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Impact of Art Installation Interventions on the Revitalization of Industrial Heritage Spaces from the Perspective of the Human–Environment Field System: A Case Study of the Zhengzhou Oil and Fat Chemical Factory

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Abstract

In the post-industrial era, art installation interventions have emerged as an important approach to the revitalization of industrial heritage spaces worldwide. However, existing studies on the mechanisms through which art installations influence spatial revitalization and their compatibility with surrounding environments have largely remained focused on the micro-scale design of individual installations, lacking both quantitative empirical evidence and a systematic evaluation framework. From the perspective of the Human–Environment Field System (HEFS), this study develops a systematic installation–space–vitality evaluation framework. Using 52 art installations within the Zhengzhou Oil and Fat Chemical Factory as empirical samples, the study employs a four-quadrant analytical model and multiple regression analysis to systematically investigate the interactive effects of installation attributes and spatial environmental factors on spatial vitality. The objective is to elucidate the mechanisms through which art installations contribute to the revitalization of industrial heritage spaces and to propose differentiated strategies for improving the spatial compatibility of installation interventions. The results indicate that the capacity of art installations to stimulate spatial vitality depends on the synergistic coordination between installations and spatial, with spatial environmental factors exerting a more pronounced influence. Interface richness is the key variable driving the intensity of spatial vitality ($\beta = 0.357$, $p < 0.01$), while the effects of installation typology, volumetric proportion, and facility diversity on spatial vitality are indirectly mediated through their synergistic interactions. Based on the four-quadrant classification, the study further proposes differentiated spatial adaptation guidelines for thematic landmark installations, narrative structural installations, and artistic decorative installations. This study establishes a quantitative explanatory framework, grounded in the HEFS perspective, for understanding how the coupling between art installations and spatial environmental conditions shapes spatial vitality. The findings provide both a theoretical foundation and practical guidance for evidence-based decision-making regarding art installation interventions and for enhancing spatial quality in the revitalization of industrial heritage spaces.

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Keywords: art installation; industrial heritage; human–environment field system; spatial vitality; art installation interventions

1. Introduction

Industrial heritage constitutes an integral component of cultural heritage, embodying the industrial memory and cultural identity of cities. The *Nizhny Tagil Charter* explicitly states that assigning new functions to industrial heritage represents a viable means of ensuring its continued survival [1]. Within the context of urban regeneration in the post-industrial era, how to revitalize dormant industrial heritage by endowing it with new forms of public life has become a central issue in urban regeneration [2]. Among the various revitalization approaches, art has increasingly been recognized as a powerful catalyst for the adaptive reuse of industrial heritage. Owing to their flexible modes of spatial intervention and their capacity to create engaging public experiences, art installations have been widely incorporated into industrial heritage sites, serving as a medium that reconnects industrial history with contemporary audiences [3,4]. Despite their widespread application, fundamental questions remain unresolved. What spatial relationships are established among outdoor industrial heritage spaces, preserved industrial facilities, and art installations? Why do some installation locations consistently attract large numbers of visitors and become popular destinations for photography and social media engagement, whereas other carefully designed artworks receive comparatively little public attention? Such pronounced disparities in spatial vitality suggest a critical yet often overlooked reality: the effectiveness of art installations in activating industrial heritage spaces is not determined solely by their intrinsic artistic qualities, but rather by the degree of compatibility and synergy between the installations and their surrounding spatial environments [5]. This raises several important questions: Does an underlying principle govern the spatial compatibility between art installations and industrial heritage environments? How should installations be configured under different spatial conditions to maximize spatial vitality? Addressing these questions has become a pressing issue in the adaptive reuse of industrial heritage. However, existing research has yet to provide a systematic quantitative explanation of these relationships.

To address these questions, it is first necessary to clarify the intrinsic attributes of art installations in the context of industrial heritage and the logic underlying their interventions. Art installations do not serve as the catalyst that initiates industrial heritage renewal; rather, they are spatial activation media inserted after the completion of infrastructure upgrades and the introduction of operational programs [6]. Their core function lies in transforming industrial history into a spatial narrative perceptible to the public and, through low-intervention, highly interactive approaches, infusing cultural connotations and social dynamics into spaces that have already undergone physical renewal, thereby fostering the re-establishment of place identity and the ongoing revitalization of spatial vitality [7]. Compared with other revitalization approaches, such as building renewal, landscape transformation, and functional replacement, the intervention of art installations in industrial heritage spaces is characterized by three distinctive features. First, low intervention [8]. Building renovation often involves irreversible physical interventions, such as structural reinforcement and spatial reconfiguration, whereas art installations are typically introduced into industrial heritage spaces as freestanding structures, wall-mounted elements, or temporary constructions, causing minimal physical disturbance to the heritage fabric and making them an ideal tool for micro-renewal. At the same time, operators can flexibly adjust the layout based on feedback on actual use, thereby avoiding the trial-

and-error costs associated with large-scale building renovation. Second, strong narrative capacity [9]. The core value of industrial heritage lies not only in its buildings and machinery but also in the urban memory and production culture embodied therein. In contrast to commercial functions that may weaken the historical context of a site, art installations can translate abstract industrial history into spatial narratives that are perceptible to the public through techniques such as material references and formal metaphors. Third, high potential for behavioral activation [10]. Through visual attraction and interactive design, art installations can directly encourage public activities such as staying, conversation, and social media sharing, transforming industrial heritage from an object of preservation into a place for active use. It is precisely this combination of low intervention, strong narrative capacity, and high behavioral activation potential that distinguishes art installations from other revitalization approaches and makes them a key medium for connecting industrial history with contemporary publics. However, art installations are not isolated aesthetic objects; rather, they function as important mediators in the revitalization of industrial heritage spaces, and their spatial activation effects are highly dependent on their synergistic fit with the surrounding spatial environment. Therefore, their role needs to be understood from a systemic installation–space–human perspective.

To characterize the relationships within the installation–space–human system and to elucidate the interaction mechanisms between art installations and industrial heritage spaces, this study introduces the HEFS as its theoretical foundation. The HEFS was proposed by Professor Liu Binyi of the College of Architecture and Urban Planning, Tongji University, and its theoretical origins can be traced to two important lines of development within human settlement theory [11]. The first traces the development from Doxiadis's theory of Ekistics to Wu Liangyong's human settlement science [12,13]. The second extends from Feng Jizhong's theory of the field concept to the "science + philosophy" advancement embodied in the triadic theory of human settlements [14]. Building on these theoretical foundations and more than four decades of research on human settlements, Liu proposed the HEFS with the aim of identifying the constituent elements underlying human settlement environments and exploring the laws governing the interactions and quantifiable relationships between humans and nature. The core proposition of this theory is that the human settlement environment is not a static physical container but a dynamic coupled system composed of three heterogeneous yet isomorphic field systems—the environment–field system, the human–field system, and the human settlement–field system—which are constituted through the flows and transitions of energy, information, and spatiotemporal elements [15] (Figure 1). Specifically, the environment field system refers to the objective material basis of the human settlement environment, through which nature provides the energy, information, and material resources necessary for human survival. In this study, it corresponds to the physical environmental elements of industrial heritage sites, including spatial form, building interfaces, and infrastructure. The human field system refers to individuals' subjective perception and cognition of the environment, encompassing their perception, understanding, and responses to their living environment. In this study, it is manifested in the public's visual perception, aesthetic evaluation, and behavioral responses to art installations. The human settlement field system represents the integration of the former two, encompassing the human settlement context, activities, and built environment jointly shaped by nature and social groups. In this study, it corresponds to the settings for public life and social interaction that emerge within industrial heritage spaces following the intervention of art installations.

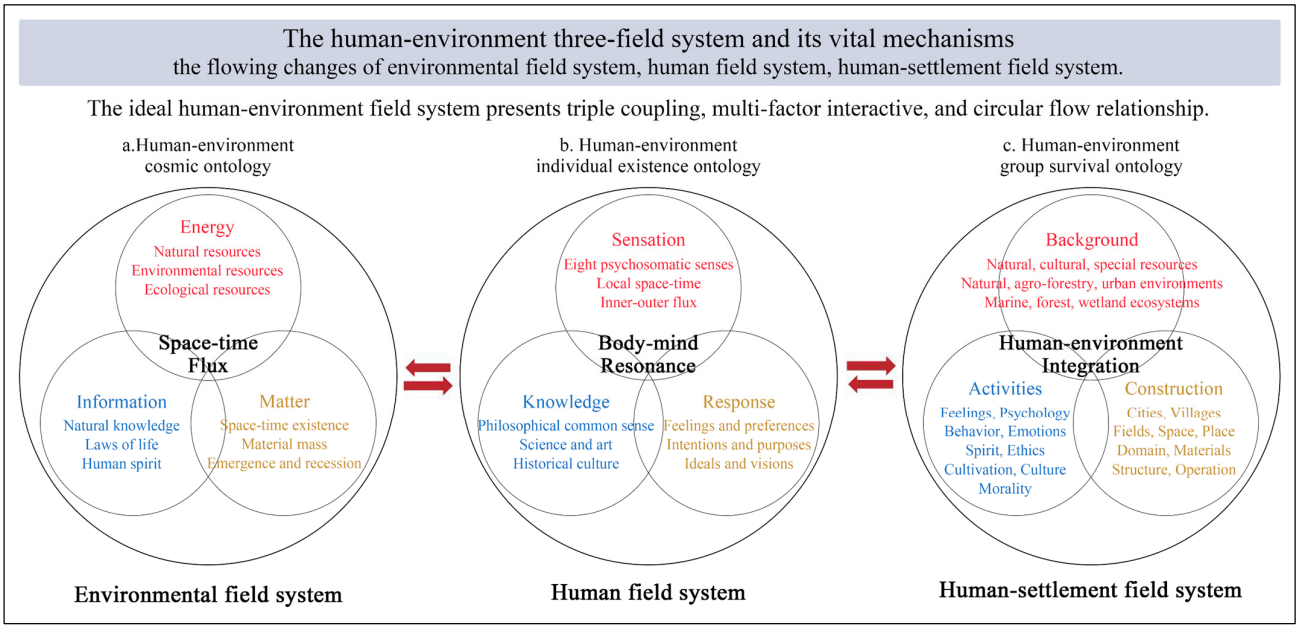


Figure 1. The human–environment field system. Translated and redrawn from [11].

The three field systems are not static and independent entities; rather, they are dynamically coupled through a circulatory transition mechanism, thereby establishing a ternary coupling relationship within the human settlement environment [16]. The circulation between the human field system and the environment field system involves interactions among energy, information, and matter on the one hand and perception, cognition, and response on the other. This interaction generates individual human–environment aesthetic experience, which is progressively internalized and externalized as a sense of design, thereby enabling a transition in human-centered qualities. The circulation between the human field system and the human settlement field system essentially represents the flow between individual and collective human–environment experiences [11]. The human settlement field system serves both as the driving force and the outcome of this interaction. As individual, relatively independent human–environment experiences develop into collective human–environment experiences, collective human–environment cognition emerges, generating a sense of meaning in the human–environment relationship that is more fundamental than aesthetic experience and thereby facilitating a transition from human–environment aesthetics to human–environment meaning [17]. Contemporary approaches to human settlement design, such as community gardens and place-making through spatial scenarios, essentially use the human settlement–field system as a medium to facilitate the interactive integration of individual and collective human–environment field systems, thereby fostering individuals' senses of security, fulfillment, and well-being through the creation of human settlement environments.

The industrial transformation of the post-industrial era disrupted the original equilibrium of the Human–Environment Field System within factories. The cessation of industrial production led to the erosion of the environment field system as a functional basis for human survival, while the relocation of the workforce resulted in the departure of the perceptual subjects constituting the human field system. Consequently, the structural relationships among the three field systems were progressively dismantled, leaving factories as physical shells in which the material framework remained but social vitality and the spirit of place had been lost [18]. In the context of urban regeneration through the adaptive reuse of existing assets, the intervention of art installations serves as a medium for reconstructing the human field system and environment field system. Through spatial nar-

ratives and functional reconfiguration, art installations introduce new anchors of meaning into industrial heritage spaces (material renewal of the environment field system), restoring and rebuilding emotional resonance and behavioral interactions between the public and industrial heritage (cognitive reconstruction of the human field system), thereby facilitating the continuity of local memory and the regeneration of spatial vitality (revitalization of the human settlement field system) [19,20].

To scientifically assess the effects of art installation interventions on stimulating spatial vitality, a systematic quantitative installation–space–vitality evaluation framework was established based on the theoretical foundations discussed above. The core logic is that the activation effects of art installations on industrial heritage spaces arise neither solely from the artistic qualities of the installations themselves nor independently from the spatial environment, but rather from the synergistic fit between installation attributes and the spatial environment within a specific context (Figure 2). Only by treating art installations as active nodes embedded within the spatial environmental system, while simultaneously considering both their intrinsic characteristics and the environmental attributes of their settings, can the underlying mechanisms of vitality generation be effectively revealed. Accordingly, this study translates the Human–Environment Field System into an empirically testable evaluation model. The environmental information and material provision conditions described by the environment–field system correspond to the spatial environment dimension; the individual perceptual and behavioral triggering conditions described by the human–field system correspond to the art installation dimension; and the human–environment coupling outcomes represented by the human settlement–field system are quantitatively measured through spatial vitality intensity.

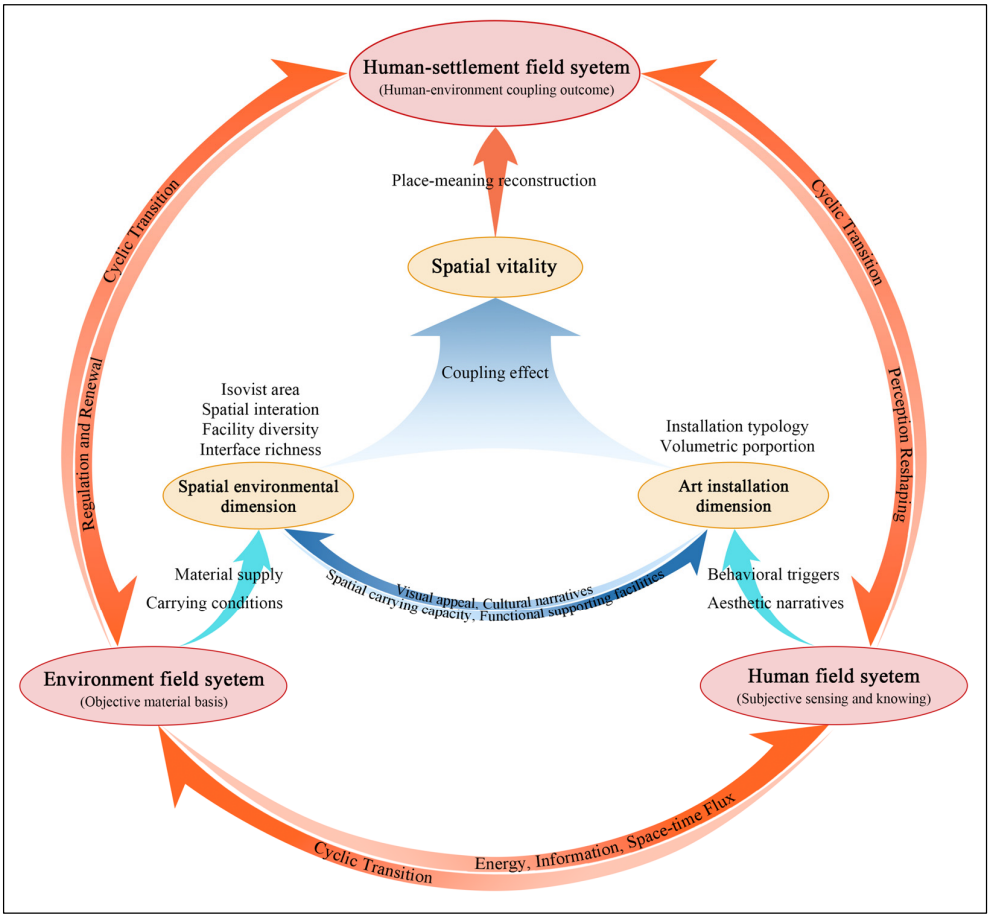


Figure 2. Theoretical framework.

Art installations are a three-dimensional art form that emphasizes immersive audience engagement and dialogue with space. Owing to their capacity for spatial intervention and experiential expression, they have increasingly become an important approach to the revitalization of industrial heritage spaces [21]. Existing studies on the application of art installations in industrial heritage regeneration have primarily focused on four aspects. First, the material characteristics of art installations. Research has focused on the formal language, material selection, and scale of art installations, examining how elements such as form, material, scale, and color respond to the historical context of industrial heritage sites and integrate aesthetic value with historical heritage [22]. Second, the relationship between art installations and the spatial environment. Studies have examined how art installations are embedded within the physical spatial structure of a site and establish visual dialogues and functional connections with spatial elements such as industrial buildings and machinery, as well as how on-site placement can be used to construct spatial narrative paths [23]. Third, the interaction between art installations and public behavior. From the perspective of public experience, studies have employed questionnaires, interviews, and other methods to document behavioral characteristics triggered by art installations, such as staying, photography, and interaction, and to examine how art installations influence the depth of behavioral interaction among the public [24]. Fourth, cultural translation and the reshaping of the spirit of place. Research has focused on the cultural translation function of art installations in the contemporary revitalization of industrial memory, examining how installations transform historical information related to industrial production into symbolic languages perceptible to the public and thereby reconstruct the cultural identity of a place [25,26].

