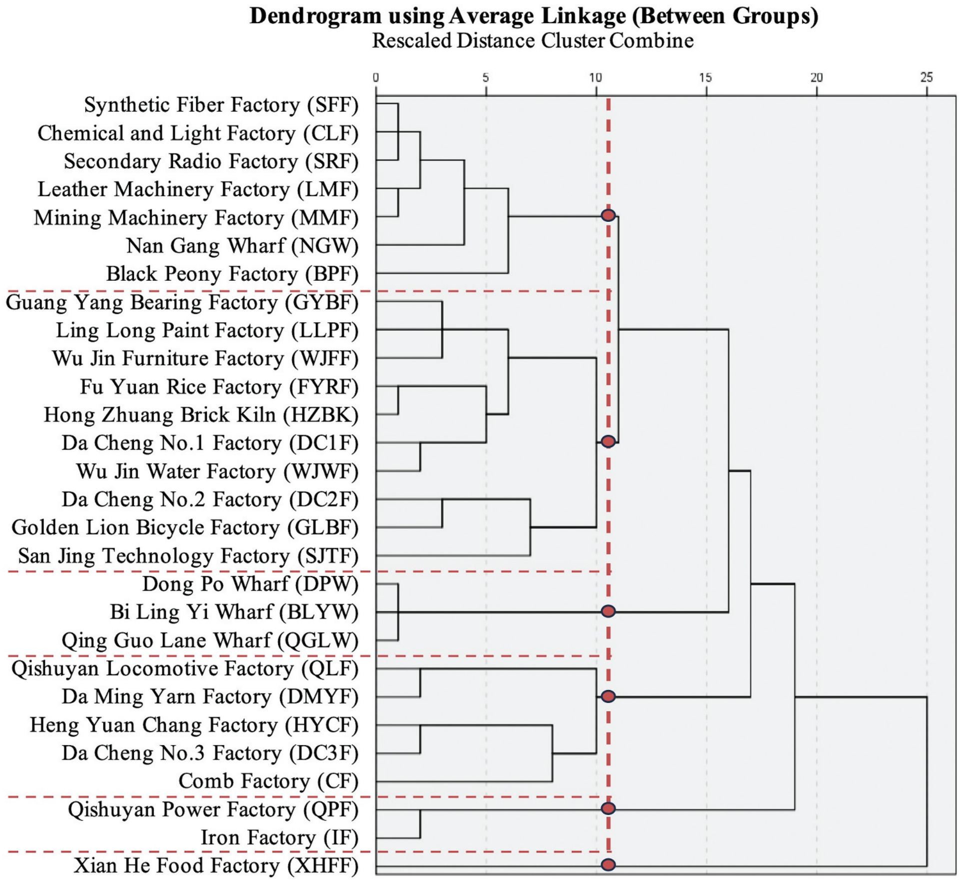


Figure 12. Cluster Analysis for 28 industrial heritage based on Factor score.

positive role that active protection policies play in sustaining heritage potential.

Canal Industrial Type (3 sites) primarily consists of open industrial ports, located near city centers and canals, which have already been integrated into daily life. This type of heritage has high historical, operational, cultural, and locational potential. However, due to being predominantly open industrial landscapes with a lack of industrial buildings, they have low spatial potential.

Function Continuation Type (2 sites) has retained its original production functions and does not require immediate transformation. This type of heritage has high spatial, historical, and cultural potential, but low operational and locational potential. This is because industries that are still in production usually need to be located away from the city due to pollution and noise and are not open to the public.

To-be-developed Type (1 site) is currently abandoned but shows enormous development potential. This type of heritage has significant variations in its indicator scores, with notable differences even among indicators within the same potential category. The uniqueness of the single case in this type confirms this characteristic. Xian He Food Factory is the only completely abandoned heritage among Changzhou's five national-level industrial heritage sites, making its revitalization and reuse an urgent issue to address (Table 7).

