

Material Flow Analysis of Construction Waste in Xining City

Yansong Bai

School of Civil Engineering and Water Resources, Qinghai University, Xining, Qinghai, 810016, China

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Abstract: This study focuses on Xining City as a case study to analyze the current status and challenges in construction waste management. Using material flow analysis, the research examines the entire process of construction waste from generation, treatment to final disposal in Xining, aiming to evaluate resource utilization efficiency and identify key issues. The analysis reveals that the comprehensive utilization rate of construction waste in Xining City is only 15.3%, with 83.1% of waste directly landfilled, indicating a low level of resource recovery. Further analysis from government, enterprise, and societal perspectives highlights systemic issues in the current management framework, including inadequate policy enforcement and supervision, outdated technologies and insufficient production capacity in recycling enterprises, as well as weak public participation awareness. Xining's construction waste management remains at a preliminary stage dominated by end-of-pipe disposal. There is an urgent need for systematic improvements through enhanced policy coordination, technological innovation, and market cultivation to accelerate the establishment of a circular economy model.

1. Introduction

Due to the continuous increase in the global population, economic development, and urbanization, the construction industry has expanded rapidly ^[1]. As a key force in the global construction industry, China's floor area has grown at an unprecedented rate, with an average annual increase of over 2 billion square meters from 2018 to 2022 ^[2]. The rapid expansion and frequent demolition of urban renewal have greatly accelerated the renewal of urban floor area. However, in this process, construction and demolition have led to various challenges, such as the unregulated accumulation and illegal disposal of construction, renovation, and demolition waste, which seriously affect ecological health and public welfare ^[3].

Construction and demolition waste is recognized as a globally critical issue ^[4]. Accounting for over 30% of total waste, it represents the largest waste stream worldwide ^[5]. The environmental impact of construction waste leads to severe air, water, and soil pollution ^[6]. Effective management of construction waste has become a priority in global sustainable development initiatives ^[7]. While traditional waste management strategies have brought some improvements, they haven't fundamentally mitigated the impact. The industry urgently needs new strategies, including

government policy support, to transition from a linear economy to a circular economy. In Europe, where construction is a priority area under the Circular Economy Action Plan, construction waste recycling rates have significantly improved^[8]. Although some developed countries have achieved high recycling rates for construction and demolition waste, the global average remains around 30% .

Currently, China classifies construction waste into five categories, including engineering spoil, engineering slurry, engineering waste, demolition waste, and renovation waste. According to the 2021 estimates by the Ministry of Housing and Urban-Rural Development, Chinas annual construction waste production exceeds 2 billion tons, which is eight times that of domestic waste and accounts for about 40% of the total urban solid waste.

2. Current Research Status

2.1 Current Status of Foreign Research

The construction industry consumes substantial resources (50% energy, 30% water, 50% materials) and generates approximately 35% of total waste. The EU has implemented a systematic "pre-treatment-transportation-processing-disposal" workflow, applying differentiated treatment models based on waste composition and recycling potential. When construction waste cannot be reused or recycled, incineration can be employed to process high-calorific components for energy recovery, which can be utilized for power generation or heating.^[9] Landfilling, as a lower-priority disposal method, is primarily suitable for non-degradable inert materials with stable physicochemical properties, such as waste concrete and asphalt. Landfills typically serve as the last resort for waste disposal^[10], strictly enforcing waste classification standards that categorize materials into hazardous, non-hazardous, and inert waste.

2.2 Domestic Research Status

Chinas regulatory framework for construction waste management was established relatively late, beginning with the 1995 "Solid Waste Pollution Prevention and Control Law of the Peoples Republic of China," which laid out fundamental requirements for solid waste disposal including construction waste^[11].

Recent studies indicate that while addressing potential environmental risks in the recycling process, it is essential to emphasize environmental risk prevention and control during the regeneration process . As of 2022, the national average resource utilization rate remains below 10%, far lower than that of developed countries and regions such as Europe and the United States^[12] .

3. Framework for Material Flow Analysis

3.1 System boundaries

This study selects Xining City as the spatial boundary of the system. Given that the "China Statistical Yearbook" is currently updated to 2023,2023 is chosen as the temporal boundary of this study. As of 2023, the total area of Xining City is 7,660 square kilometers^[13], and the GDP of Xining City in 2023 was approximately 180.11 billion yuan. The total amount of construction waste in Xining City in 2023 serves as the input end of the system, excluding inputs from outside the city. The input end of the system includes engineering waste soil and foundation materials, demolition and construction waste, decoration and renovation waste, and metal and electrical waste, with the total amount of by-products serving as the output end.