A common characteristic of these studies is that they typically take an individual art installation or a single industrial heritage project as the unit of analysis, with a primary focus on design concepts and cultural expression. Most adopt qualitative descriptions or design-oriented analyses to interpret the symbolic meanings and aesthetic values of art installations [27]. However, industrial heritage sites generally comprise factory buildings, outdoor spaces, machinery, and complex circulation networks. Art installations do not exist in isolation; rather, they function as important mediators that interact systematically with spatial structures, pedestrian flows, surrounding functions, and other site-specific factors [28,29]. Research examining the overall relationship between art installations and industrial heritage spaces remains limited. In particular, the material attributes of the spatial environment have rarely been incorporated into analytical models, and the interactive relationship between art installations and spatial environments has yet to be systematically revealed. Although a small number of studies have begun to explore the interactions between art installations and public behavior, as well as the adaptability and transformability of installations [30], these investigations remain largely confined to the domain of experiential design and lack quantitative assessments of how art installation interventions influence the spatial vitality of industrial heritage sites. Moreover, existing research has predominantly concentrated on the planning and design phases prior to implementation, with relatively little attention devoted to the long-term post-occupancy performance of completed projects, such as spatial attractiveness, visitor dwell time, and behavioral diversity [31]. Consequently, existing studies provide limited empirical feedback to support subsequent spatial management, operation, and iterative optimization.

From a methodological perspective, existing studies have predominantly relied on qualitative case analyses [32], while a limited number have employed questionnaires or interviews to collect subjective evaluations [33]. However, objective approaches to measuring spatial vitality—such as image-based pedestrian counting and movement trajectory analysis—have rarely been adopted to establish quantitative relationships between

the characteristics of art installations and spatial vitality. Consequently, a systematic evaluation framework capable of integrating installation-related attributes (e.g., scale, interactivity, and materiality), spatial environmental characteristics (e.g., accessibility, interface openness, and functional diversity), and spatial vitality outcomes has yet to be established. This methodological gap limits the ability to quantitatively explain the mechanisms through which art installations influence spatial vitality and hinders the development of evidence-based strategies to support planning and design decision-making.

Based on the theoretical framework of the HEFS and responding to contemporary trends in the conservation and adaptive reuse of industrial heritage, this study translates the theory into an empirically testable, systematic quantitative installation–space–vitality evaluation framework. The framework focuses on the intrinsic attributes of art installations through the art installation dimension and on the spatial carrying conditions of the industrial heritage site in which the art installations are situated through the spatial environment dimension, thereby establishing a two-dimensional evaluation model encompassing the human field system and the environment field system. Spatial vitality intensity is used as the outcome variable representing the coupling between the two dimensions. Taking the Zhengzhou Oil and Fat Chemical Factory and its 52 distributed art installations as an empirical case, this study systematically investigates the mechanisms through which installation-related attributes and spatial environmental factors influence the vitality of industrial heritage spaces. By integrating field survey data with multiple regression modeling, the study quantitatively examines the relationships between the dual-dimensional factors and spatial vitality intensity, identifying the key drivers and synergistic patterns underlying vitality generation. The study aims to address the limitations of existing research in examining the relationship between art installations at the micro scale and the vitality of industrial heritage spaces. It provides theoretical support and practical design guidance for the refined enhancement of spatial quality within the context of adaptive reuse, thereby contributing to the sustainable revitalization of industrial heritage and the high-quality development of human-centered urban public spaces.

2. Materials and Methods

2.1. Study Area and Object

The Zhengzhou Oil and Fat Chemical Factory is located at No. 68 Huanghe Road, Jinshui District, Zhengzhou City (Figure 3). The industrial complex covers an area of approximately 80,000 m^2, with a total floor area of about 37,000 m^2. It has retained 28 Soviet-style industrial buildings in their entirety, 12 of which have been officially designated as historic buildings in Zhengzhou.

The plant was founded in 1952 and commenced production in 1954, gaining renown for its Zhongzhou brand soap [34]. After the 1960s, through technological upgrades and joint ventures, it grew into the largest production base for washing products and soybean protein in Henan Province. From the 2000s onward, its operations declined due to management difficulties, and in 2007, the plant's land and machinery were auctioned off. In 2015, with policy support from the Zhengzhou municipal government, the redevelopment of the old plant site obtained planning approval, with the intention of transforming it into a cultural and creative industrial park. The project was officially launched in 2019 under the model of "government guidance, enterprise participation, and market operation." The renovation preserved the Soviet-style building complex, chimneys, water towers, storage tanks, and other industrial relics intact. After three years of transformation, the old factory site was reborn as a national-level tourist and leisure district, and by 2021 it had attracted more than 30 cultural and creative enterprises.

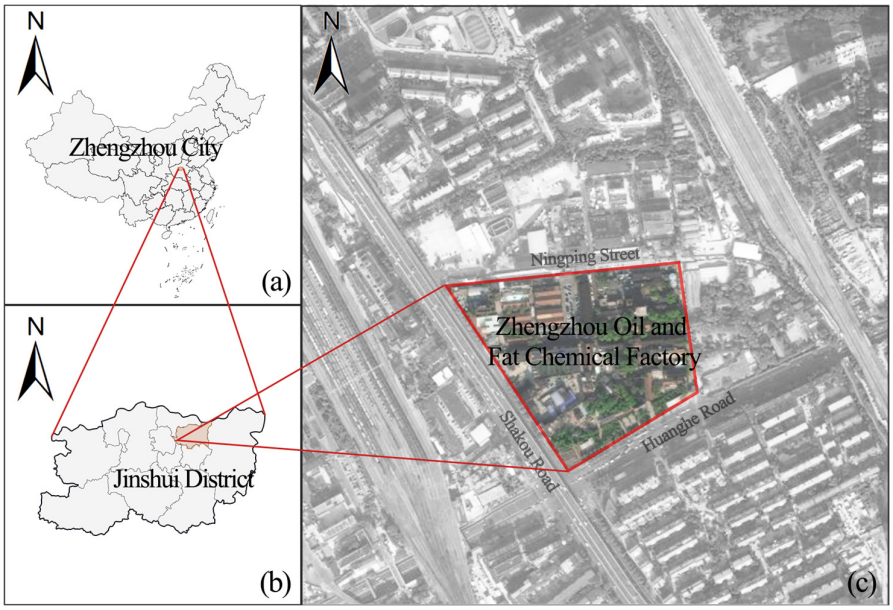


Figure 3. Study area. (**a**) China. (**b**) Zhengzhou City. (**c**) Zhengzhou Oil and Fat Chemical Factory.

Subsequently, the park entered an operational enhancement phase focused on functional infilling and scene construction. By 2026, it had become a new cultural landmark in Zhengzhou, hosting over 230 shops and receiving more than 250,000 visitors on holidays. During this period, on the basis of the existing building renovations, the park converted industrial spaces such as warehouses and production lines into cultural venues like art centers and museums, and systematically introduced art installations as a key means of spatial activation. Art installations were deployed as tools for improving spatial quality, serving to reinforce the genius loci, construct industrial narratives, and encourage public engagement and interaction. At the same time, tenant shops also use art installations to beautify their storefront spaces and as eye-catching signage to attract customers.

At present, the factory has been transformed into a mixed-use district integrating cultural, commercial, and leisure entertainment, serving as a representative example of the adaptive reuse of industrial heritage in Zhengzhou.

Zhengzhou Oil and Fat Chemical Plant represents a type of light industrial heritage, with factory buildings and equipment that are considerably smaller in scale than those found in heavy industrial heritage sites such as power plants and steelworks. The clear spans of the outdoor plazas, streets, and passageways within the site fall between those of conventional urban public spaces and large-scale industrial buildings. The largest open space, Shuiyue Plaza, has a span of approximately 25 m, while the clear heights of the outdoor passageways are generally between 4 and 12 m. Accordingly, all art installations examined in this study are structures embedded within outdoor or semi-outdoor public spaces. Furthermore, all art installations included in the sample are fixed or permanent exhibits established to meet the long-term operational needs of the site, ensuring that the measurement of spatial vitality intensity reflects stable spatial effects rather than temporary concentrations of activity associated with specific events.

Based on the above criteria, 52 art installations within the site were selected as the study objects (Figure 4). The specific installations are listed in Appendix A. Most of them are located at site entrances, plazas, and along major roads, with high-density clusters primarily concentrated around Shuiyue Plaza and along both sides of the two main streets. These installations not only function as visual focal points in themselves but also influence the overall spatial vitality through their interactions with industrial spaces, architectural interfaces, and the surrounding environment. Therefore, they provide valuable observa-

tion samples for investigating the mechanisms of spatial transformation and revitalization in industrial heritage sites.

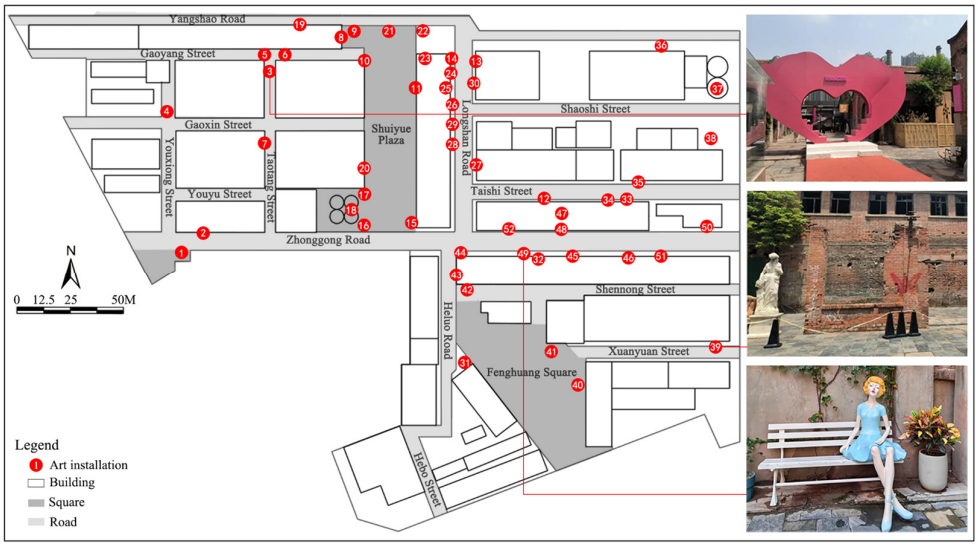


Figure 4. Study objects.

2.2. Study Framework

Taking art installations within industrial heritage adaptive reuse spaces as the research entry point, this study develops a systematic quantitative installation–space–vitality evaluation framework. The framework systematically examines the mechanisms through which the intrinsic properties of art installations and spatial environmental factors are associated with interactive vitality intensity. Following the logical sequence of theoretical framework construction–data acquisition–data analysis–strategy formulation, with the specific workflow illustrated in Figure 5.

2.3. Art Installation Evaluation Model

2.3.1. Model Development

Within the context of adaptive reuse of industrial heritage, art installations should not be regarded as isolated aesthetic objects, but rather as mediating elements that connect industrial historical spaces with contemporary public perceptions [35]. To scientifically evaluate the capacity of art installations to stimulate spatial vitality, this study conducted a systematic literature review to examine and integrate existing scholarly findings in the fields of urban public art, industrial heritage revitalization, and spatial vitality. Based on the HEFS theory, six core evaluation indicators were selected from two dimensions: art installation attributes and spatial environmental characteristics. Accordingly, a dual-dimensional coupling evaluation framework for art installations within the context of industrial heritage adaptive reuse was established. The construction of the indicator system follows the principles of systematicity, quantifiability, and data availability, aiming to objectively reveal the intrinsic relationship between artistic interventions and the spatial regeneration of industrial heritage environments.

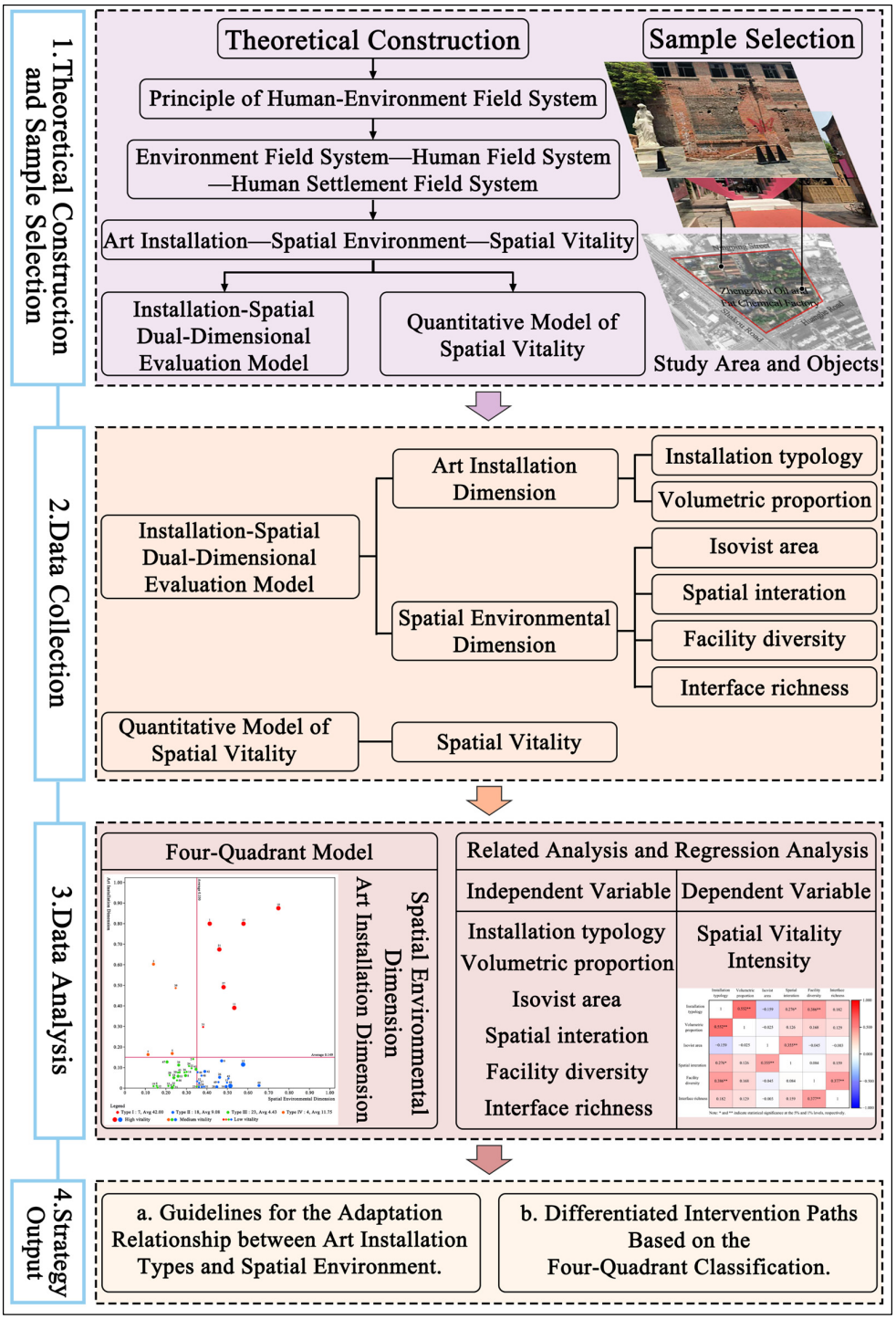


Figure 5. Study framework.

The art installation dimension focuses on the physical form and cultural expression of installations, quantifying their comprehensive capacity as visual focal points, information carriers, and catalysts for place-based narratives [36]. Art installation typology reflects the inherent attributes of installations in stimulating public engagement potential [37]. Different types of installations (e.g., static sculptures, dynamic mechanical installations, and digital interactive media) vary in their ability to attract public attention and encourage participation. Within the context of industrial heritage, installations that incorporate interactive features or respond to industrial memories tend to generate stronger emotional resonance with the place. Within the context of industrial heritage, drawing on classification ap-

proaches in the field of public art that categorize works according to their social functions and expressive characteristics, the 52 art installations were classified into three types based on three dimensions: spatial role, narrative level, and functional positioning [38]. The specific judgment criteria are shown in Table 1. Thematic landmark installations are characterized by strong visual impact and highly condensed symbolic languages that encapsulate the overall image of the site, serving as cultural symbols and landmark destinations for visitors. Narrative structural installations convey specific urban memories, industrial production processes, or the passage of time through scene construction or the juxtaposition of symbols, and possess clear commemorative significance for the site. Artistic decorative installations primarily serve to enhance the environment, create a distinctive spatial atmosphere, improve public leisure experiences, enrich the visual layering of streets and lanes, and provide opportunities for interaction and play. Volumetric proportion reflects the physical presence of art installations within industrial heritage spaces [39]. Industrial heritage sites are typically characterized by large-scale spatial structures, extensive spans, and high ceilings. When the scale of an installation is incompatible with the surrounding spatial context, it may result in visual imbalance or a sense of spatial oppression. Appropriate volumetric proportions therefore provide a fundamental basis for establishing spatial order and visual harmony.

Table 1. Classification criteria for art installation types.