4. Discussion

4.1. *The conflict between heritage intrinsic value and reuse potential*

Society's attention is increasingly focused on industrial heritage with significant historical value and high levels of protection. On the one hand, as Daldanise has argued, the active participation of local communities and scientific experts significantly enhances the creative potential of heritage sites (Daldanise and Clemente 2022). On the other hand, heritage with protected status demonstrates higher levels of operational potential, which validates Chu's assertion that governance is a critical factor affecting the implementation performance of heritage renewal (Chu, Zhou, and Wu 2024).

Notably, while Ye concludes that richer industrial history correlates with higher spatial renewal value (Ye, Kweon, and He 2024) this study finds that historical potential scores may not fully indicate reuse potential. Some industrial heritage sites possess high historical and cultural value, yet their reuse potential is limited due to improper preservation or spatial constraints. Changzhou has been involved in regenerating the inner downtown area as well as demolishing the former industry zone and replacing it with commercial buildings, with commercial residential housing cashing the rent-gap (Wu et al. 2018). However, this has also led to the destruction or disappearance of numerous large-scale industrial sites with high architectural value and significant spatial scale, which reflects the conflict between economic benefits and cultural heritage protection during rapid urban development (Yang and Han 2020; Yin and Sun 2018). For instance, despite its rich historical and cultural significance, the Da Cheng No.1 Factory has seen most of its heritage buildings demolished and replaced with high-end residential developments. This destruction of authenticity has severely impacted its reuse potential. The Hong Zhuang Brick Kiln faces a similar situation, where most industrial heritage structures were demolished, leaving only a small site of less than 50 square meters, making adaptive reuse difficult. This also validates Emilie Savoie's point: despite the demonstrated benefits of adaptive reuse in balancing heritage preservation and contemporary urban needs, small cities face significant challenges: financial constraints, regulatory barriers and technical limitations (Savoie, Sapinski, and Laroche 2025).

Conversely, some industrial heritage sites without protected status, while having lower historical value, demonstrate high reuse potential, highlighting how industrial heritage can be integrated into modern society and community life (Gao and Chen 2020; Y. Li et al. 2018). The Nan Gang Wharf, though no longer functioning as a shipping port, has retained extensive wharf-specific heritage features like containers, clock towers, and warehouses. Combined with its advantageous location near the city center, it has the potential to become a representative example of canal wharf heritage. As mentioned by Maria J. Andrade, port-city interface is a mediation space with a dynamic and changing character throughout history (Andrade et al. 2024). Additionally, while the San Jing Industrial Park is relatively recent, one of its factory buildings has been successfully transformed into a fashion brand store, generating significant social impact and demonstrating exemplary effects (Zhuang, Wang, and Deng 2018). This transformation has established a strong foundation for overall revitalization by attracting visitor flow and building a reputation. Similar situations have also been confirmed in international cases. Germany's Heritable Building Lease enables ordinary, non-protected industrial sites to be reused by civic groups for community-oriented contemporary functions, integrating them into everyday urban life (Kip and Oevermann 2022). Taken together, these cases show that non-designated industrial sites, despite modest heritage value, can become daily civic assets and catalysts for broader urban regeneration.

Despite growing awareness of the cultural and socio-economic value these sites contribute, the regulatory focus largely neglects the adaptive reuse and conservation of industrial heritage landscapes (Mukherjee and Banerji 2025). This has led to a situation where the authenticity of cultural heritage and the spirit of place have given way to the demand for land appreciation when capital-driven spatial production dominates heritage regeneration. On the contrary, the successful regeneration of heritage considered to be of low value reveals that bottom-up governance paths can also activate heritage values through incremental renewal. Therefore, the key to adaptive reuse of heritage should lie in the establishment of a dynamic heritage assessment system that breaks through the simple correspondence between the level of heritage protection and reuse potential. The most successful adaptive reuse projects are those that retain a building's heritage significance as well as add a contemporary layer that provides value for the future (Samadzadehyazdi et al. 2020).