3.2 Evaluation Indicators

See Table 1 for details.

Table 1. Evaluation indicators for material flow analysis of construction waste

Related section	metric	computational method
system input terminal	Regional construction waste generation (W)	
	The intensity of construction waste generation	Waste volume per unit of GDP
systemic transformation	Recycling rate of construction waste	Waste input ÷ Total construction waste
	Resource conversion rate	(Regenerated raw material output ÷ Waste input) × 100%
	Resource recovery loss rate	Losses – Recycled construction waste volume
system output terminal	Comprehensive utilization rate of construction waste	The ratio of recycled material output to total construction waste generation is multiplied by 100%.
	End-of-pipe emissions	ratio of residual material to be disposed of by landfill

3.3 Data Sources

The data for this study mainly comes from official statistical data such as the "2023 Annual Report on Solid Waste Pollution Prevention and Control in Xining City", the "China Statistical Yearbook", and the "Xining Statistical Yearbook", as well as industry white papers and relevant policy documents released by the Xining Municipal Ecology and Environment Bureau. It also incorporates academic literature ^[14], market analysis reports, and industrial forecasting research. This study did not quantify the hidden material flows in informal recycling channels. The matching relationship between waste generation characteristics of each subsystem and regeneration technology pathways is detailed in Table 2

Table 2. Composition and treatment methods of construction waste in Xining City in 2023

ingredient	Production (10,000 tons)	processing method
muck	56.90	Backfilling and Landscaping after Dehydration and Curing
aggregated rock	3.00	Regenerated aggregate material or landfill
sandy soil	2.50	Regenerated aggregate material or landfill
concrete block	1.00	reclaimed aggregate, landfill
Broken brick or block	0.60	recycled brick, landfill
engineering mud	0.36	dumping
wood	0.18	incineration, composite panels
plastics	0.08	landfill, crush, pyrolysis
glass	0.05	dumping
plasterboard	0.06	dumping
Reinforced steel structures	0.07	recrystallization
Aluminum/copper	0.03	metal recovery
Waste electrical equipment	0.17	professional disassembly and landfill
amount to	65.00	/

Note: Based on experiences from other cities and Xinings actual conditions, the construction waste estimation coefficient is set at 1.3t/m³.

3.4 Material Flow Analysis

The material flow analysis model is established by using the Sankey diagram. The basic information of the model is as follows: The source of construction waste is shown on the left side, and the contribution of each source to the construction waste production (W) in Xining city is positively correlated with the proportion of the bar node. (See Figure 1 for details and See Table 3 for details)

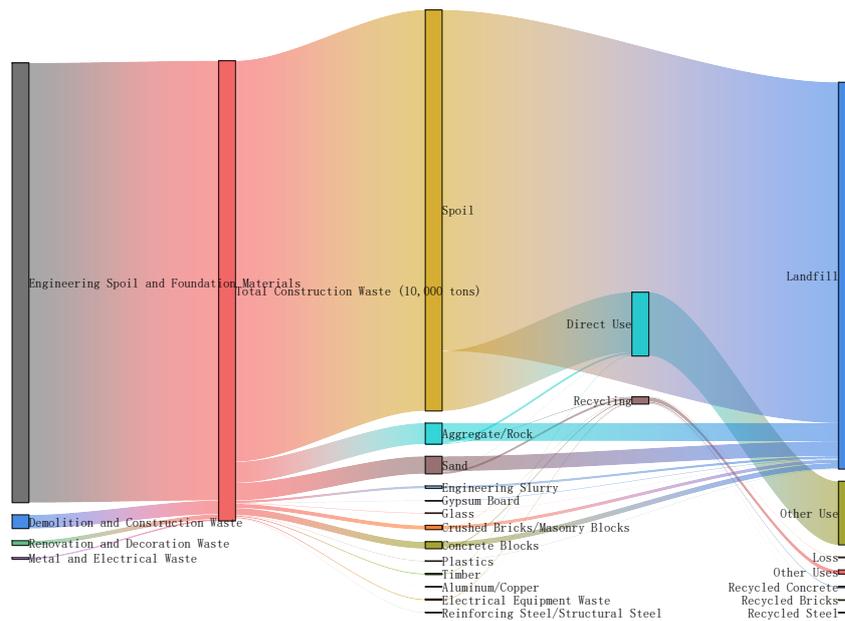


Figure 1. Sanchi Map of Construction Waste Material Flow in Xining City in 2023

Table 3 Evaluation Index Results of Construction Waste in Xining City in 2023

metric	calculated value
Regional construction waste generation (W)	650,000 tons
Intensity of construction waste generation	0.036 million tons per billion yuan
Recycling rate of construction waste	15.5%
Resource conversion rate	3.4%
Resource recovery loss rate	6.2%
Comprehensive utilization rate of construction waste	15.3%
End-of-pipe emissions	83.1%