Installation Typology	Determination Principles
Thematic landmark installations	Located at global spatial nodes (entrances, core plazas); primarily freestanding three-dimensional structures with significant massing and strong visual dominance; conveys the overall image of the park through highly condensed symbolic language; positioned as "destination-type" attractions, serving the function of place identity recognition.
Narrative structural installations	Spatially co-located and thematically bound to specific industrial remains (production equipment, sites of historical events, original functional spaces); the installation itself or its associated industrial elements (e.g., red-brick walls of old factory buildings, machine components, heritage structures) carry identifiable historical information; possesses a readable narrative structure, telling particular industrial memories or the passage of time through scene reconstruction or symbolic juxtaposition.
Artistic decorative installations	Distributed in general public spaces such as streets, commercial frontages, and corners; primary functions are visual beautification, atmosphere creation, or micro-interactions (e.g., storefront visual merchandising, graffiti, playful sculptures, colored stairs); lacks unique thematic identity or strong binding to specific industrial memories; is attached to commercial facilities and serves merely as embellishment to enrich street vitality.

The spatial environment dimension focuses on the characteristics of the industrial heritage site environment in which art installations are embedded, quantifying the capacity of spatial contexts to accommodate artistic interventions and generate social attractiveness [40]. Isovist area refers to the unobstructed area visible from the location of an art installation when looking outward in all directions, reflecting the visual openness of the space [41]. Isovist area directly determines the probability that an installation will be visually noticed by the public: a larger area indicates that the installation can be seen from greater distances and across a wider range of viewing angles, resulting in stronger visual dominance and greater spatial legibility. Spatial interation is a core indicator in space syntax theory for measuring the accessibility of a space within the overall topological network [42]. It represents the aggregate shortest topological distance from a given space

to all other spaces; a higher value indicates greater potential for movement through the space within the overall spatial structure, making it more likely to function as a key node along pedestrian routes. Facility diversity refers to the variety of public service facilities located around art installations [43]. Single-function spaces often struggle to sustain continuous vitality throughout the day, whereas mixed arrangements of commercial, recreational, and service facilities can extend visitor dwell time and generate synergistic effects. Interface richness refers to the degree of visual integration and contextual information density between art installations and the surrounding industrial heritage interfaces, such as red-brick walls, steel structures, and pipeline components [44]. The façades, ground surfaces, and preserved industrial elements of heritage sites constitute distinctive spatial textures. When installations establish material correspondence, color coordination, or formal dialogue with these existing interfaces, they can enhance the narrative quality of the place and strengthen their attractiveness as destinations for visitor engagement and photography.

The six indicators collectively constitute a comprehensive evaluation system for assessing the adaptability of art installations within industrial heritage spaces. The specific definitions and quantification methods of each indicator are presented in Table 2. The art installation dimension characterizes the mediating attributes and integration capacity of installations by examining their intrinsic properties and visual relationships with site interfaces. The spatial environment dimension evaluates the environmental carrying capacity and locational advantages based on the characteristics of the surrounding spatial context. Together, these two dimensions establish a comprehensive indicator system within the installation–space coupling framework, providing a systematic data foundation for subsequent correlation analysis and the application of the four-quadrant model.

Table 2. Definitions and quantification methods of evaluation indicators.

Dimension	Indicator	Definition	Formula	Quantification Methods
Art installation dimension	Installation typology	Reflects the spatial role, narrative function, and cultural significance of art installations in industrial heritage regeneration. Scores are assigned according to the contribution of each installation to anchoring the spirit of place and conveying the industrial heritage narrative, with higher contributions receiving higher scores.	--	Thematic landmark installations are assigned a value of 3; narrative structural installations are assigned a value of 2; artistic decorative installations are assigned a value of 1.
	Volumetric proportion	Represents the ratio between the bounding-box volume of an art installation and the net spatial volume of its surrounding environment, reflecting the physical presence of the installation within the space.	$R_v = R_{art} / R_{space}$	R_{art} represents the bounding-box volume of the art installation, and R_{space} represents the net volume of the surrounding space.

Table 2. *Cont.*

Dimension	Indicator	Definition	Formula	Quantification Methods
Spatial Environment dimension	Isovist area	The unobstructed area visible from the location of the art installation when looking in all directions (m^2), reflecting the visual openness of the space.	--	A two-dimensional plan model of the site was established in Depthmap (Depthmap X v0.8.0 Space Syntax Laboratory, ULC, London, UK), with each art installation location designated as the viewpoint to generate an isovist polygon, from which the isovist area was calculated.
	Spatial interation	The accessibility of the space occupied by the art installation within the site's axial-line topological network.	$I_i = \frac{n\left[log_2\left(\frac{n}{3}\right)-1\right]+1}{TD_i-n+1}$	n represents the number of art installations, and TD_i represents the total topological depth of the i-th art installation.
	Facility diversity	Represents the richness of public service facilities within a 40 m buffer zone surrounding the art installation.	--	Calculated by counting the number of public service facilities within a 40 m buffer zone around each art installation.
	Interface richness	Represents the degree of visual integration and contextual information density between art installations and industrial heritage interfaces.	--	$\leq$2 material types, monochromatic, with no visible industrial heritage elements, scored as 1; 2–3 material/color types, with occasional traces of industrial heritage, and a visually flat structure, scored as 2; 3–4 material/color types, with 1–2 types of industrial heritage elements and a discernible spatial hierarchy, scored as 3; 4–5 material/color types, with $\geq$2 types of industrial heritage elements and a clear visual hierarchy, scored as 4; 5–6 material/color types, with $\geq$3 types of industrial heritage elements and a pronounced dialogue between the installation and surrounding interfaces, scored as 5; $\geq$6 material/color types, with $\geq$4 types of industrial heritage elements and deep interaction between the installation and industrial heritage elements, scored as 6.

2.3.2. Evaluation Calculation Model

To compare the quantitative characteristics of art installations and spatial environments, this study develops a dual-dimensional evaluation calculation model. The model separately calculates the scores of installation attributes and spatial environmental characteristics. These two scores jointly constitute a comprehensive representation of the spatial attributes of each art installation and are subsequently used to examine the explanatory power of different dimensions on spatial vitality intensity. The rationale for calculating the dual-dimensional scores separately rather than aggregating them into a single composite score is to preserve the independence between installation attributes and spatial environmental attributes [45]. The typology and volumetric proportion of art installations primarily reflect the design intervention characteristics of spatial nodes, whereas spatial openness, centrality, facility diversity, and interface richness mainly represent the supporting conditions provided by the surrounding environment. These two categories of factors may influence spatial vitality through distinct mechanisms.

Because the indicators across the two dimensions differ in both number and measurement scale, the raw data were first subjected to Min–Max normalization to rescale all indicators to the [0, 1] interval. A combined AHP–CRITIC weighting method was then employed [46]. For the AHP procedure, four experts with more than 10 years of professional experience in heritage conservation, urban regeneration, architectural design, and operations management were invited to construct pairwise comparison matrices based on Saaty's 1–9 scale. After consistency testing confirmed that all consistency ratios were below 0.1, the subjective weights were obtained. For the CRITIC procedure, objective weights were calculated from the normalized data based on indicator variability and conflict. For detailed calculation procedures, see the Supplementary Materials (File S1). The final combined weights were derived through multiplicative normalization (Table 3).

Table 3. Results of indicator weight calculation.

Dimension	Indicator	AHP Weight	CRITIC Weight	Integrated Weight
Art installation dimension	Installation typology	0.3958	0.6165	0.50615
	Volumetric proportion	0.6042	0.3835	0.49385
Spatial environment dimension	Isovist area	0.1806	0.2852	0.23290
	Spatial interation	0.3756	0.2419	0.30875
	Facility diversity	0.1906	0.2016	0.19610
	Interface richness	0.2532	0.2713	0.26225

Art installation dimension score

$$A_i = L_i\omega_1 + R_i\omega_1. \quad (1)$$

Spatial environmental dimension score

$$B_i = K_i\omega_3 + Z_i\omega_4 + D_i\omega_5 + I_i\omega_6 \quad (2)$$

where A_i denotes the composite art installation dimension score of installation i, and B_i denotes the composite spatial environmental dimension score associated with installation i. L_i represents the installation typology score, while R_i denotes the volumetric proportion of installation i. ω_1 and ω_2 are the weighting coefficients for installation typology and volumetric proportion, respectively, satisfying $\omega_1 + \omega_2 = 1$. K_i represents the isovist area value, Z_i the spatial interation value, D_i the facility diversity score, and I_i the interface

richness score of installation i. The weighting coefficients corresponding to these four indicators are denoted by ω_3, ω_4, ω_5, and ω_6, respectively, satisfying $\omega_3 + \omega_4 + \omega_5 + \omega_6 = 1$.

2.4. Data Collection and Processing of Spatial Vitality Intensity

The concept of spatial vitality can be traced back to the urban vitality theories of Jane Jacobs and Jan Gehl [47]. Jane Jacobs, starting from urban streets, argued that cities gain vitality through the intertwined process of human activities and living places [48]. Jan Gehl believed that people engage in a series of spontaneous activities in public spaces such as streets and plazas, and that these spontaneous activities are the primary source of urban vitality [49]. Spatial vitality intensity provides the most direct indication of the effectiveness of space utilization and the occurrence of human activities. In this study, spatial vitality is defined as the intensity and frequency of public behaviors—such as staying, viewing, and interacting—triggered by art installation interventions within the outdoor public spaces of industrial heritage sites. It serves as a quantitative representation of the extent to which the social functions and public value of industrial heritage spaces are realized through artistic activation [50]. To effectively capture this latent construct while minimizing potential bias arising from observations at a single point in time, this study adopts the number of stationary visitors within a 10 m buffer zone surrounding each art installation as the primary indicator of spatial vitality. The average number of stationary visitors recorded over a continuous observation period is used to characterize the static attractiveness of each space and its potential to generate vitality. Based on the temporally aggregated results of this indicator, the spatial vitality intensity associated with each art installation was systematically quantified, providing an objective data foundation for the subsequent analyses.

2.4.1. Data Collection for Spatial Vitality Intensity

In *How to Study Public Life*, Jan Gehl and Birgitte Svarre used people's spontaneous stopping, lingering, and social interaction behaviors as quantitative measures of public space vitality, and collected data through methods such as on-site counting and video recording [51]. The Zhengzhou Oil and Fat Chemical Factory was selected as the study area, with the public art installations distributed throughout the site and their surrounding spaces serving as the primary observation objects. A comprehensive dataset covering multiple installation locations and observation periods was established to provide a robust empirical basis for the subsequent assessment of spatial vitality intensity [52]. The research team conducted fixed-point photography and manual counting at the spaces occupied by the 52 art installations within the site, recording the total pedestrian flow and major behavioral types (e.g., viewing, photography, conversation, and resting) within the buffer zones of the art installations. These observations were compiled to generate sample data on the spatial vitality of the areas surrounding the art installations.

2.4.2. Calculation of Spatial Vitality Intensity

To systematically quantify the spatial vitality intensity of industrial heritage spaces containing art installations, this study integrates field observation and image-based survey data to develop a spatial vitality intensity calculation model. The model is designed to quantitatively evaluate the visitor dwell data obtained through on-site observations, thereby generating a comprehensive and measurable indicator of spatial vitality intensity that objectively reflects the effectiveness of art installations in stimulating public activities within industrial heritage spaces [53]. The calculation model is expressed as follows:

$$V_i = \frac{\sum_k^K (n_{ik}\omega_b)}{K} \quad (3)$$

where V_i denotes the spatial vitality intensity of the space associated with the i-th art installation; K represents the total number of observation days; k denotes the k-th observation day; n_{ik} is the number of stationary visitors recorded within the observation area of the i-th art installation on the k-th observation day; and ω_b represents the behavioral activity weighting coefficient, reflecting the relative contribution of different types of visitor activities to spatial vitality.

This study adopts the classification of human activities proposed by Jan Gehl in *Life Between Buildings*, in which human behavior is categorized into necessary activities, optional activities, and social activities [49]. Drawing on statistical observations of visitor activities at the Zhengzhou Oil and Fat Chemical Factory, and combining the AHP with expert judgment, different weighting coefficients were assigned to the three categories of activities: ω_b(necessary) = 0.10, ω_b(optional) = 0.45, and ω_b(social) = 0.45.

3. Results

3.1. Results of the Two-Dimensional Evaluation

3.1.1. Art Installation Dimension

According to the survey data, the 52 art installations within the Oil and Fat Chemical Plant site can be classified into three types based on their functional attributes and cultural themes: 43 artistic decorative installations (82.6%), 5 narrative structural installations (9.7%), and 4 thematic landmark installations (7.7%). The three types exhibit a pronounced gradient in their distribution by number, which is closely associated with the spatial functions they serve. As shown in Figure 6, the art installations are mainly distributed around Shuiyue Square and along both sides of Zhonggong Road and Longshan Road. Specifically, there are 13 installations around Shuiyue Square, 11 along Zhonggong Road, and 9 along Longshan Road. Other art installations are scattered in other areas of the park, such as along roads, in plazas, in open spaces, and on building facades.

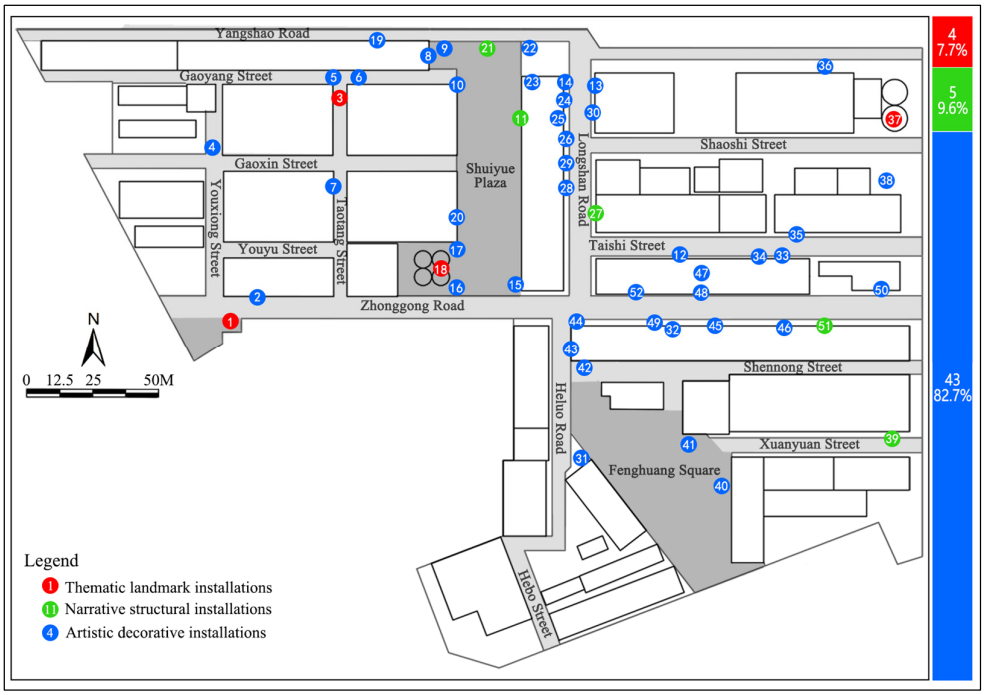


Figure 6. Types and spatial distribution of art installations.

Among the three categories, thematic landmark installations are the least numerous, with only four examples distributed at prominent locations such as site entrances and

plazas. These installations are typically large in scale and characterized by distinctive industrial cultural themes. Their locations are selected to maximize visual accessibility and spatial prominence, enabling them to reach the broadest possible audience while serving to represent and communicate the overall identity of the site.

Narrative structural installations constitute an important component of the spatial narrative network of the industrial heritage site. A total of five such installations were identified, most of which are located at former production circulation nodes and sites associated with significant historical events. These installations are generally small to medium in scale and often incorporate existing machinery, structures, and other industrial elements. By transforming the historical memory of industrial sites into perceptible spatial narratives, they establish connections with the original production equipment and historical events, with their locations emphasizing the contextual relationship with existing industrial facilities and heritage values.

Artistic decorative installations represent the most prevalent category, accounting for 43 of the 52 surveyed installations. They are widely distributed throughout the site, particularly within plaza spaces, commercial spaces and along major circulation routes. These installations exhibit diverse forms, including murals, sculptures, and interactive installations, with flexible scales and a primary emphasis on environmental enhancement and spatial atmosphere creation. They provide visual backgrounds and interface supports for the site, thereby attracting public gatherings, stays, and interactions.

The evaluation results of the volumetric proportion of the 52 art installations are shown in Figure 7.

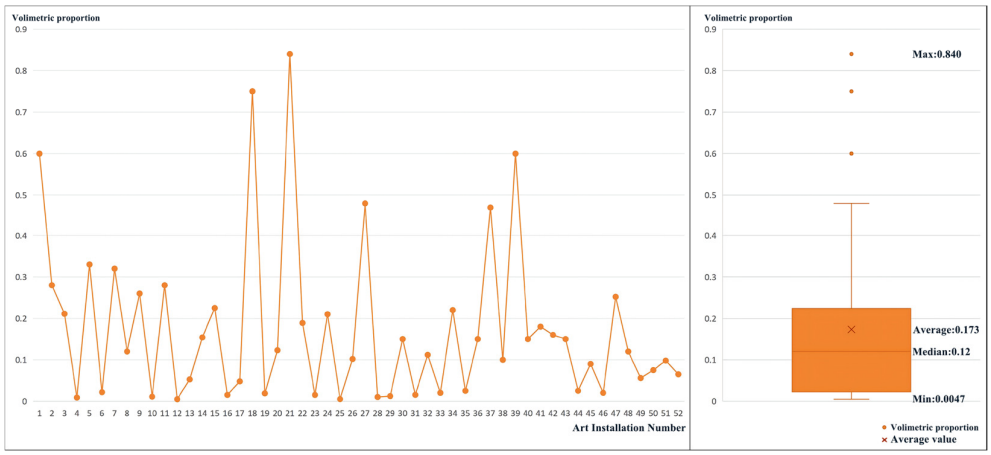


Figure 7. Evaluation results of volumetric proportion of art installations.