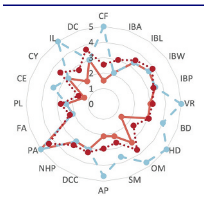
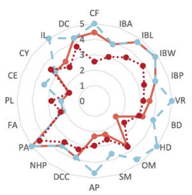
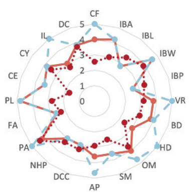
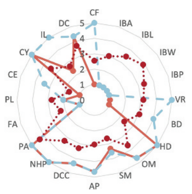
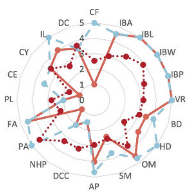
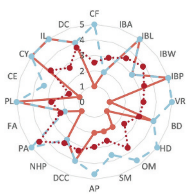
In summary, prioritizing structural adaptability, cultural value, and long-term sustainability over profit-driven redevelopment models is essential (Savoie, Sapinski, and Laroche 2025). While the question of what factors can be used to assess the success of heritage adaptive reuse projects remains a subject of debate with no definitive answer, projects that consider the integrity and original value of the heritage site, add valuable contemporary elements for future generations, and respect and preserve the heritage significance of the building are increasingly seen as the most successful examples of heritage adaptive reuse (Vafaie, Remøy, and Gruis 2023).

4.2. Targeted adaptive reuse for different potential of each type

Given the instability and contradictions between society and nature in industrial heritage regeneration, it is necessary to develop differentiated adaptive reuse strategies (Bartolini and DeSilvey 2020). For the unbalanced development type with significant locational advantages but historical and cultural shortcomings, historical and cultural IP can be introduced to drive the transformation of locational value. For the synergistic development type, where spatial potential is superior but other potentials are not prominent, its low rents and weak government control help provide creative space for individual artists (Zielke and Waibel 2014). Exemplary leading types with comprehensive strengths can build a brand matrix to achieve a demonstration effect. Canal industrial integration type needs to combine the strengths of artifacts (Geijo et al. 2022) and industrial landscapes to be further integrated into everyday life. Functional continuity type focuses on living heritage, realizing the continuation of industrial genes while maintaining production functions. To-be-developed type requires the establishment of a dynamic repair pathway through systematic assessment to activate and bridge multidimensional potential faults in a staged manner (Table 8).

Adaptive reuse is one of the main strategies to help industrial heritage relics develop an additional use when they are left abandoned and in danger of destruction (Samadzadehyazdi et al. 2020). This strategy, on one hand, helps identify priorities and urgency for heritage conservation, enabling governments to allocate resources effectively. On the other hand, it assists governments in developing different categories of heritage protection lists, thereby formulating targeted conservation measures and policies. The essence of adaptive reuse is a shift from static preservation to dynamic adaptation, requiring the creation of a common communication interface that connects different stakeholder groups to coordinate the relationship between conservation and transformation (Della Lucia and Pashkevich 2023). The adaptive reuse potential assessment provides dual-track support for heritage governance from policies to grassroots participation, which not only optimizes resource allocation but also stimulates social governance. At the policy and management level, the evaluation system provides basic decision support for the process of allocating public funds for heritage reuse (Cucco et al. 2023). At the participatory level, this system

Table 8. Characteristics, adaptive reuse aims, and strategies of the 6 industrial heritage types.

	Type	Characteristic	Aim	Strategy
	Unbalanced Development Type	High locational potential Medium spatial and operational potential Low cultural and historical potential	Strengthen cultural and historical aspects	Leverage location advantages to promote cultural dissemination and explore historical value
	Synergistic Development Type	High spatial potential Medium other potentials	Elevate from balanced medium to excellent level	Utilize spatial advantages to promote functional integration and innovation
	Exemplary Leading Type	High cultural, operational, and historical potential Medium spatial and location potential	Maintain strengths while enhancing weaker aspects	Establish brand effect, optimize spatial design, improve location connectivity
	Canal-Industry Integration Type	High historical, operational, cultural, and location potential Low spatial potential	Maximize strengths while addressing spatial limitations	Strengthen the advantages of the industrial landscape
	Functional Continuity Type	High spatial, historical, and cultural potential Low operational and locational potential	Maintain production and preserve cultural heritage	Preserving functional characteristics and inheriting industrial culture
	To Be Developed Type	Large disparities among all indicators	Systematically activate all potential aspects	Assess potential positioning, implement phased renovation and enhancement

Type score   Average score   Max score

Note: Max scores of types are different because some indicators such as industrial building width, construction year are intrinsic properties and cannot be changed.

helps identify high-potential but under-appreciated heritage sites, mobilizing participation, self-organization, and temporary use, thereby revitalizing underused spaces and strengthening local resilience (Fava 2022).