In 2023, Xining City generated 650,000 tons of construction waste, including 3,600 tons of engineering slurry, 624,000 tons of construction spoil and foundation materials, and 22,400 tons of construction debris. The majority of construction waste was disposed of through landfilling, with 540,000 tons buried^[15]. If the market standard for resource recovery is set at 30-60 yuan per ton, the market value of construction waste resource recovery in Xining City in 2023 would range between 19.5 million and 39 million yuan. While most construction debris, stone materials, and sand were landfilled, with an end-of-pipe discharge rate of 83.1%, only 101,000 tons of construction waste

entered the resource recovery system, achieving a 15.5% recovery rate. The resource recovery loss rate stood at 6.2%, and the comprehensive utilization rate of construction waste was merely 15.3%. This indicates low resource recovery efficiency in Xining City, significantly lagging behind the 35% comprehensive utilization rate required by the "Implementation Opinions on Promoting Construction Waste Reduction and Resource Utilization" issued by ten departments in Qinghai Province^[16]. From the material flow perspective, scrap steel demonstrated the highest regeneration rate at 85%, highlighting its economic advantages in recycling. In contrast, construction waste components like concrete, sand, and brick waste (accounting for 12% of total construction waste) had regeneration rates around 13%. The generation intensity of construction waste serves as a key indicator of resource utilization efficiency and environmental impact in the construction industry. With a generation intensity of 0.036 million tons per billion yuan, construction waste...The low value conversion rate of 3.4% of the resources is the reason for the low strength of the brick and stone.

4. Current Situation of Construction Waste Resource Utilization in Circular Economy in Xining City

4.1 Status of Construction Waste Treatment Facilities in Xining City

Table 4 presents the status of construction waste treatment facilities in Xining City, with data sourced from field surveys and official records including public information from government departments such as the Xining Municipal Ecology and Environment Bureau, Urban and Rural Construction Bureau, and Statistics Bureau^[17]. In 2023, 540,000 tons of construction waste were disposed of at the Songjiagou Construction Waste Disposal Site, which has a designed annual processing capacity of 1,844,700 tons. (See Table 4 for details)

Table 4 Status of Construction Waste Treatment Facilities in Xining City

processing unit	type	area
Xixingyuan Landfill	landfill site	North City District
Zhengyuan Construction Waste Disposal Site	landfill site	East City District
Shenjiagou Waste Recycling Plant	regenerative field	West District
Songjiagou Construction Waste Disposal Site	landfill site	Huangzhong County
Liujiagou Construction Waste Disposal Site	landfill site	Huangzhong County
Qinghai Jingwei Concrete Co., Ltd.	concrete batching plant	City District
Qinghai Taiyang Concrete Co., Ltd.	concrete batching plant	East City District
Qinghai Juyi Concrete Co., Ltd.	concrete batching plant	City District
Senchang Concrete Company	concrete batching plant	Datong County
Xining Weiye Concrete Co., Ltd.	Component Factory	West City District
Xining Shengping Concrete Components Co., Ltd.	Component Factory	City District
Lihui Non-fired Brick Factory	brickfield	West District
Xinyuan Hollow Brick Factory	brickfield	West District
Fucaai Building Materials Factory	Building materials factory	North City District
Xidagou Construction Waste Landfill	landfill site	City District
Dingfeng Gas-Infused Brick Factory	brickfield	Datong County
Xining Chengbei Xichuan Insulation Building Materials Factory	Building materials factory	North City District
Qinghai Lishou Renewable Resources Recycling Co., Ltd.	Rebuild Project	North City District
Qinghai Qixin Renewable Resources Co., Ltd.	Rebuild Project	Datong County