The results show that the mean volumetric proportion of art installations in the Oil and Fat Chemical Plant is 0.173, with a maximum value of 0.840 and a minimum value of only 0.0047, indicating substantial variation. The skewness coefficient is 2.03 and the kurtosis coefficient is 4.52, suggesting that the distribution of volumetric proportion exhibits a pronounced positive skewness and leptokurtic characteristics. A total of 46 art installations (88.46%) have volumetric proportions concentrated within a low range of 0.0047–0.3300. Only 6 installations (11.54%) exhibit large-scale characteristics, with volumetric proportions ranging from 0.47 to 0.84. The maximum value of 0.840 is 168 times greater than the minimum value of 0.0047, reflecting substantial differentiation in the physical presence of installations within the spatial environment.

According to the classification by installation typology (Table 4), the three types of art installations exhibit significant differences in volumetric proportion. Thematic landmark installations have the highest mean volumetric proportion (0.540), ranging from 0.211 to

0.750. These installations typically function as core cultural landmarks and visual anchors within the site. Narrative structural installations have the second-highest mean volumetric proportion (0.434), with values ranging from 0.098 to 0.840. Among them, Art Installation No. 21 has a volumetric proportion of 0.840, representing the maximum value of the entire sample. This installation was transformed from an outdoor loading platform, using a large-scale structure to accommodate composite behaviors including viewing, movement through, and staying within the space. Artistic decorative installations demonstrate the lowest mean volumetric proportion (0.109). The volumetric proportions of the 43 installations are concentrated between 0.0047 and 0.330, exhibiting the typical characteristics of being delicate, lightweight, and integrated with surrounding spatial interfaces.

Table 4. Volumetric proportion of different art installation typologies.

Installation Typology	Number	Average	Range
Thematic landmark installations	4 (7.7%)	0.540	0.211–0.750
Narrative structural installations	5 (9.7%)	0.434	0.098–0.840
Artistic decorative installations	43 (82.6%)	0.109	0.0047–0.3300

Based on Equation (1) for calculating the art installation dimension, the scores of the 52 art installations within the Oil and Fat Chemical Plant were calculated, and the results are shown in Figure 8.

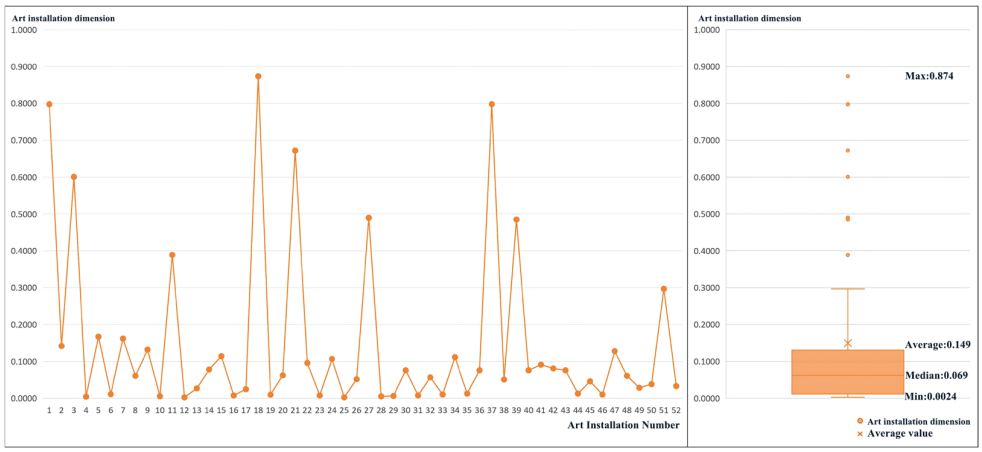


Figure 8. Evaluation results of the art installations dimension.

The results show that the mean score of the art installation dimension for the 52 art installations is 0.149, with a maximum value of 0.874 and a minimum value of 0.0024, indicating substantial variation. The skewness coefficient is 1.98 and the kurtosis coefficient is 3.20, suggesting that the dimension scores exhibit a pronounced positive skewness and leptokurtic distribution. A total of 47 art installations (90.38%) have relatively low dimension scores, ranging from 0.0024 to 0.4899. Only 5 installations (9.62%) achieve high scores, with values ranging from 0.6606 to 0.8735. A total of 11 installations have scores above the mean value, accounting for only 21.2% of the total sample, further confirming the highly concentrated distribution pattern of high scores. The remaining 41 installations (78.8%) fall below the mean, reflecting the structural characteristic that the dimension scores are predominantly concentrated within the lower range.

The maximum score of the art installation dimension is 0.8735, corresponding to Art Installation No. 18 (thematic landmark installations, volumetric proportion = 0.750). Located in the core plaza of the site, this installation combines the highest typological level with substantial spatial dominance, representing the art installation with the most comprehensive qualities within the site. The minimum score is 0.0024, corresponding to Art

Installation No. 12 (artistic decorative installations, volumetric proportion = 0.0047), which is located within the commercial interface space of Taishi Street and is embedded into the industrial building interface through an extremely lightweight approach.

3.1.2. Spatial Environment Dimension

The evaluation results of the isovist area of the 52 art installations are shown in Figure 9.

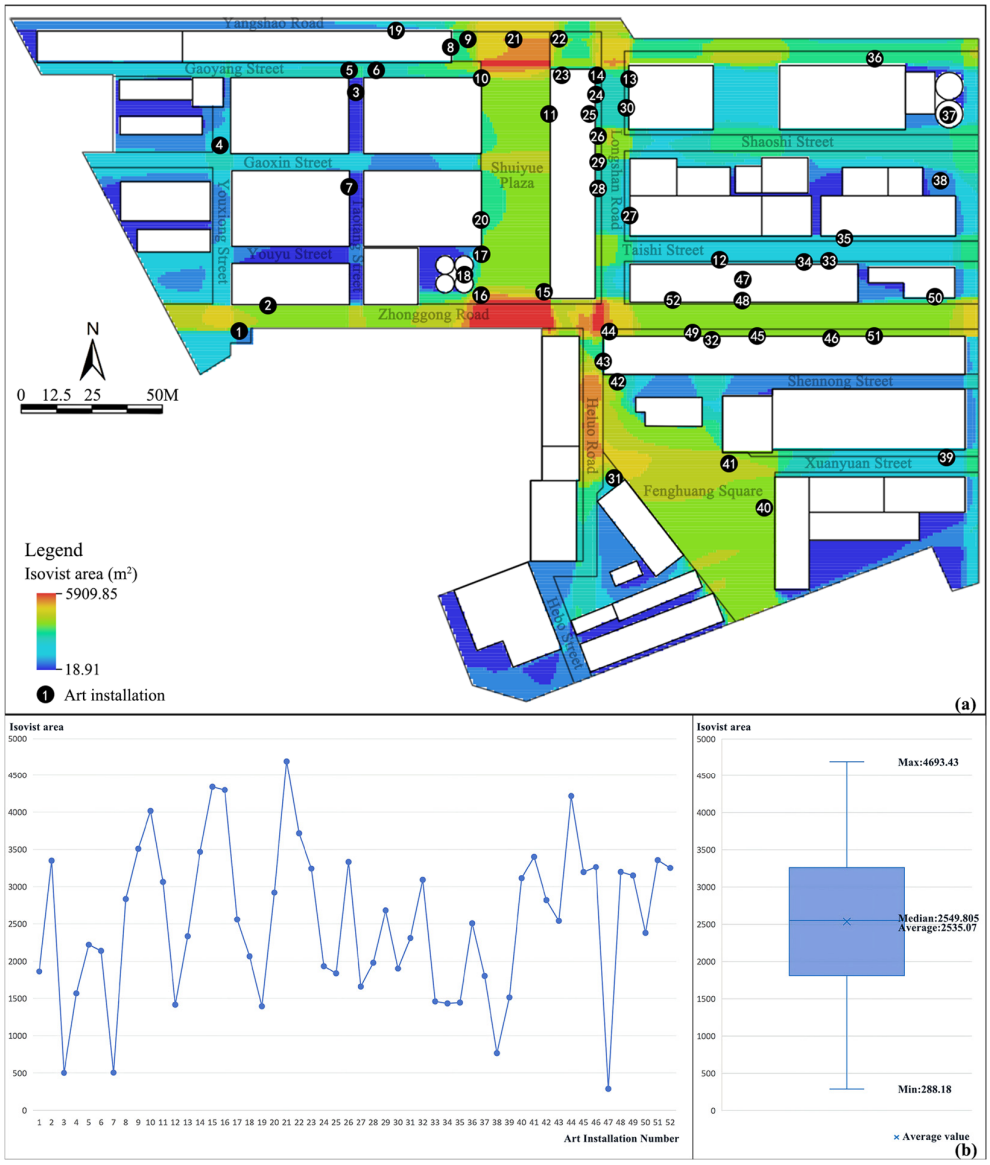


Figure 9. Evaluation results of isovist area. (**a**) Analysis of isovist area within the site. (**b**) Evaluation results of isovist area of art installations.

The results show that the mean isovist area of the art installations is 2535.07 m^2, with a maximum value of 4693.43 m^2 and a minimum value of only 288.18 m^2, indicating substantial variation. The skewness coefficient is 0.13, suggesting that the distribution of isovist area approximately follows a symmetrical distribution without a significant skew tendency. The kurtosis coefficient is −0.50, indicating that the distribution is slightly flatter than a normal distribution, with thinner tails; the data are relatively dispersed around the central region rather than concentrated around the peak value. Overall, the isovist area is

relatively evenly distributed among the locations of the installations within the site, with most installations exhibiting a moderate level of visual openness.

The evaluation results of the spatial interation of the 52 art installations are shown in Figure 10.

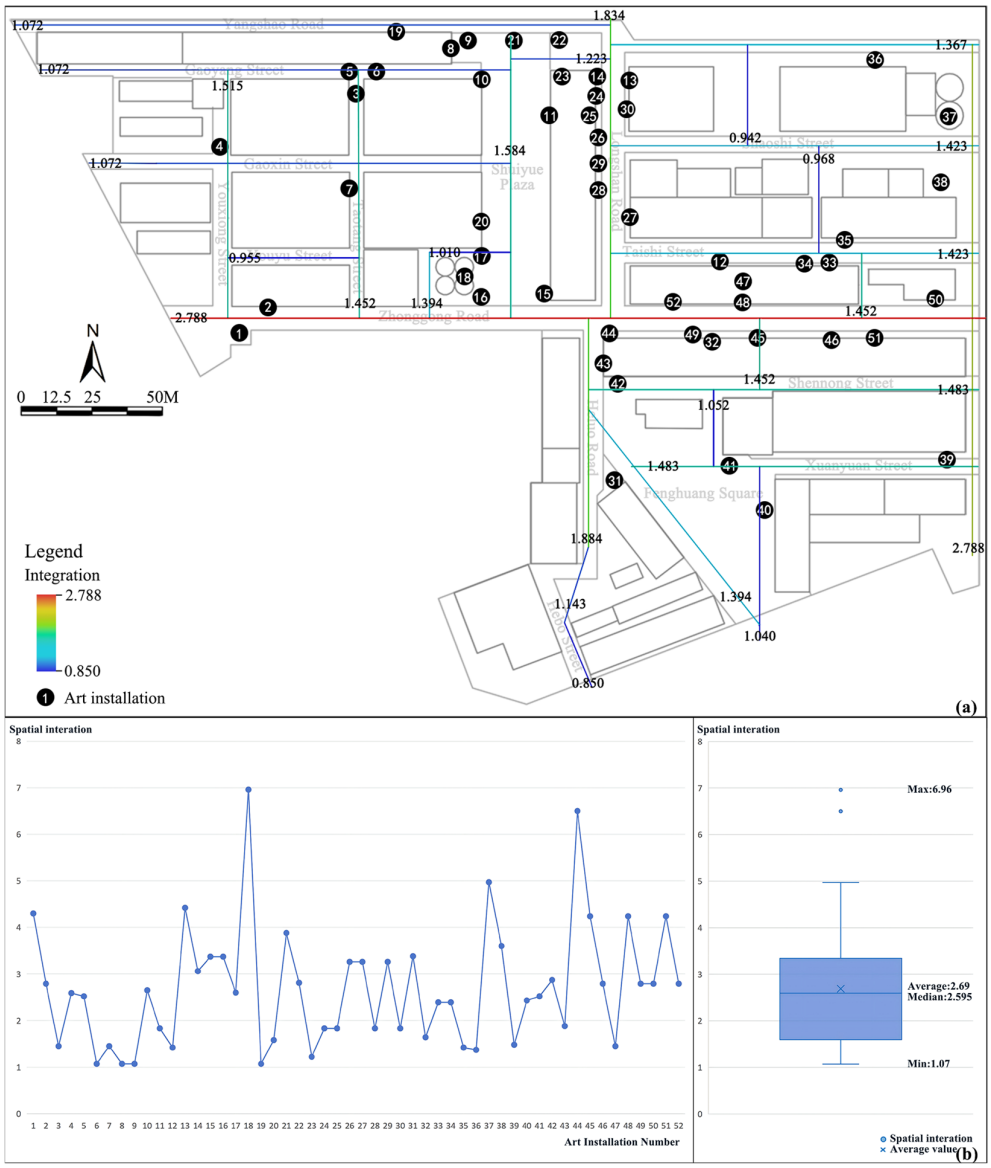


Figure 10. Evaluation results of spatial interation. (**a**) Analysis of spatial interation within the site's road network. (**b**) Evaluation results of spatial interation of art installations.

The results show that the mean spatial interation value of the spaces occupied by the art installations is 2.69, with a maximum value of 6.96 and a minimum value of 1.07, indicating substantial variation. The median value (2.60) is close to the mean value (2.69); however, the skewness coefficient of 1.45 and kurtosis coefficient of 2.87 indicate that the distribution of spatial interation exhibits pronounced positive skewness and leptokurtic characteristics. Among the 52 art installations, 44 (84.62%) are located in spaces with relatively low spatial interation, ranging from 1.07 to 3.88. Only 8 installations (15.38%) are located in spaces with very high spatial interation, with values ranging from 4.24 to 6.96.

The evaluation results of the facility diversity of the 52 art installations are shown in Figure 11.

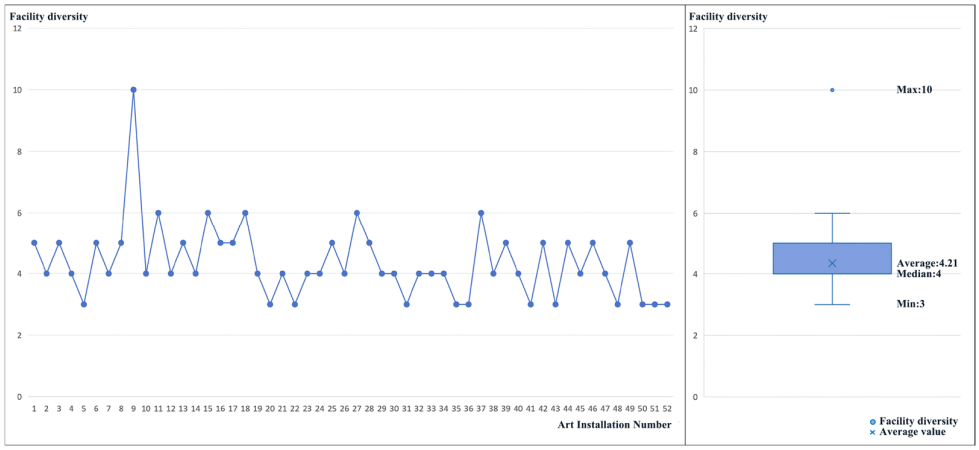


Figure 11. Evaluation results of facility diversity of art installations.

The results show that the mean facility diversity value around the art installations is 4.21, with a maximum value of 10 and a minimum value of 3, resulting in a range of 7. The skewness coefficient is 2.14 and the kurtosis coefficient is 8.41, indicating that facility diversity exhibits a pronounced positive skewness and an extremely leptokurtic distribution. Among the 52 art installations, 46 (88.5%) have surrounding facilities concentrated within the range of 3–5 types. Only 6 installations (11.5%) are surrounded by more than 6 types of facilities, among which Art Installation No. 9 has 10 types of surrounding facilities, standing out as a significant outlier.

The evaluation results of the interface richness of the 52 art installations are shown in Figure 12.