5. Conclusion

This study provides a data-driven analytical framework for the reuse potential of industrial heritage. Taking Changzhou's industrial heritage as an example, the reliability and usability of the proposed methodology are verified, and the following conclusions are drawn:

- Correlation Analysis reveals the relationship network of potential indicators. The cultural potential builds public awareness through multi-media synergy, the spatial potential is reflected in the structural consistency of building scale and layout, and the locational potential is manifested in the differentiated value distribution of heritage between the central and suburban areas.
- Factor Analysis deconstructs the driving kernel of multidimensional potential. This method reduces the dimensionality of potential indicators, identifying five key dimensions of reuse: spatial potential, cultural potential, locational potential, operational potential, and historical potential.
- GIS spatial analysis demonstrates the regional differentiation of potential. The contrast between the distribution of spatial and historical potential reflects the evolution of industrial development from the urban center to the periphery.
- Hierarchical Cluster Analysis constructs the decision-making basis for typology governance. Based on the scores of 28 industrial heritage sites on five factors, the method classifies them into six categories, including unbalanced development type, synergistic development type, exemplary leading type, canal industrial type, functional continuity type, and to-be-developed type.

The potential for adaptive reuse of industrial heritage reflects the dynamic needs of heritage governance. The break between institutional constraints and implementation failures in some of the high-protection heritage has led to the suppression of its historical and cultural potential. In contrast, some low-protection heritage sites have unlocked their spatial potential through functional remodeling. This reflects the original building's layouts, the history behind that, the architecture of the old and new parts, the socio-cultural impacts of reuse and the economic justification and financial benefits play vital roles in the success of adaptive reuse projects (Vafaie, Remøy, and Gruis 2023). Therefore, effective regeneration strategies require building dual adaptation mechanisms. This requires systematic protection of heritage through top-down institutional strengthening, while bottom-up community empowerment opens up resilient renewal pathways for heritage.

This article also has several limitations. First, the data in this study are mainly from retrieved data and field research data, focusing on empirical measurements related to physical and social attributes, but lacking in qualitative insights such as the level of social impact and the level of production technology, which need to be gained through expert knowledge and stakeholder perspectives. This research lays the foundation through quantitative data such as social media and official media word frequencies, which can be followed up by combining expert judgment, supplementing indicators that are difficult to quantify, and assigning weights to validate quantitative conclusions, leading to a more reliable adaptive reuse potential model. Second, the study is regionally focused on Changzhou as a single city. Although it employs a moderate sample size, the framework is transferable and could be applied to other industrial cities, which means future work can expand the sample and include cross-regional comparisons.

Based on the framework for assessing the adaptive reuse potential of industrial heritage, as more heritage data accumulate, existing models can be continuously optimized and improved, enhancing their accuracy and explanatory power. Methodologically, a consolidated multi-level dataset is assembled and standard analyses are performed. Pearson correlation, factor analysis, GIS mapping, and hierarchical cluster analysis are applied to link indicator patterns with typological governance. In addition, the analytical framework established in this study can serve as a reference for other similar heritage reuse, identifying common characteristics and personalized needs through comparative analysis. Furthermore, industrial heritage is diverse and numerous, and its sustainable adaptive reuse is a catalyst for urban regeneration, so for cities with similar industrial backgrounds and scales, the methodology and empirical findings offer valuable insights that can aid in regional heritage reuse.

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Author contributions

Conceptualization: JZ, NJ
Data curation: JZ

Formal analysis: JZ, NJ, YD
Funding acquisition: NJ
Investigation: JZ
Methodology: JZ, YD
Project administration: NJ
Software: JZ
Resources: JZ, NJ
Supervision: NJ, TC
Validation: JZ
Visualization: JZ
Writing – original draft: JZ
Writing – review & editing: JZ, NJ, YD, TC

Data availability statement

Data can be provided upon request from the corresponding author.

Method statement

This study did not involve human participants; therefore, ethical approval and informed consent are not applicable.

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