4.2 Policies on the Resource Utilization of Construction Waste in Xining City

Since 2012, Xining City has progressively established a comprehensive policy framework

covering construction waste management, circular economy, and urban-rural waste governance, transitioning from single-point management to integrated solutions. The 2012 "Xining Urban Construction Waste Management Measures" mandated approval for waste disposal, required transportation units to obtain licenses, and standardized landfill management under the principles of "reduction, resource recovery ^[18], and harmlessness." This policy replaced the 2004 "Urban Construction Waste and Engineering Slag Management Measures," reinforcing the "polluter-pays" accountability mechanism. The 2022 "Implementation Plan for Waste Recycling System Development" expanded management to all types of waste materials, proposed industrial clustering for recycled resource processing, and promoted second-hand trade and remanufacturing industries. The 2014 "Urban Construction Waste and Engineering Slag Management Measures" required licensed transportation operations with designated routes, establishing a preliminary closed-loop management framework of "application-transport-disposal." The 2023 "Special Rectification Plan for Urban Construction Waste" focused on full-process supervision of construction, transportation, and disposal, cracking down on illegal dumping and advancing resource recovery projects. The 2025 "Huangzhong District Urban-Rural Waste Management Measures" extended coverage to rural areas, proposing a "household sorting-village collection-district transfer" model and encouraging private capital participation. The policies issued by Xining City regarding the construction of recycling collection points are detailed in Table 5.

Table 5. Policies on the Recycling of Construction Waste in Xining City

Policy Name	release time	core content
Xining City Construction Waste Management Measures	2012	<ol style="list-style-type: none"> 1. Encourage the development of construction waste recycling projects, with priority given to using recycled construction waste products. 2. Construction waste disposal requires official approval; unauthorized disposal is prohibited. 3. Transportation requires permits, waste disposal sites must sort materials by category, and construction waste should be encouraged for backfilling purposes.
Measures for the Management of Urban Construction Waste and Engineering Slag in Xining City	2014	<ol style="list-style-type: none"> 1. Implement the principle of "who generates, who is responsible for disposal" and "unified management, comprehensive utilization", and encourage centralized disposal and resource utilization. 2. Transporters must apply for a Construction Waste and Engineering Slag Transport Permit, specifying the route, schedule, and disposal site.
Implementation Plan for the Construction of a Recycling System for Waste Materials in Xining City	2022	<ol style="list-style-type: none"> 1. The overarching goal is to establish a comprehensive recycling system for waste materials by 2025. 2. Tackle the problem of scattered, disorderly and polluting industries, and promote the recycling industry. 3. Promoting the second-hand commodity trade and remanufacturing industry
Special Work Plan for the Rectification of Urban Construction Waste	2023	<ol style="list-style-type: none"> 1. Crack down on illegal dumping, establish a governance system, and enhance governance capacity. 2. Strengthen supervision over construction, transportation, and disposal processes, promote resource utilization projects, and enhance the levels of waste reduction and resource recovery.
Measures for the Management of Urban and Rural Waste in Huangzhong District, Xining City	2025	<ol style="list-style-type: none"> 1. Establish a source reduction mechanism to promote the reduction and recycling of packaging materials. 2. Construction waste disposal requires qualification approval, and construction sites must be enclosed with washing facilities. 3. Encourage private capital participation by establishing recycling points to support renewable resource recovery.

4.3 Status of Construction Waste Recycling Enterprises in Xining City

Most construction waste recycling enterprises in Xining operate on a small to medium scale, primarily adopting the "Internet + recycling" model to reduce costs. Many companies use mobile crushing equipment on-site, resulting in low product value-added and widespread dust and noise

pollution during production. The recycled materials often fail to meet quality standards, with most operations limited to basic material size reduction. Unstable raw material supply severely hampers quality improvement, while high investment requirements and long payback periods further restrict expansion^[19]. Notably, some companies are at a competitive disadvantage due to lack of land policy benefits, making it difficult for the industry to cultivate large-scale leading enterprises. This extensive development model significantly impedes the healthy growth of the construction waste recycling sector. The main construction waste recycling enterprises in Xining City are shown in Table 6.