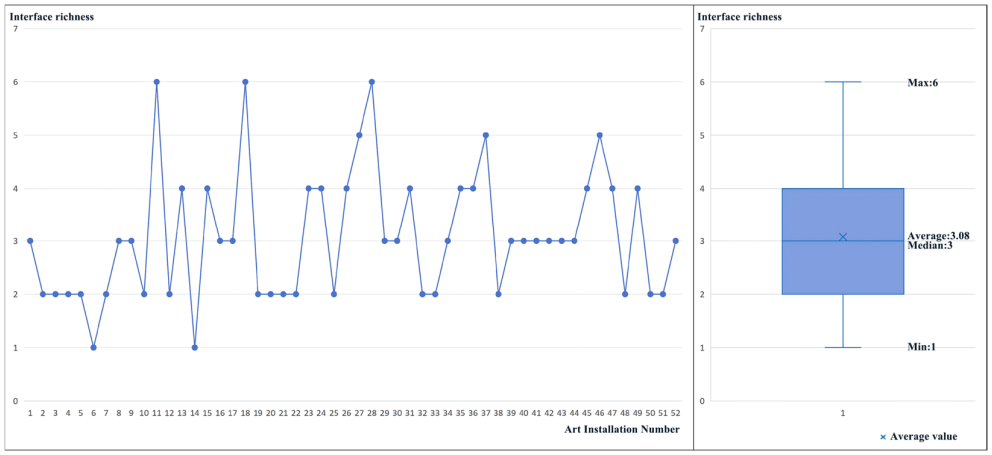


Figure 12. Evaluation results of interface richness of art installations.

The results show that the mean interface richness score of the art installations is 3.08, with a maximum value of 6 and a minimum value of 1. The skewness coefficient is 0.59, indicating that interface richness exhibits a slightly positively skewed distribution. The kurtosis coefficient is −0.09, suggesting that the distribution shape is close to the kurtosis level of a normal distribution, without significant peakedness or flatness. Among the 52 art installations, those with an interface richness score of 2 constitute the largest group, with 18 installations (34.6%). Installations with scores of 3 and 4 represent the second-largest groups, accounting for 15 installations (28.85%) and 11 installations (21.15%), respectively. Together, these three categories account for 84.6% of the total sample. Only 6 installations (11.5%) achieve a high level of interface richness (scores of 5–6). This distribution pattern indicates that the interface richness of most art installations in the Oil and Fat Chemical

Plant is concentrated within the medium-to-low range (2–4 points), and these installations collectively constitute the foundational layer of interface quality across the site.

Based on Equation (2) for calculating the spatial environment dimension, the scores of the 52 spatial environments associated with the art installations in the Oil and Fat Chemical Plant were calculated, and the results are shown in Figure 13.

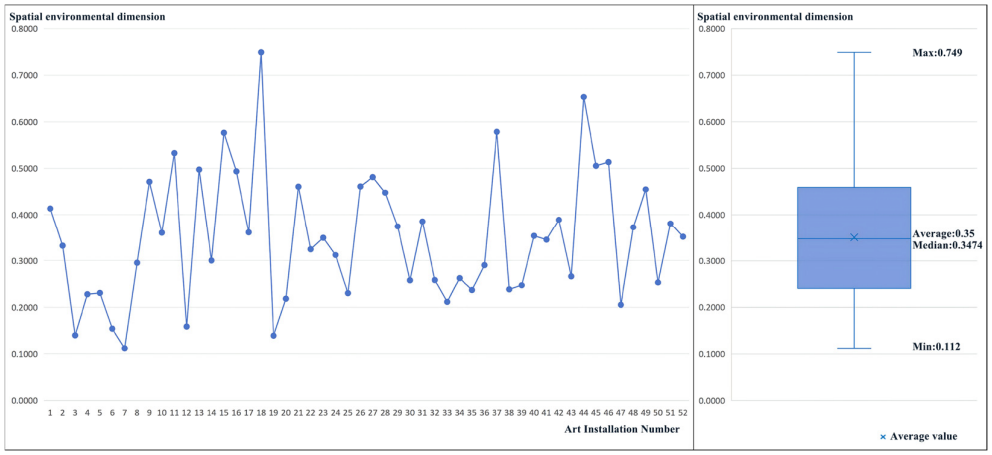


Figure 13. Evaluation results of the spatial environment dimension.

The results show that the mean score of the spatial environment dimension of the art installations is 0.350, with a maximum value of 0.749 and a minimum value of only 0.112. The skewness coefficient is 0.81, indicating that the scores of the spatial environment dimension exhibit a moderately positively skewed distribution. Most installations are concentrated within the intermediate range around the mean value, while a small number of installations achieve significantly higher scores than the average. The kurtosis coefficient is 0.97, indicating a leptokurtic distribution pattern, with data relatively concentrated around the central region. Among the 52 art installations, 45 are located within the medium-score range of 0.2–0.6, 5 are located within the low-score range of <0.2, and only 2 are located within the high-score range of >0.6.

3.2. Spatial Vitality Intensity

Based on the spatial vitality intensity calculation model, the spatial vitality intensity values of the 52 art installations at the Zhengzhou Oil and Fat Chemical Factory were calculated. The results are presented in Figure 14.

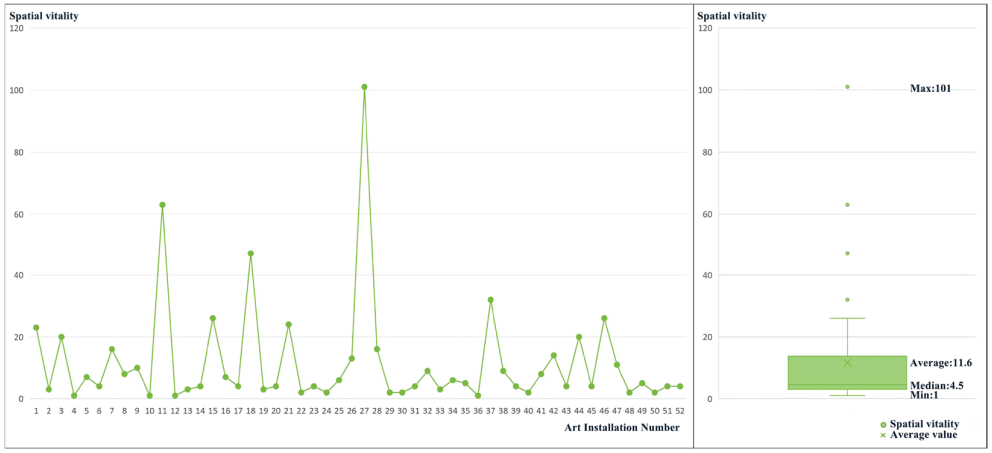


Figure 14. Evaluation results of spatial vitality intensity of art installations.

The results show that the spatial vitality intensity of art installations at the Zhengzhou Oil and Fat Chemical Factory ranges from a maximum value of 101 to a minimum value of 1, with a mean value of 11.65, a standard deviation of 17.41, and a median value of only 4.50. The skewness coefficient reaches 3.45, while the kurtosis coefficient is 14.29. These statistical characteristics indicate that the spatial vitality intensity of art installations exhibits a highly positively skewed and sharply peaked distribution. The interaction frequency of most art installations is concentrated at relatively low levels, whereas a small number of installations demonstrate exceptionally high vitality values, resulting in a significant imbalance in vitality distribution. Among all installations, 14 sites exhibit spatial vitality intensity values above the average level, accounting for 26.9% of the total.

According to the natural breaks classification method, the spatial vitality intensity values were divided into three levels. The results are presented in Table 5.

Table 5. Classification of spatial vitality intensity levels.

Vitality Level	Classification Range	Number	SVI-Min	SVI-Max	SVI-Average
Low vitality	≤5	28 (53.8%)	1	5	3.00
Medium vitality	6–20	16 (30.8%)	6	20	12.25
High vitality	>20	8 (15.4%)	23	101	42.75

The results indicate that low-vitality art installations (SVI $\leq$ 5) account for 28 cases, representing 53.8% of the total sample, with an average vitality intensity of only 3.00. These installations constitute the majority of cases and form the fundamental spatial characteristics of the study area. Medium-vitality art installations (6 < SVI $\leq$ 20) include 16 cases, accounting for 30.8% of the total, with an average vitality intensity of 12.25. High-vitality art installations (SVI > 20) comprise 8 cases, accounting for 15.4%, with an average vitality intensity reaching 42.75, which is 14.25 times higher than that of low-vitality installations. Among them, Art Installation No. 27 (vitality = 101), Art Installation No. 11 (vitality = 63), and Art Installation No. 18 (vitality = 47) represent the dominant vitality cores within the spatial network. This distribution pattern demonstrates that spatial vitality within the study area does not exhibit a uniform or gradual transition. Instead, vitality is highly concentrated around a limited number of specific locations, revealing pronounced spatial heterogeneity.

Further analysis was conducted to examine differences in vitality intensity among different types of art installation nodes, with the results presented in Table 6. The results show that narrative structural installations have the highest mean vitality intensity (39.2), but exhibit substantial internal variation, with a maximum value of 101 and a minimum value of only 4, resulting in a range of 97 and indicating significant vitality differentiation. Thematic landmark installations demonstrate the most balanced vitality performance, with all installations achieving a high level of vitality intensity and only minor fluctuations among individual installations. Artistic decorative installations represent the largest category in terms of quantity but have the lowest mean vitality intensity (6.7), with most installations exhibiting medium-to-low levels of vitality intensity.

Table 6. Spatial vitality intensity of different types of art installations.

Type	Number	SVI-Min	SVI-Max	SVI-Average
Artistic decorative installations	43 (82.6%)	1	26	6.7
Narrative structural installations	5 (9.7%)	4	101	39.2
Thematic landmark installations	4 (7.7%)	20	47	30.5

3.3. Four-Quadrant Model Analysis

To reveal the interactive influence of the matching relationship between art installation attributes and spatial environmental characteristics on spatial vitality intensity, this

study employed a four-quadrant model for typological analysis. The spatial environmental characteristic score was set as the horizontal axis, while the art installation attribute score was set as the vertical axis. The mean values of the two dimensions, 0.350 and 0.149, were respectively used as the threshold values for quadrant division. The results are presented in Figure 15.

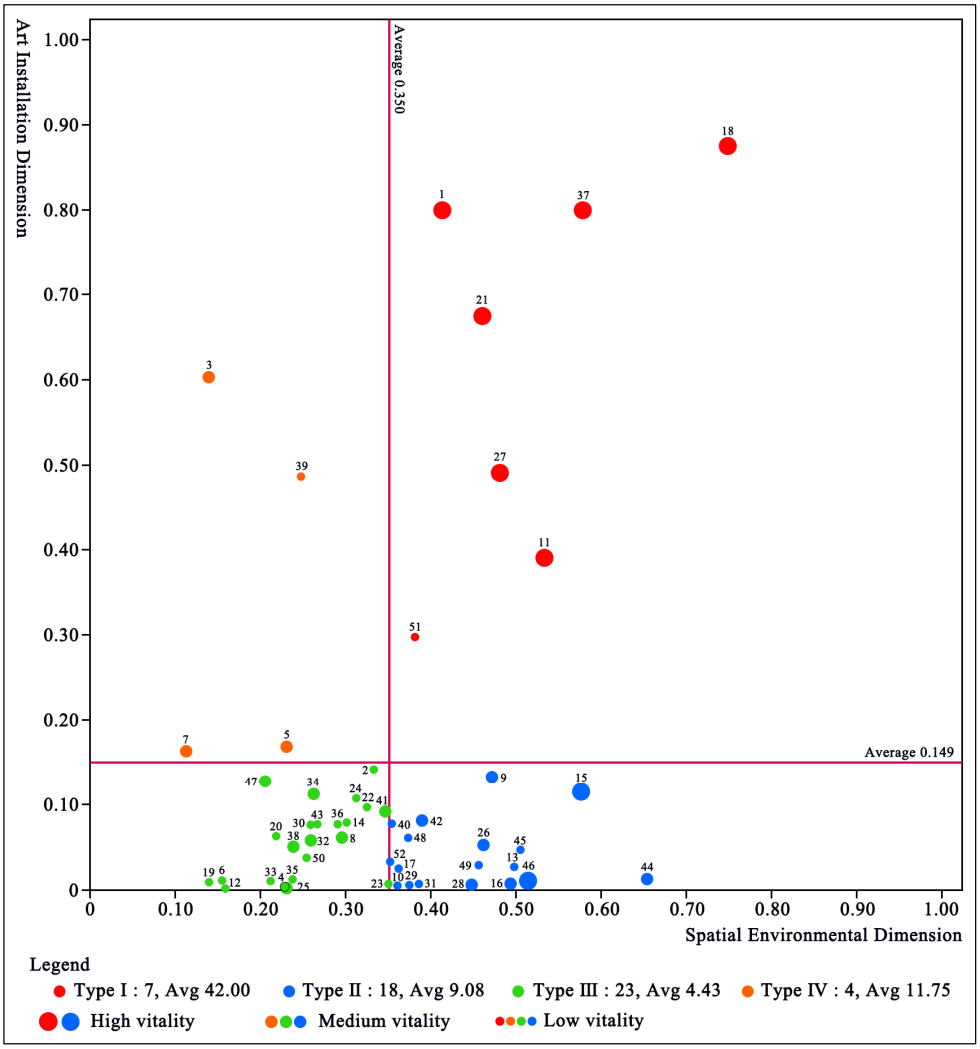


Figure 15. Four-quadrant model analysis.

The 52 research samples were classified into four basic types: Type I (high spatial environment characteristics–high installation attributes), Type II (high spatial environment characteristics–low installation attributes), Type III (low spatial environment characteristics–low installation attributes), and Type IV (low spatial environment characteristics–high installation attributes). The number of samples, proportions, mean values of spatial environmental characteristics, mean values of installation attributes, and mean spatial vitality intensity for each type are presented in Table 7.

Table 7. Characteristics of four quadrant types.

Type	Number	Spatial Environmental-Average	Art Installation-Average	SVI-Average
Type I	7 (1.35%)	0.514	0.581	42.00
Type II	18 (34.6%)	0.446	0.039	9.06
Type III	23 (44.2%)	0.255	0.055	4.43
Type IV	4 (7.7%)	0.182	0.354	11.75

The results show that Type III (low–low) samples represent the largest group, with 23 installations (44.2%), constituting the main component of the site's art installations. Type II (high–low) samples rank second, with 18 installations (34.6%). The numbers of Type I (high–high) and Type IV (low–high) samples are relatively limited, accounting for 7 installations (13.5%) and 4 installations (7.7%), respectively. This distribution pattern indicates that nearly half of the art installations in the Oil and Fat Chemical Plant face the dual constraints of poor spatial environments and low installation quality, with deficiencies in art installation quality being the more prominent issue.

The mean vitality intensity of Type III art installations is the lowest. However, the mean score of the art installation dimension shows only a minimal difference compared with Type II, while the difference between the two types in the spatial environment dimension is substantial. This comparison indicates that, when the quality of art installations remains at a similarly low level, improvements in spatial environmental conditions can directly enhance spatial vitality.

The mean score of the art installation dimension for Type IV art installations is 0.354, while the mean score of the spatial environment dimension is only 0.182, with a mean vitality intensity of 11.75. Although these installations possess superior qualities, their performance is constrained by low-quality spatial environments. In contrast, Type II art installations have a mean spatial environment dimension score of 0.446, but a mean art installation dimension score of only 0.039; nevertheless, their mean vitality intensity reaches 9.06, showing only a limited difference compared with Type IV installations. This finding indicates that, within the spatial context of Zhengzhou Oil and Fat Chemical Plant, favorable spatial environmental conditions can compensate for deficiencies in art installation quality, whereas high-quality installations without the support of a high-quality spatial environment cannot fully realize their vitality potential.

In summary, the influence of art installations on spatial vitality does not result from the independent effects of installation characteristics or spatial attributes, but rather from the synergistic matching between the two. Within the current sample, spatial characteristics play a more critical driving role, and the quality of spatial conditions largely determines the baseline level of vitality intensity.

3.4. Correlation and Regression Analysis of Art Installation Evaluation Indicators and Spatial Vitality Intensity

To quantify the influence mechanisms of individual art installation indicators on spatial vitality intensity, this study sequentially conducted Pearson correlation analysis and multiple linear regression analysis. Based on the 52 art installations, the analyses aimed to reveal the association patterns between variables and spatial vitality intensity, and to identify key predictive factors with explanatory power while controlling for the effects of other variables.

3.4.1. Correlation Analysis: Effects of Different Art Installation Indicators on Spatial Vitality Intensity

To investigate the relationships between individual evaluation indicators of art installations and spatial vitality intensity, this study conducted a Pearson correlation analysis. Six indicators—including installation typology, volumetric proportion, isovist area, spatial interation, facility diversity, and interface richness—were selected as independent variables, while spatial vitality intensity was treated as the dependent variable. The analysis aimed to identify whether significant linear relationships existed between each variable and vitality intensity, as well as to determine the direction and strength of these relationships. The results are presented in Table 8.

Table 8. Pearson correlation analysis between evaluation indicators and spatial vitality intensity.

Variable	Spatial Vitality Intensity	
	Correlation Coefficient	*p*-Value
Installation typology	0.486 **	0.000
Volumetric proportion	0.463 **	0.001
Isovist area	0.011	0.938
Spatial interation	0.204	0.148
Facility diversity	0.578 **	0.000
Interface richness	0.397 **	0.004

Note: ** indicates statistical significance at the 1% levels, respectively.

The results show that installation typology, volumetric proportion, facility diversity, and interface richness all exhibit significant positive correlations with vitality intensity, whereas isovist area and spatial interation do not demonstrate statistically significant relationships with vitality intensity.

The correlation coefficient between facility diversity and vitality intensity is the highest (r = 0.578, $p < 0.01$), indicating a moderately strong and statistically significant positive correlation. This suggests that the greater the number of public service facilities within the 40 m buffer zone surrounding an art installation, the higher the vitality intensity of the space. The distribution of service facilities around art installations represents the primary spatial environmental factor driving interactive vitality.