Table 6 Major construction waste recycling enterprises in Xining City

enterprise	founding time	main business
Qinghai Weiyang Renewable Resources Co., Ltd.	2023	The recycling and comprehensive utilization of construction waste encompasses the processing of recycled aggregates, as well as the manufacturing and distribution of cement-based products including concrete blocks and asbestos cement products.
Huangzhong Fakui Mining and Trading Co., Ltd.	2012	The facility processes 100,000 tons of recycled construction waste and limestone slag annually. Through crushing and sorting, it produces recycled aggregates that are blended with limestone slag to manufacture eco-friendly building materials, including roadbed materials and permeable bricks.
Qinghai Jinglang Renewable Resources Co., Ltd.	2023	Construction waste removal, non-metallic waste processing, and production/sales of recycled building materials (e.g., metal structures, plastic products, glass products).
Qinghai Chianan Renewable Resources Recycling Co., Ltd.	2021	The company focuses on developing recycled construction waste technologies, producing lightweight building materials (including innovative energy-efficient wall materials), and distributing eco-friendly materials.
Xining Sheneng Huangshui Environmental Protection Co., Ltd.	2020	As a municipal solid waste incineration power plant, the slag generated is utilized by downstream enterprises to produce recycled building materials such as eco-bricks and roadbed materials, creating a synergistic effect between waste incineration and construction waste resource utilization.

4.4 Problems in the reuse of construction waste under the circular economy in Xining

4.4.1 From the governments perspective

The policy enforcement and regulatory oversight remain inadequate. Although Xining City has implemented the "Special Campaign Plan for Urban Construction Waste Management" with phased implementation, regulatory gaps persist in actual enforcement. For instance, illegal dumping and unauthorized disposal of construction waste continue despite repeated bans, revealing insufficient law enforcement and incomplete establishment of routine supervision mechanisms. Furthermore, while the campaign emphasizes resource utilization, it lacks explicit fiscal support or tax incentives for construction waste treatment^[20], leaving enterprises without sustainable development momentum.

The development of planning and infrastructure lags behind. Although Xining City has

incorporated construction waste treatment facilities into its territorial spatial planning, the actual construction lacks centralized processing facilities. Some enterprises still rely on mobile crushing equipment for open-air operations, exacerbating dust and noise pollution. Meanwhile, the progress in managing existing construction waste remains slow. Landfill sites (such as Songjiagou Construction Waste Landfill) have limited processing capacity, struggling to meet the classified disposal needs of renovation and engineering waste. Additionally, the number of recycling facilities is insufficient. The Xining City Construction Waste and General Solid Waste Resource Recovery Project, scheduled to begin in 2025, will add one new recycling facility with an annual processing capacity of 400,000 cubic meters of construction waste and 200,000 tons of other general solid waste. While this can meet Xining's construction waste processing demands, the facility is located in Datong County, and transportation costs for construction waste from other districts remain a challenge.

Insufficient cross-departmental coordination has led to fragmented management chains. With unclear division of responsibilities and weak collaborative mechanisms, the construction waste management system involves multiple departments including urban management, environmental protection, housing and urban-rural development, and transportation. However, Xining City has yet to establish an efficient interdepartmental collaboration mechanism. For instance, while construction waste transportation requires approval from urban management authorities, transportation routes are regulated by transportation departments, and environmental pollution is monitored by environmental protection agencies, practical implementation faces challenges such as delayed information sharing and buck-passing. These issues make it difficult to eradicate behaviors like littering and illegal dumping during transportation. Such fragmented management has resulted in a lack of specialized policy support. Although the "Zero-Waste City" initiative covers solid waste management, there are few dedicated policies for construction waste resource utilization, lacking land incentives or green finance support for recycling enterprises. For example, municipal solid waste incineration power generation projects receive substantial funding, while construction waste resource utilization projects rely on corporate self-funding, leading to prolonged investment return cycles.

The development of quality standards for recycled materials lags behind, with limited coverage. China has issued technical regulations such as the "Technical Code for Application of Recycled Aggregate" (JGJ/T 240-2011), "Technical Code for Application of Recycled Aggregate Permeable Concrete", "Technical Code for Durability Control of Recycled Aggregate Concrete" (CECS 385:2014), "Recycled Aggregate Floor Tiles and Permeable Bricks" (JG/T 400-2012), and "Technical Standard for Construction Waste Treatment" (CJJ/T 134-2019) to regulate recycled product quality. However, most of these are recommended standards with weak enforcement, making it difficult for private enterprises to process construction waste according to these standards for profit maximization. Moreover, there is a lack of unified specifications for recycled aggregates cleanliness and recycled product performance indicators. Industry standards like Xining City's "Management Standard for Construction Waste Transportation and Disposal" primarily target municipal solid waste and urban management, while specialized technical standards for construction waste recycling remain incomplete. For instance, construction waste crushed materials are only used for low-value products like roadbed materials or eco-friendly bricks, lacking quality specifications for high-value-added products such as recycled concrete and prefabricated building materials. Additionally, the absence of third-party quality certification has resulted in low market recognition for recycled products. While technical processes and environmental certifications exist for slag bricks from municipal solid waste incineration plants, standardized systems for recycled construction waste products (e.g., recycled aggregates) have yet to be established. The quality certification system restricts its market promotion.

4.4.2 From the perspective of the recycling enterprise

Technological backwardness and insufficient production capacity. Most construction waste recycling enterprises in Xining City operate on a small scale, relying on traditional crushing and sorting methods that yield inconsistent recycled products. These enterprises primarily produce low-value-added materials like roadbed materials with low resource conversion rates. In contrast, municipal solid waste incineration plants have mature slag recycling technologies, while the lack of advanced sorting equipment (such as intelligent sorting modules) for construction waste results in recycled aggregates with low cleanliness levels.

The supply of raw materials and market demand are constrained. The sources of construction waste are unstable, and some construction sites illegally dump or dispose of it, resulting in raw material shortages for recycling enterprises. Meanwhile, the market acceptance of recycled products is low, and the proportion of recycled building materials used in municipal projects is not mandatory, limiting the sales channels of enterprise products.

Regenerative enterprises face steep operational costs, including transportation, sorting, and environmental disposal expenses. For example, construction waste must be sorted and transported to different disposal sites, significantly increasing logistics costs. Moreover, the lack of policy subsidies makes it difficult for companies to cover investments in technological upgrades and equipment replacements.

4.4.3 From a social and public perspective

Insufficient awareness of waste classification and low public participation. Although the "Huangzhong District Urban-Rural Waste Management Measures" mandates waste sorting, the public's ability to distinguish between construction waste and household waste remains inadequate. For instance, renovation waste is often mixed with household waste during disposal, complicating downstream sorting and reducing resource recovery efficiency. According to a survey by the Qinghai Provincial Social Conditions and Public Opinion Survey Center, the awareness rate of "waste-free city" construction education and training in Xining City stands at 85.34%, while government agencies, enterprises, and the public show participation at 80.01%. Some citizens still harbor a dependency mentality, believing the government should handle everything.

The lack of public oversight mechanisms remains a critical issue. China's current environmental management system for construction waste lacks a robust information disclosure framework, with significant gaps in public supervision. Firstly, the development of environmental information platforms lags behind, as most regions still lack unified and transparent channels for releasing waste disposal data. Key information about resource utilization (such as recycling technology pathways and product distribution channels) remains fragmented and incomplete. Public access to information is primarily limited to post-incident pollution control progress, while transparency in preventive measures like source control and waste classification remains severely inadequate, resulting in prolonged passive public response. Secondly, public participation mechanisms remain superficial. Statutory procedures like environmental impact assessments are predominantly organized by administrative departments, with citizen engagement often limited to post-policy briefings rather than substantive involvement in core project phases like preliminary planning and technology selection. This top-down participation model fails to motivate public initiative, compounded by information asymmetry that confines opinions to predetermined frameworks, hindering the formation of a diversified social co-governance framework. Social capital participation remains low. Public trust in recycled building materials remains insufficient, with a preference for traditional materials. Additionally, the lack of incentive mechanisms (such as trade-in subsidies) fails to effectively engage residents and enterprises. Industry participation in construction waste recycling

enthusiasm.

5. Conclusion

Guided by the "dual carbon" goals, the resource utilization of construction waste is entering a critical development phase. Future efforts should prioritize circular economy initiatives to maximize the value of construction waste. By establishing a closed-loop management system encompassing "generation-recycling-utilization", we can ultimately transition from end-of-pipe disposal to comprehensive resource utilization throughout the entire lifecycle, thereby providing robust support for urban sustainable development.

Research indicates that Xining City should accelerate the establishment of a collaborative governance mechanism featuring government leadership, enterprise participation, and social engagement to effectively enhance construction waste recycling rates, achieving a win-win outcome for both economic and environmental benefits. Taking Xining as a case study, this research focuses on analyzing the current status and challenges in its construction waste management. By employing material flow analysis, the study details the entire lifecycle of construction waste from generation to disposal, evaluates recycling efficiency, and identifies key issues. The findings reveal low recycling rates. The analysis further examines systemic problems across three dimensions: government oversight, corporate practices, and public participation. Key issues include inadequate policy implementation and supervision, outdated recycling technologies with insufficient production capacity, and weak public awareness of recycling initiatives.

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