Installation typology also shows a significant positive correlation with vitality intensity (r = 0.486, $p < 0.01$), indicating that, within the sample examined in this study, installation types with higher spatial roles and narrative levels tend to correspond to higher levels of spatial vitality intensity. The cultural attributes of art installations play a positive role in promoting vitality concentration.

The positive correlations of volumetric proportion (r = 0.463, $p < 0.01$) and interface richness (r = 0.397, $p < 0.01$) with vitality intensity represent moderately weak-to-moderate relationships. These findings indicate that both the physical presence of installations within the spatial environment and their visual integration with industrial heritage interfaces are important factors influencing vitality generation.

The correlation coefficients between isovist area (r = 0.011, $p = 0.938$) and spatial interation (r = 0.204, $p = 0.148$) with vitality intensity do not reach statistical significance, and their absolute correlation coefficients are relatively low. This finding indicates that, at the scale of the industrial heritage site examined in this study, the absolute visual openness of installation locations and their topological centrality are not key determinants of vitality levels. Instead, favorable spatial environmental conditions provide a more direct explanation for actual public staying behaviors.

The correlation coefficient matrix analysis among the independent variables (Figure 16) reveals a series of significant correlations between variables, indicating the complex patterns of interconnection and co-occurrence among these factors within the actual spatial environment.

Positive synergy between installation typology and volumetric proportion. Installation typology and volumetric proportion exhibit a significant positive correlation (r = 0.552, $p < 0.01$), indicating that installation types with higher spatial roles and narrative levels tend to possess larger volumetric proportions, whereas artistic decorative installations that primarily serve environmental beautification and atmosphere creation are relatively more refined in scale. The positive synergistic relationship between the two indicates that, at the scale of the industrial heritage site examined in this study, there is an inherent consistency between the spatial role positioning of installations and their volumetric configurations. Installations responsible for anchoring the spirit of place and conveying industrial nar-

ratives require sufficient physical presence to establish spatial dominance and narrative authority. In contrast, decorative installations integrate into everyday spatial interfaces through flexible and lightweight approaches, avoiding visual competition with large-scale industrial environments.

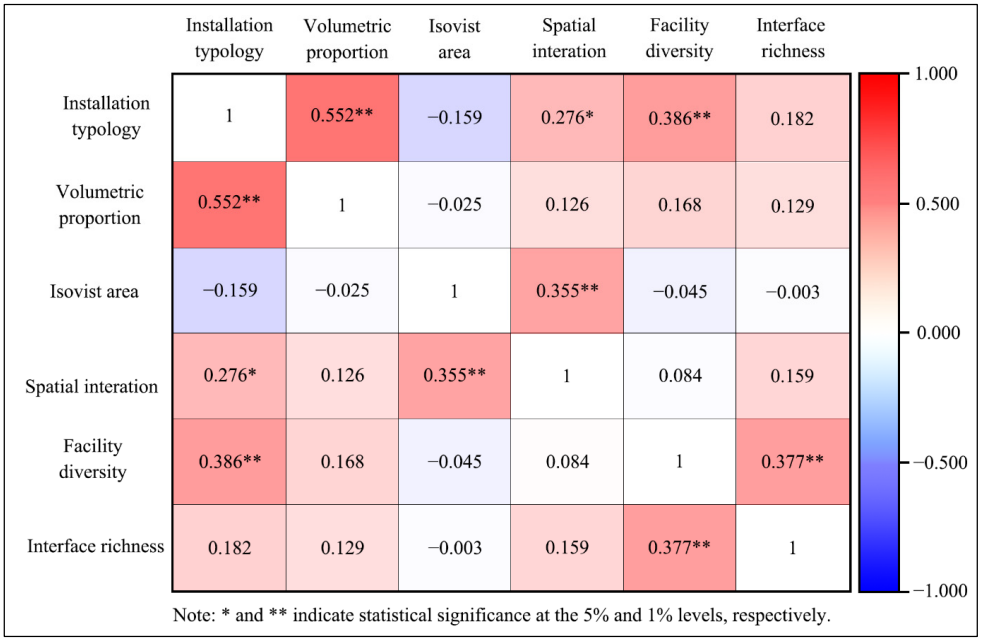


Figure 16. Correlation coefficient matrix of independent variables.

Positive association between installation typology and facility diversity. Installation typology and facility diversity also exhibit a significant positive correlation (r = 0.386, $p < 0.01$), indicating that installations with higher typological levels tend to be located in nodes with richer service facility configurations. This positive relationship suggests that art installations with greater spatial roles are more likely to be coupled with multifunctional nodes during the planning process, and that the coordinated configuration of installations and facilities has strategic significance for vitality generation. Thematic landmark installations and narrative structural installations are typically located in the site's core plazas, main street nodes, or important intersections of production circulation routes. These locations naturally attract diverse functions, including outdoor dining areas, resting facilities, information guidance systems, and commercial services, thereby forming a synergistic pattern in which installations and facilities mutually enhance each other.

Positive synergy between facility diversity and interface richness. Facility diversity and interface richness exhibit a significant positive correlation (r = 0.377, $p < 0.01$), indicating a clear synergistic relationship between the two within the actual spatial context. The increase in the types and quantity of service facilities is typically accompanied by the enrichment of interface elements, such as shop windows, outdoor furniture, signage systems, and landscape features. These two factors mutually reinforce each other, jointly shaping spatial environments characterized by functional diversity and visual vitality. This positive synergistic relationship suggests that, in spatial optimization practices, enhancing facility configurations and enriching interface designs should be advanced as an integrated strategy to maximize their combined effects.

Positive correlation between spatial interation and isovist area. Spatial interation exhibits a significant positive correlation with isovist area (r = 0.355, $p < 0.01$), indicating that spaces with higher accessibility within the site's axial-line topological network also tend to have greater visual openness. These two indicators identify the core nodes with superior spatial structural positions within the site. Positive correlation between spatial interation

and installation typology. Spatial interation also exhibits a significant positive correlation with installation typology (r = 0.276, $p < 0.05$), indicating that installations serving landmark and narrative functions tend to be located toward topological centers. This finding suggests a statistical consistency between spatial structural centrality and functional importance. However, isovist area and spatial interation do not exhibit direct significant correlations with vitality intensity, indicating that the potential pedestrian movement generated by topological centrality requires transformation through indicators such as installation typology before it can be effectively translated into actual behavioral staying and vitality concentration.

3.4.2. Regression Analysis: Comparison Between the Full-Variable Regression Model and the Optimized Regression Model

To quantify the independent explanatory power of each art installation indicator on spatial vitality intensity and identify the key variables influencing vitality, this study employed a multiple linear regression model. Spatial vitality intensity was set as the dependent variable, while installation typology, volumetric proportion, isovist area, spatial interation, facility diversity, and interface richness were selected as independent variables. Two progressive regression models were constructed, and their results were compared.

Full-variable regression model. All six indicators were included in the regression equation, and the results are presented in Table 9. The overall model was statistically significant ($F = 9.195$, $p < 0.001$), with an adjusted R^2 of 0.491, indicating that the six indicators jointly explained 49.1% of the variance in spatial vitality intensity. The collinearity diagnosis showed that the variance inflation factors (VIFs) of all independent variables were far below the critical threshold of 10 (1.225–2.075), and all tolerance values exceeded 0.4, indicating no serious multicollinearity among the predictors. Therefore, the estimated regression coefficients were considered stable and reliable. The Durbin–Watson (D–W) value was 2.114, which is close to 2, suggesting that the residuals exhibited no significant autocorrelation.

Table 9. Results of the full-variable regression model.

	Unstandardized Coefficients		**Standardized Coefficients**	***t***	***p***	**Collinearity Diagnosis**	
	B	**Std. Error**	***Beta***			**VIF**	**Tolerance**
Constant	−8.204	5.245	--	−1.564	0.125	--	--
Installation typology	13.712	8.492	0.232	1.615	0.113	2.075	0.482
Volumetric proportion	22.799	11.995	0.240	1.901	0.064	1.602	0.624
Isovist area	−1.167	8.545	−0.016	−0.137	0.892	1.329	0.753
Spatial interation	2.647	9.666	0.034	0.274	0.785	1.507	0.664
Facility diversity	20.071	11.264	0.201	1.782	0.082	1.272	0.786
Interface richness	25.139	7.898	0.352	3.183	0.003 **	1.225	0.817
R^2				0.551			
Adjusted R^2				0.491			
F				F (6,45) = 9.195, p = 0.000			
D–W value				2.114			

Note: ** indicate statistical significance at the 1% levels, respectively.

Among the six independent variables, only interface richness reaches a statistically significant level. The standardized regression coefficient of interface richness is Beta = 0.352 ($p < 0.01$), indicating that, after controlling for other variables, an increase in interface richness is associated with an increase in vitality intensity. The regression coefficients of installation typology, volumetric proportion, isovist area, spatial interation, and facility diversity do not reach statistical significance ($p > 0.05$). Among them, isovist area

has the lowest absolute value of the standardized coefficient (|*Beta*| = 0.016), suggesting that it provides almost no independent explanatory contribution to vitality intensity.

Optimized regression model. Considering that isovist area and spatial interation showed no statistical significance in the correlation analysis, and their regression coefficients and standardized coefficients were highly insignificant and close to zero in the full-variable regression model, these two variables were removed. The optimized model was constructed by retaining installation typology, volumetric proportion, facility diversity, and interface richness as independent variables. The results are presented in Table 10. The optimized model was statistically significant overall (F = 14.362, p < 0.001), with an adjusted R^2 of 0.512, representing an improvement of 2 percentage points compared with the full-variable regression model. This indicates that the simplified model achieved enhanced explanatory performance while sacrificing very limited information. The removal of redundant variables improved both the parsimony and effectiveness of the model.

Table 10. Results of the optimized regression model.

	Unstandardized Coefficients		**Standardized Coefficients**	***t***	***p***	**Collinearity Diagnosis**	
	B	**Std. Error**	***Beta***			**VIF**	**Tolerance**
Constant	−8.251	3.640	--	−2.267	0.028 **	--	--
Installation typology	14.663	7.394	0.249	1.983	0.053	1.640	0.610
Volumetric proportion	22.836	11.652	0.241	1.960	0.056	1.577	0.634
Facility diversity	19.516	10.804	0.195	1.806	0.077	1.220	0.819
Interface richness	25.529	7.609	0.357	3.355	0.002 **	1.185	0.844
R^2				0.550			
Adjusted R^2				0.512			
F				F (4,47) = 14.362, p = 0.000			
D–W value				2.125			

Note: ** indicates statistical significance at the 1% levels, respectively.

In the optimized model, the direction of regression coefficients and significance levels of the four independent variables remained highly consistent with those in the full-variable regression model. The coefficient estimates exhibited only minor changes, indicating good robustness of the parameter estimation. Interface richness remains the primary influencing factor (*Beta* = 0.376, p < 0.01). Its standardized coefficient remains highly stable across both the full-variable model and the optimized model, further confirming the reliability of interface richness as the core driver of vitality intensity. The p-values of installation typology, volumetric proportion, and facility diversity approach the critical significance threshold of 0.05, indicating that, after controlling for spatial environmental conditions, the contributions of these three indicators to vitality intensity do not reach the conventional level of statistical significance but nevertheless demonstrate clear positive trends.

A synthesis of the regression results from both models reveals three key findings. First, among the six evaluation indicators of art installations, interface richness is the core variable driving vitality intensity. Second, isovist area and spatial interation do not demonstrate independent linear explanatory power for vitality intensity within the present sample. Third, the vitality-enhancing effects of installation typology, volumetric proportion, and facility diversity may be indirectly manifested through their synergistic interactions with interface richness. This indicates that the stimulation of spatial vitality by art installations cannot be achieved through a single factor alone; rather, the synergistic configuration of the inherent characteristics of art installations and the supporting elements of the spatial environment constitutes the key mechanism.

4. Discussion

4.1. Construction of the Installation–Space–Vitality Evaluation Framework from the HEFS Perspective

The installation–space–vitality systematic evaluation framework from the perspective of the HEFS aims to quantitatively characterize the interactive effects of two dimensions, namely art installations and their surrounding spatial environments, on spatial vitality. This framework addresses the limitations of existing studies, which often separate art installations from spatial environments or lack relatively objective and systematic analytical approaches.

Research in the fields of art and design primarily focuses on the formal language, symbolic translation, and aesthetic value of installations, treating installations as self-contained artworks independent of their spatial contexts [54]. In contrast, studies in urban planning and architecture tend to emphasize the functional transformation, circulation organization, and spatial morphology of industrial heritage sites, while art installations are often mentioned only as supplementary elements for spatial beautification [55]. Neither of these two approaches adequately reveals how the attributes of art installations and spatial environments jointly influence human behavioral responses. Consequently, they fail to explain why an apparently ordinary installation can attract substantial public engagement within a specific spatial context, whereas some carefully designed artworks may become overlooked decorative objects with limited social interaction.

From the perspective of the HEFS, this study establishes spatial vitality—represented by the intensity of human behaviors such as staying and interaction—as the outcome variable for evaluating the effectiveness of art installation interventions, and subsequently develops a quantitative analytical framework. Within this framework, art installations are not regarded as isolated aesthetic objects; rather, they are measured through two indicator factors: installation typology and volumetric proportion. The attributes of installations reflect the intensity of design intervention at specific nodes, with their underlying mechanisms involving visual attraction and cultural narration. Similarly, the spatial environment is not considered a passive container, but is evaluated through indicator factors including isovist area, spatial interation, facility diversity, and interface richness. The attributes of the spatial environment represent the place-supporting capacity of specific nodes, with their underlying mechanisms involving accessibility support and functional provision. Human vitality response serves as the ultimate criterion for examining the interaction between installations and spatial environments. The two dimensions may influence vitality performance independently, synergistically, or even antagonistically. If these two dimensions are conflated, it becomes impossible to identify which configuration patterns can achieve the optimal conditions for vitality generation.

The introduction of the four-quadrant classification framework enhances the practical diagnostic function of the "installation–space" dual-dimensional analytical model. By using the mean values of the two dimensions as classification thresholds, the 52 art installations were categorized into four basic types, corresponding to four human–environment matching conditions: "high installation–high space," "low installation–low space," "high space–low installation," and "low space–high installation." This classification reveals the diversity and complexity of vitality generation pathways. Spatial vitality is not a simple linear function of installation characteristics or spatial environmental attributes alone, but rather the outcome of their synergistic interactions under specific site conditions. The four-quadrant model serves as a bridge connecting quantitative evaluation and spatial intervention strategies, providing an evidence-based foundation for developing targeted optimization recommendations in subsequent design practices.

4.2. Analysis of Indicator Factors and Their Mechanisms Influencing Spatial Vitality

The correlation and regression analyses reveal the key driving factors and their underlying mechanisms within the quantitative relational model. Among the six evaluation indicators, interface richness is identified as the primary driving factor, while installation typology, volumetric proportion, and facility diversity constitute auxiliary positive variables. Together, these four indicators explain 51.2% of the variance in vitality intensity (adjusted $R^2 = 0.512$).

In this study, interface richness was identified as the primary factor influencing spatial vitality, highlighting the critical driving role of visual information density in industrial heritage environments. From the perspective of cognitive psychology, human perception and processing of spatial information are naturally characterized by exploratory tendencies. Moderately complex visual environments can stimulate users' attention and desire for exploration, thereby extending their staying duration and encouraging interactive behaviors such as photography and discussion [56]. Interface richness measures the degree of visual integration and information density between art installations and the surrounding industrial heritage interfaces, including red brick walls, steel truss structures, and preserved pipeline remnants, in terms of color, material, and formal characteristics. In the empirical context of Zhengzhou Oil and Chemical Plant, art installations with high interface richness generally exhibit two typical compositional patterns. The first is the interface superposition pattern, in which art installations are arranged in relation to the red brick walls of factory buildings. The forms and colors of the installations interact with industrial textures, weathering traces, and historical signage embedded in the walls, generating a multilayered visual composition and creating narrative scenes with a strong sense of historical depth [57]. The second is the interface extension pattern, in which diverse interface elements, such as shop windows, outdoor furniture, landscape features, and signage systems, are densely distributed around the installations, forming visually layered street environments. Regardless of the specific pattern, the spatial effect generated by interface richness fundamentally lies in enhancing spatial legibility and discoverability. High-information-density environments provide users with continuous visual cues for exploration, transforming the act of staying into an intrinsically meaningful experience of spatial appreciation and engagement [58].

The influence of installation typology on spatial vitality is essentially transmitted indirectly through its synergistic interactions with other variables. The transition from a significant positive correlation in the correlation analysis ($r = 0.486$, $p < 0.001$) to a non-significant effect in the regression analysis (Beta = 0.249, $p = 0.053$) confirms this underlying mechanism. Further correlation analysis reveals that installation typology is significantly positively correlated with facility diversity ($r = 0.386$, $p < 0.01$), while facility diversity is significantly positively correlated with interface richness ($r = 0.377$, $p < 0.01$). This transmission pathway reveals the indirect mechanism through which installation typology influences spatial vitality: installations with higher role level tend to be located in areas with richer facility configurations during the planning and site-selection process, while increased facility density is typically accompanied by the simultaneous enrichment of interface elements, such as shop windows, outdoor furniture, and signage systems. These factors jointly contribute to the generation of spatial vitality. When facility diversity and interface richness are incorporated into the regression model, the direct effect of installation typology is sufficiently explained, and its regression coefficient becomes statistically insignificant. This indicates that the contribution of installation typology to vitality intensity does not operate as an independent effect, but is instead indirectly transmitted through facility diversity and interface richness.

The mechanism through which volumetric proportion influences spatial vitality can be understood from three perspectives. Visual attention [59]. Industrial heritage spaces are characterized by large spans and high ceilings. Volumetric proportion determines whether an art installation can stand out from the complex industrial background. Behavioral accommodation capacity [60]. The significance of volumetric proportion lies not only in visual scale but also in its role as a physical carrier of spatial activities. Taking Art Installation No. 21 as an example, which has the highest volumetric proportion in the entire sample (0.840), the installation was transformed from an unloading platform, allowing visitors to enter, move through, and conduct performances within the structure. In this case, the installation is transformed into a behavioral container. Industrial-scale adaptation [61]. The vitality effect of volumetric proportion does not increase linearly with scale; rather, it requires a dialogue with the existing dimensional order of industrial spaces. In the empirical context of the Zhengzhou Oil and Fat Chemical Plant, art installations with volumetric proportions ranging from 0.2 to 0.6 generally achieve a better balance between visual prominence and spatial coordination. Within the monumental scale of industrial heritage environments, art installations should adequately respond to the spatial logic of industrial structures and moderately increase their volumetric proportion while maintaining visual harmony, thereby simultaneously enhancing spatial dominance and behavioral accommodation capacity.

The diversified configuration of facilities provides the material foundation for supporting a wide range of activity types. In his public space theory, Jan Gehl proposed that the duration of human stays in public spaces is positively associated with the diversity of activities occurring within them [62]. In the empirical context of Zhengzhou Oil and Chemical Plant, service facilities within a 40 m radius around art installations with high facility diversity include outdoor dining facilities, shading and resting facilities, children's play facilities, and information guidance facilities. These facilities attract users to stay, stimulate diverse behavioral patterns, and consequently enhance spatial vitality. The contribution of facility diversity to spatial vitality is also reflected in its capacity to accommodate the needs of different user groups. A diversified combination of facilities can serve a wide range of populations with different ages, consumption levels, and behavioral purposes. The significant positive correlation between facility diversity and interface richness reflects a mutually reinforcing pathway through which art installations generate vitality by integrating functional and visual dimensions. An increase in facility types not only provides additional behavioral purposes but also introduces spatial elements—including shop window displays, tables, chairs, shading umbrellas, lighting systems, and signage—that become important components of the visual interface. Consequently, functional diversity and visual richness jointly contribute to the formation of active and attractive industrial heritage spaces.

4.3. Guidelines for the Compatibility Relationship Between Art Installation Types and Spatial Environments

In the practice of integrating art installations into industrial heritage spaces, whether identifiable association patterns exist between installation typology and spatial environments remains an important question. The empirical data from this case reveal the distribution characteristics and vitality performance of the three types of installations, and further propose differentiated spatial environment configuration strategies based on different installation typologies.

Thematic landmark art installations serve as core symbols and cultural landmarks within industrial heritage sites. Their primary functions are to establish site identity, convey industrial cultural themes, create visual dominance, and form spatial anchors. In the empirical sample of the Zhengzhou Oil and Fat Chemical Plant, all thematic landmark in-

stallations are located at nodes with relatively large isovist areas and high spatial interation, such as the site entrance and plazas. An in-depth analysis of the four installations reveals that differences in vitality intensity are closely associated with the comprehensive configuration of multiple spatial environmental dimensions. The space accommodating Art Installation No. 18 not only possesses the most advantageous locational conditions and interface quality but is also equipped with the most complete service facilities. The combined effects of these multiple factors make it the most vital node among the thematic landmark installations. The other three installations exhibit relatively lower levels of interface richness, facility diversity, and volumetric proportion, accompanied by a corresponding decline in vitality intensity. This comparison reveals that thematic landmark installations have the highest overall requirements for spatial environmental conditions. Favorable visual openness and locational advantages provide only the basic foundation; the synergistic integration of multiple factors, including interface richness, volumetric proportion, and facility diversity, is essential for maximizing vitality. Therefore, preserving or enhancing industrial interface elements and adding resting and service facilities can effectively transform locational advantages into tangible vitality outcomes.

Narrative component art installations demonstrate the most prominent vitality-generating performance among all installation types examined in this study, with an average spatial vitality intensity of 39.2. The outstanding performance of narrative structural installations is attributed to their favorable performance in key indicators such as facility diversity and interface richness. Art Installations No. 11 and No. 27 demonstrate that high interface richness is the core driving condition for the vitality of narrative structural installations, while facility diversity determines the efficiency of behavioral transformation. Therefore, narrative structural installations should integrate the design of the installation itself, the utilization of industrial interfaces, and the configuration of service facilities as a unified spatial scenario. Interface richness represents the material correspondence, color coordination, and morphological dialogue between art installations and industrial heritage interfaces, serving as the primary carrier for the transmission of narrative information. A systematic heritage assessment of the historical information embedded within surrounding interfaces should be conducted to maximize the preservation and creative transformation of historical evidence, enabling installations and interfaces to jointly construct a readable and perceptible narrative text. Regarding facility diversity, narrative structural installations should fully utilize their volumetric advantages by simultaneously planning diverse supporting facilities, including resting areas, dining spaces, and information guidance systems. Through such configurations, a complete behavioral sequence involving viewing, staying, consumption, and social interaction can be established around the installations.

Artistic decorative installations represent the largest and most widely distributed category within Zhengzhou Oil and Chemical Plant, while also exhibiting the greatest differentiation in spatial vitality performance. Therefore, optimizing this type of installation is a critical pathway for enhancing the overall vitality of the site. Due to their diverse forms, flexible scales, and broad thematic possibilities, artistic decorative installations can be adapted to various spatial types; however, their specific forms should be selected according to the characteristics of different spatial contexts. The enhancement of vitality for artistic decorative installations should prioritize addressing deficiencies in spatial environmental conditions rather than simply replacing the installations themselves. Facility diversity represents the most significant structural limitation of this installation type, as many nodes lack functional facilities that support staying, consumption, and leisure activities. Therefore, facility-oriented micro-renewal strategies should be applied to existing artistic decorative installation nodes, with priority given to introducing supporting elements such

as seating, shading facilities, and small-scale service points around installations. These low-cost interventions can effectively extend users' stay duration and stimulate spatial vitality. In terms of interface richness, artistic decorative installations should strengthen their visual connections with existing industrial interfaces by incorporating symbolic elements related to industrial history, thereby enhancing contextual compatibility between the installations and the site's cultural narratives. Regarding volumetric proportion, considering that artistic decorative installations are characterized by refinement and subtlety, excessive enlargement of individual installations should be avoided. Instead, their spatial influence and behavioral accommodation capacity can be indirectly enhanced through grouped arrangements and collective compositions.

4.4. Differentiated Intervention Pathways Based on Four-Quadrant Classification

The four-quadrant model is a commonly used approach for classification-based differentiated guidance, clearly illustrating four typical matching patterns between art installations and spatial environments. The differences in spatial vitality intensity among the four quadrants provide empirical evidence for developing differentiated intervention strategies.

Type I (High–High): Enhancing the demonstration effect. This type of art installation (7 installations, with a mean vitality intensity of 42.0) achieves high levels in both art installation quality and spatial environmental conditions, representing a benchmark for the integration of art installations into industrial heritage regeneration. To further strengthen their demonstrative and leading role, long-term monitoring of spatial use behaviors around high-vitality installations should be conducted to establish a database of successful practices. Meanwhile, dynamic content, such as seasonal art exhibitions and oral history workshops on industrial memory, can be introduced to continuously maintain spatial novelty and encourage repeated visits. These interventions can prevent vitality decline caused by content stagnation and ensure the sustained activation of industrial heritage spaces.

Type II (High Spatial–Low Installation): Addressing installation quality deficiencies. In the Zhengzhou Oil and Fat Chemical Plant, this type of art installation (18 installations) benefits from favorable spatial environmental conditions; however, the mean score of their art installation dimension is only 0.039, indicating that the existing installations have significant deficiencies in artistic quality and narrative depth related to the site. Their spatial vitality is therefore highly dependent on the attraction generated by spatial environments and supporting facilities. While retaining the existing spatial environment, more strongly place-narrative art installations should be introduced to transform industrial memories into perceptible spatial languages. Emphasis should be placed on incorporating interactive art installations that respond to the historical context of the site, thereby effectively transforming the advantages of the spatial environment into cultural meaning.

Type III (Low–Low): Prioritizing basic spatial improvement. This type of art installation (23 installations, with an average vitality intensity of 4.43) faces deficiencies in both installation quality and spatial environmental conditions, making it the category most in need of intervention. For such low-vitality spaces, improvement should follow a progressive strategy that prioritizes foundational enhancement before artistic upgrading. First, fundamental spatial conditions should be addressed to ensure that basic requirements, including lighting, infrastructure, accessibility, and overall environmental quality, are adequately satisfied. Improving these basic conditions provides the necessary foundation for subsequent vitality activation. Second, low-cost micro-intervention approaches should be introduced to stimulate spatial potential while minimizing the risks associated with large-scale investment. Possible strategies include wall murals, small-scale interactive components, temporary art events, and other flexible interventions. These approaches al-

low the spatial attractiveness and user response of the site to be tested before committing to more substantial renewal measures. Finally, after improvements in spatial attractiveness have been verified, customized and highly recognizable art installations can be introduced to establish distinctive spatial identities. This phased renewal approach helps avoid excessive commercialization.

Type IV (Low Spatial–High Installation): Enhancing Spatial Quality. This type of art installation (4 installations) is constrained by relatively poor spatial environmental conditions, which prevents the artistic qualities of the installations from being fully translated into spatial attraction. Nevertheless, these installations possess considerable potential for spatial revitalization. Interventions for this type should prioritize improvements in facility diversity and interface richness. Around existing high-quality art installations, lightweight supporting facilities such as resting seats, small-scale commercial outdoor settings, and interactive information signage can be introduced to provide additional behavioral opportunities and encourage longer stays. Meanwhile, the visual quality of the surrounding interfaces should be improved by removing visual obstructions, enhancing lighting conditions, introducing appropriate landscape elements, and strengthening the dialogue between interface materials and installation forms. These measures can reduce the spatial isolation of high-quality installations, enhance their visibility and accessibility, and enable their artistic value to be effectively perceived and transformed into public spatial vitality.

4.5. Study Limitations

This study has several limitations that should be acknowledged. First, the research is based on a single case study of Zhengzhou Oil and Chemical Plant, and the external validity of the findings requires further verification. Industrial heritage sites encompass diverse categories, including early modern national industries, Third Front Movement industrial sites, and post-reform light industrial facilities, each characterized by distinct spatial structures and heritage values. Therefore, the applicability of the proposed evaluation model across different types of industrial heritage remains to be tested. Future research should expand the sample scope across multiple cities and industrial heritage categories to examine the universality and boundary conditions of the indicator system.

Second, this study is based on cross-sectional data collected during the observation period and therefore cannot capture the seasonal fluctuations and climatic sensitivity of spatial vitality. The staying behaviors of users in outdoor spaces of industrial heritage sites may change significantly under conditions such as high summer temperatures, cold winter climates, or rainy seasons. Whether art installations possess adaptability to different climatic conditions represents an important variable affecting the stability of their vitality effects. Furthermore, the vitality of industrial heritage sites often exhibits cyclical characteristics across multiple temporal scales, including holidays versus weekdays, daytime versus nighttime, and off-season versus peak-season periods. Differences in exhibition duration may also generate distinct vitality trajectories between public novelty and familiarity. Therefore, observations conducted within limited time periods may either underestimate or overestimate the actual vitality levels of certain art installations. Future research should incorporate time-series analysis methods to conduct continuous tracking of spatial vitality over periods exceeding one year, thereby establishing vitality prediction models with stronger dynamic explanatory capacity.

Third, the current model primarily adopts observable behavioral data—such as pedestrian volume and staying duration—as the dependent variables, without incorporating users' subjective perceptions and satisfaction evaluations of spatial quality. Behavioral data reveal what happens, whereas perceptual data explain how people experience and evaluate spaces; together, they constitute a more comprehensive understand-

ing of spatial vitality. Future research could introduce structural equation modeling to incorporate subjective perception variables, such as place attachment, perceived safety, and aesthetic pleasure, thereby improving the comprehensiveness and accuracy of spatial vitality assessment.

Finally, due to limitations in data availability and research timing, this study did not incorporate social media image data into the quantitative analysis. Future research could utilize open social media APIs to collect user-generated images and textual reviews over longer time spans. Through deep learning-based analysis of visual information, including crowd density and behavioral patterns, social media data could be combined with field observations for cross-validation, improving the temporal-spatial coverage and statistical robustness of the evaluation framework.

5. Conclusions

This study takes the Zhengzhou Oil and Fat Chemical Plant as an empirical case, adopts the HEFS as the theoretical foundation, and constructs a systematic installation–space–vitality evaluation framework to deeply analyze the mechanisms through which art installations influence the vitality of external spaces in industrial heritage sites. By applying four-quadrant classification and multiple regression modeling to 52 art installation nodes within the site, the study draws the following main conclusions:

(1) In the spatial context of Zhengzhou Oil and Fats Chemical Plant, the vitality-generating effect of art installations depends on the synergistic matching between installation and space, rather than the independent contribution of installation quality alone. The findings indicate that spatial environmental factors play a more dominant role in shaping the vitality performance of industrial heritage spaces.

(2) The spatial environment dimension is the dominant factor driving spatial vitality in industrial heritage sites. Interface richness is the core variable driving vitality intensity, while the vitality-enhancing effects of installation typology, volumetric proportion, and facility diversity are indirectly transmitted through their synergistic interactions with interface richness.

(3) The optimization pathways for different types of art installations vary significantly. Thematic landmark installations should be positioned in fully open spaces with strong centrality advantages while improving supporting facilities to enhance user engagement. Narrative component installations should adopt an integrated strategy combining installation design, heritage interface utilization, and facility configuration to maximize their vitality-generating potential. Artistic decorative installations should prioritize spatial enhancement, improving vitality performance through functional facility supplementation and interface enrichment rather than relying solely on improvements to the installations themselves.

This study addresses the limitations of previous studies on the quantitative relationship between art installation interventions and spatial vitality in industrial heritage sites at the micro scale. It establishes an operational installation–space–vitality systematic evaluation framework, providing theoretical support and evidence-based guidance for the application of art installations in industrial heritage regeneration. Future research can extend the investigation to industrial heritage sites of different types and scales, while incorporating multi-temporal longitudinal data to further improve the explanatory power of the model and refine practical intervention guidelines.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/buildings16183616/s1. File S1. Indicator weight calculation. Table S1: Expert Basic Information Overview. Table S2: Components of the Two-Dimensional Evaluation Model Indicators. Table S3: Proportional Scale Table. Table S4: Standard Values of the Average Random Consistency Index RI.

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Abbreviations

The following abbreviations are used in this manuscript:

HEFS	Human–Environment Field System
SVI	Spatial Vitality Intensity
AHP	Analytic Hierarchy Process
CRITIC	Criteria Importance Through Intercriteria Correlation

Appendix A. Photographs of the 52 Art Installations

Table A1. Images, classifications, dimensions, and brief introductions of 52 art installations.

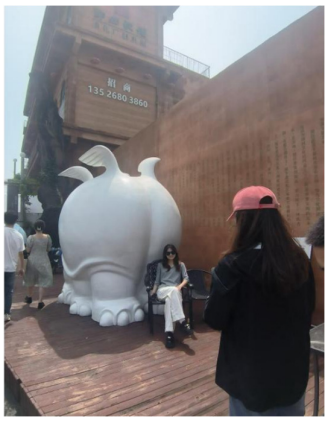
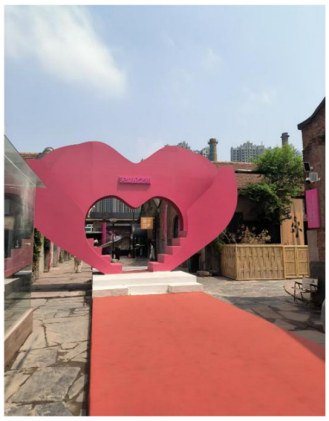
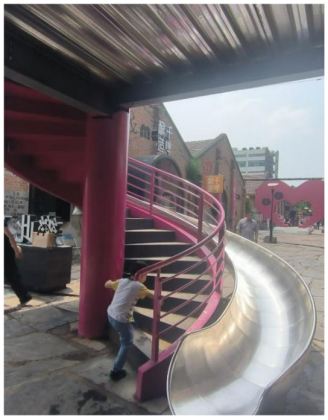
	No.01 Typology: Thematic landmark installations Dimensions: Approximately 3.5 m in height, 3 m in length, and 2 m in width Description: A large white rabbit sculpture located in the plaza in front of the red-brick building. With its rounded and full form, it serves as a core visual symbol and a landmark attraction of the site.		No.02 Typology: Artistic decorative installations Dimensions: Approximately 3.5 m in height Description: The installation features a tilted oversized white coffee cup as its main structure, with green plants accompanied by small white flowers cascading from the cup opening to the ground, creating a visually striking green waterfall effect.
	No.03 Typology: Thematic landmark installations Dimensions: Approximately 3.5 m in height and 4 m in width Description: A freestanding heart-shaped archway located along the main passage of the site, serving as an entrance frame. A red carpet is laid in front of the arch, creating a strong visual impact and a distinctive sense of place.		No.04 Typology: Artistic decorative installations Dimensions: The rabbit figure is approximately 1.5 m in height; the banner is approximately 3 m in height Description: A red cartoon rabbit figure sculpture wearing a black hood, accompanied by a pink vertical banner displaying the phrase "You are well known to everyone." It functions as a playful visual decoration at the street corner.
	No.05 Typology: Artistic decorative installations Dimensions: Approximately 4 m in height, with a floor area of approximately 6 m^2 Description: A bright pink metal spiral staircase attached to the exterior wall of an old red-brick building. The curved panel on one side of the staircase functions as a slide, combining circulation, interactive, and recreational functions.		No.06 Typology: Artistic decorative installations Dimensions: Approximately 2 m in length and 0.5 m in width Description: A dark wooden linear bench located at the intersection of a traditional wooden-style eave and a red-brick wall. Artificial greenery is wrapped around the upper part of the bench, creating a relaxed and leisure-oriented atmosphere.

Table A1. *Cont.*

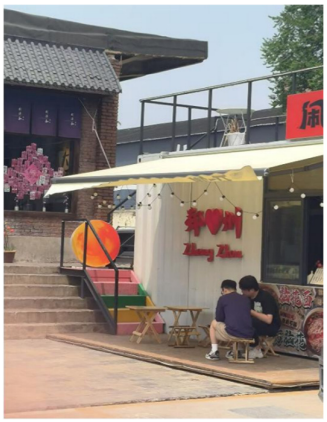
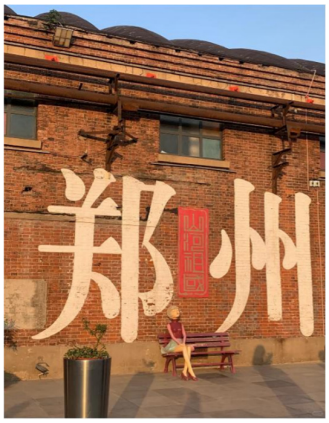
	No.07 Typology: Artistic decorative installations Dimensions: Approximately 2 m × 2 m for the display window Description: A square glass display window embedded within a red-brick wall, featuring a dense collage of photo wall stickers inside and marked with the address sign Shan 9. The installation conveys a strong sense of community-oriented commercial atmosphere.		No.08 Typology: Artistic decorative installations Dimensions: Approximately 3 m in frontage width Description: A storefront of a commercial space transformed from an old factory building, featuring a black-and-white signboard reading Liu Yang He Kao Rou, decorated with large red fabric drapes and accompanied by gray stone steps at the entrance.
	No.09 Typology: Artistic decorative installations Dimensions: The tent covers an area of approximately 3 m × 3 m Description: A square white folding tent stall located beside the steps, printed with the words “Zheng Hao Kan” and equipped with folding tables and chairs. It represents a typical form of small-scale commercial facility within the street block.		No.10 Typology: Artistic decorative installations Dimensions: The mural is approximately 2 m × 2 m Description: A painted mural on a red-brick wall featuring a silhouette of an urban skyline. The wall is decorated with red heart motifs and the word “Encounter,” with a set of outdoor bar seating arranged below.
	No.11 Typology: Narrative structural installations Dimensions: The mural is approximately 4 m × 4 m Description: A large-scale wall mural featuring the Chinese characters Zhengzhou, located on the extensive red-brick wall surface of the former factory building. The installation directly utilizes the original architectural interface as a medium for cultural narrative and collective expression.		No.12 Typology: Artistic decorative installations Dimensions: Approximately 2 m in width and 3 m in height Description: A glass display window enclosed by colorful graffiti and red-brick walls covered with handwritten marks. Exhibition or branded space can be vaguely seen inside, with the installation functioning primarily as a decorative element of the building facade.

Table A1. *Cont.*

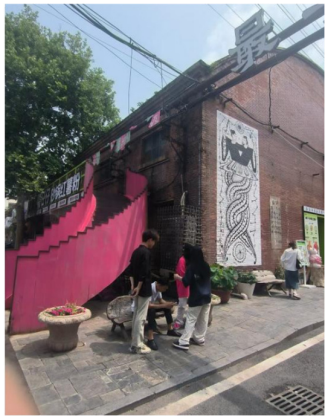
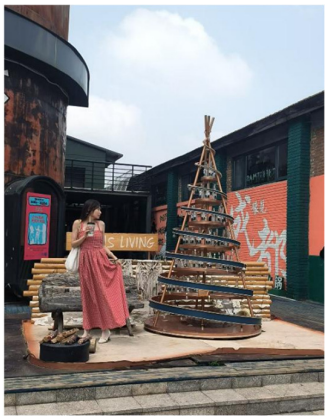
	No.13 Typology: Artistic decorative installations Dimensions: Approximately 3 m in storefront width and 2.5 m in facade height Description: Multiple Hello Kitty figure sculptures are embedded into the walls of the Candy Star trendy toy shop. A large wall mural on the right side features a red bow and Hello Kitty portrait pattern, creating a playful and visually distinctive commercial facade.		No.14 Typology: Artistic decorative installations Dimensions: Approximately 3 m in storefront width Description: A wooden outdoor seating area in front of the Kuaile Xiaogou Handmade shop, equipped with colorful round stools and cartoon face display boards. The storefront is decorated with cute signage text and graphic elements, creating a lively and playful commercial atmosphere.
	No.15 Typology: Artistic decorative installations Dimensions: Approximately 3 m in height and 2 m in width Description: A bright pink metal decorative staircase attached to the exterior of an old red-brick building, connecting pedestrian platforms at different elevations. Its high-saturation color adds visual vibrancy and highlights the street corner.		No.16 Typology: Artistic decorative installations Dimensions: Approximately 2.5 m in height Description: A freestanding sculpture/decorative object located in front of the rusted cylindrical building. Serving as a visual complement to the cylindrical landmark structure, it enhances the aesthetic quality of the surrounding space.
	No.17 Typology: Artistic decorative installations Dimensions: Approximately 3 m in height, with a base diameter of approximately 2 m Description: A pyramid-shaped art installation composed of numerous stacked and interconnected wooden logs. The installation incorporates internal lighting and functions as a public art piece within the plaza.		No.18 Typology: Thematic landmark installations Dimensions: Approximately 5 m in height and 4 m in diameter Description: A large rusted metal cylindrical structure. Located at a significant global spatial node within the site, it functions as a major visual landmark and cultural symbol of the industrial heritage park.

Table A1. *Cont.*

	No.19 Typology: Artistic decorative installations Dimensions: The archway is approximately 4 m in height and 2.5 m in width Description: An arched entrance combining gray brick and red brick elements. A large moon circular disc and a bed-shaped sculptural installation are embedded within the arch opening, creating a distinctive facade for a Live House venue.		No.20 Typology: Artistic decorative installations Dimensions: Approximately 2 m × 2 m Description: A stepped glass display cabinet cleverly embedded into the uneven texture of the red-brick wall. The cabinet contains neatly arranged horizontal rows of blue glass bottles, creating an independent and visually engaging commercial window display.
	No.21 Typology: Narrative structural installations Dimensions: Approximately 6 m in width and 3 m in depth Description: An outdoor performance stage transformed from a former industrial unloading platform preserved from the old factory buildings. The installation retains traces of the industrial era and carries strong commemorative significance as a representation of the site's historical memory.		No.22 Typology: Artistic decorative installations Dimensions: The flower frame is approximately 3 m in height and 2 m in width Description: A black metal framework with a strong industrial aesthetic, covered with dense green vines and red flowers. The installation forms a three-dimensional landscape feature, integrating industrial character with greenery as a spatial decorative element.
	No.23 Typology: Artistic decorative installations Dimensions: Approximately 4 m in storefront width Description: A small tavern facade designed in the style of an old factory building. The wall features a white signboard reading "137," while discarded tires and other rough-textured decorative objects are placed at the entrance.		No.24 Typology: Artistic decorative installations Dimensions: The graffiti wall is approximately 3 m × 2 m Description: A brick wall featuring rainbow-colored HAPPY graffiti, accompanied by a cartoon white dog sculpture. A metal staircase leading to the upper level is integrated into the scene, creating a playful and interactive spatial composition.

Table A1. *Cont.*

	No.25 Typology: Artistic decorative installations Dimensions: The letter composition is approximately 2 m × 1.5 m Description: Raised white three-dimensional English letters spelling WISH TODAY are mounted on a rough-textured white wall. Attached to red-brick and concrete surfaces, the installation represents a localized landscape treatment of the building facade.		No.26 Typology: Artistic decorative installations Dimensions: The umbrella has a diameter of approximately 3 m Description: An open-air beverage and snack seating area with outdoor commercial elements. It features a large red sun umbrella, pink tables and chairs, and a storefront decorated with cute pink cartoon figures, creating a colorful and lively atmosphere.
	No.27 Typology: Narrative structural installations Dimensions: The mural is approximately 4 m × 4 m Description: A large-scale Zhengzhou artistic graffiti mural on the exterior wall of the red-brick factory building, viewed from another perspective. Dappled sunlight filtered through tree canopies falls across the wall surface, enhancing the site's urban cultural narrative.		No.28 Typology: Artistic decorative installations Dimensions: Approximately 4 m in storefront width Description: A traditional red-brick storefront with a dark wooden signboard reading Yakitori House hanging above the entrance. The wall features child-themed cartoon graffiti, creating a strong handcrafted workshop atmosphere.
	No.29 Typology: Artistic decorative installations Dimensions: The staircase is approximately 4 m in height Description: The wall beneath the dark metal staircase is painted with exaggerated graffiti-style faces and smiley patterns, accompanied by the word "WELCOME." The installation functions as a visual decoration within a corner space of the site.		No.30 Typology: Artistic decorative installations Dimensions: approximately 3 m in width Description: The red-brick exterior wall of the former factory building is almost entirely covered by dense green climbing plants, with only a small window remaining visible. The naturally cascading vegetation covers both the wall surface and part of the adjacent leisure seating area.

Table A1. *Cont.*

	No.31 Typology: Artistic decorative installations Dimensions: The bear sculpture is approximately 1 m in height Description: A brown seated bear sculpture located beside the left column of a commercial storefront. The bear wears a blue bow and holds a yellow yogurt cup with both hands, while pink flowers form the background.		No.32 Typology: Artistic decorative installations Dimensions: Approximately 3.5 m in height and 3 m in width Description: A deep arched passageway constructed with red bricks, guiding the viewer's line of sight inward. A red decorative plaque is mounted on the exterior wall of the entrance, enhancing the visual character of the architectural interface.
	No.33 Typology: Artistic decorative installations Dimensions: Approximately 2.5 m in height and 1 m in width Description: A classic British-style dark green public telephone booth installation positioned beside a red-brick building and wooden fence. It functions as a decorative streetscape element with a nostalgic sense of time and spatial transformation.		No.34 Typology: Artistic decorative installations Dimensions: The bench is approximately 1.5 m in length Description: A wooden bench surrounded by pink balloon-shaped decorations and greenery. Combined with a layout featuring the words "Spring Seat," the installation has a clear function as a photo-taking and social media check-in spot.
	No.35 Typology: Artistic decorative installations Dimensions: The swing span is approximately 2 m Description: A children's interactive installation located under the shade of trees, featuring yellow spherical seats suspended from the frame. Pink cherry blossom branches are attached around the structure.		No.36 Typology: Artistic decorative installations Dimensions: The staircase is approximately 4 m in height Description: A blue-green metal spiral staircase attached to an old building and integrated with surrounding tree growth. Beneath the staircase is an outdoor blackboard sign for a café.

Table A1. *Cont.*

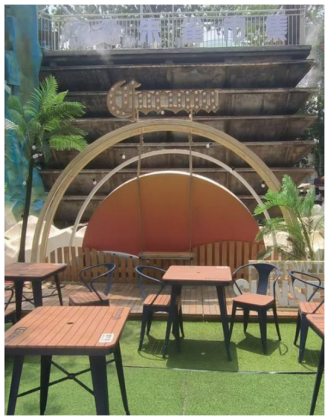
	No.37 Typology: Thematic landmark installations Dimensions: The cylindrical structure is approximately 4 m in height, with a circumference of approximately 10 m Description: A large rusted metal cylindrical structure covered with extensive handwritten-style white poetry on its exterior surface. Located at a global spatial node, it functions as an iconic freestanding structure and a prominent visual landmark within the site.		No.38 Typology: Artistic decorative installations Dimensions: Approximately 3 m in total length and 1.5 m in height Description: A wave-shaped public bench assembled from wooden modules, with a yellow sun-shaped backdrop panel attached to one end. It functions as both a resting facility and a landscape feature suitable for photography.
	No.39 Typology: Narrative structural installations Dimensions: The preserved wall fragment is approximately 5 m in width Description: A landscape heritage node retaining the weathered red-brick wall remains of the former factory building. A white classical statue and greenery are placed in front of the wall, conveying the site's temporal transformation and industrial memory.		No.40 Typology: Artistic decorative installations Dimensions: The tabletop diameter is approximately 0.8 m Description: An outdoor courtyard area covered with artificial green turf, featuring a long wooden table and metal chairs at the center. A semi-circular wooden decorative structure is placed in the background, forming an outdoor seating area for a café.
	No.41 Typology: Artistic decorative installations Dimensions: Approximately 2 m in height Description: A pink heart-shaped hollow photo spot frame constructed around a tree trunk, accompanied by a curved pink bench. Located at a tree-shaded street corner, the installation creates a romantic and interactive landscape feature.		No.42 Typology: Artistic decorative installations Dimensions: Approximately 3 m in storefront width Description: A wooden framed storefront structure of the "Hegu" Japanese-style tea bar, accompanied by an outdoor setting inspired by Japanese dry landscape gardens. The ground is covered with gravel and arranged with potted plants and stones.

Table A1. *Cont.*

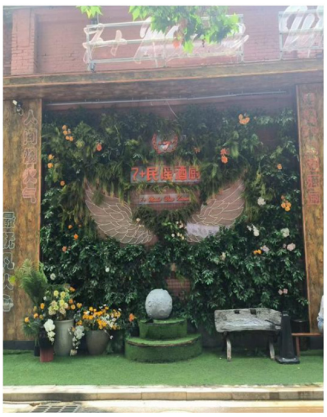
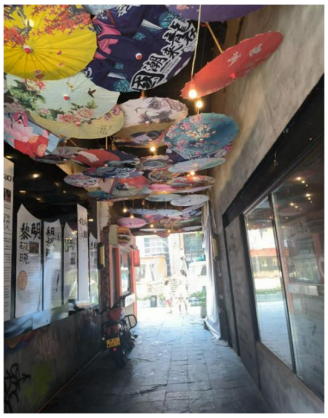
	No.43 Typology: Artistic decorative installations Dimensions: Approximately 3.5 m in storefront width Description: A commercial space featuring tea, coffee, and Chinese cuisine. The facade adopts an earthen-yellow textured finish, combined with dark wooden window frames and a prominent "Hegu" signboard, presenting a rustic and natural commercial aesthetic.		No.44 Typology: Artistic decorative installations Dimensions: The wooden barrel diameter is approximately 0.5 m Description: Outside the bar, a set of traditional wooden barrels is used as alternative seating elements. Above the seating area, a flower frame with cascading lush magenta flowers creates a strong atmospheric and decorative effect.
	No.45 Typology: Artistic decorative installations Dimensions: The wall surface is approximately 3 m × 3 m Description: A dense green foliage wall featuring a pair of white sculptural elements resembling "angel wings" at its center. With rich symbolic meaning, the installation is highly suitable for visitor interaction and photo-taking activities.		No.46 Typology: Artistic decorative installations Dimensions: Approximately 3 m × 1.5 m Description: A painted wall installation attached to the exterior facade of the building, featuring a white background with black calligraphic text presenting a long modern poem. It functions as a minimalist form of wall-based artistic decoration.
	No.47 Typology: Artistic decorative installations Dimensions: Approximately 3 m in span Description: A large number of colorful traditional oil-paper umbrellas are suspended above a narrow pedestrian alley, transforming an ordinary passageway into a visually distinctive corridor with a strong traditional Chinese aesthetic and dynamic interplay of light and shadow.		No.48 Typology: Artistic decorative installations Dimensions: The entrance is approximately 4 m in height and 3 m in width Description: A red square metal tube framework forming an entrance structure embedded within a red-brick building. A site wayfinding sign is placed beneath the frame, creating a distinctive storefront entrance display.

Table A1. *Cont.*

	No.49 Typology: Artistic decorative installations Dimensions: The support structure is approximately 2.5 m in height Description: A black wrought-iron structure located at a street corner, featuring painted graffiti elements on its surface and a hanging red vertical banner. A white bench is placed beside it, forming a localized landscape node within the site.		No.50 Typology: Artistic decorative installations Dimensions: The staircase is approximately 3.5 m in height Description: A pink metal spiral staircase ingeniously constructed around the thick trunk of a large tree. Leading to a small viewing platform beneath the tree canopy, the installation combines an industrial aesthetic with natural landscape elements.
	No.51 Typology: Narrative structural installations Dimensions: Approximately 2 m × 1.5 m Description: An industrial-style art component created by reassembling and recombining discarded industrial machinery parts, such as gears, metal frames, and rollers. The installation preserves traces of the site's industrial heritage.		No.52 Typology: Artistic decorative installations Dimensions: The staircase is approximately 3.5 m in height Description: A blue-green metal spiral staircase constructed around an old tree trunk. The base of the staircase provides outdoor seating, while the structure itself functions as a streetscape element integrating circulation guidance and aesthetic enhancement.

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