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Cross-Stage Coordination Dilemmas in Construction and Demolition Waste Recycling: A Transaction Cost Analysis of Renovation Waste Governance in Shanghai

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Abstract: The recycling of construction and demolition (C&D) waste is not a single end-of-pipe treatment activity but a continuous process consisting of four stages: generation and source disposal; collection, transportation and transfer; resource recovery and recycled material production; and engineering procurement and use. In this paper, cross-stage coordination means that the materials, information and responsibility arrangements formed in an upstream stage satisfy the reception, processing or use requirements of the downstream stage; a cross-stage coordination dilemma arises when adjacent stages each operate yet fail to connect stably because of incompatible requirements in quantity, quality, timing, cost or responsibility. Taking the governance of renovation waste in Shanghai as a case, and drawing on public statistics and survey records covering government disclosures, industry information and regulatory platform information, together with policy documents and related studies, this paper conducts an exploratory, theory-guided qualitative analysis of the coordination problems that persist after sorting management and treatment facilities have been established. The case material reveals three dilemmas: an intake coordination dilemma among generation and disposal, collection and transportation, and centralized treatment; a quality coordination dilemma between source sorting on the one hand and resource recovery and recycled material production on the other; and an application coordination dilemma between recycled material production and engineering procurement and use. Transaction cost theory indicates that the uncertainty of material delivery, the specificity of quality-related investment and the performance requirements of engineering procurement must be matched with arrangements for notification, acceptance, responsibility and cost allocation, and adjustment procedures; insufficient matching may reduce the reliability of handovers, and downstream application constraints may in turn affect upstream intake and treatment. On this basis, the paper proposes a governance path that connects intake allocation, quality responsibility and engineering procurement. The Shanghai case provides an analytical framework for cities in developing countries with similar material and organizational conditions to identify coordination dilemmas and their governance conditions. The proposed mechanisms are case-grounded conditional propositions that still require cross-stage process evidence.

Keywords: Construction and demolition waste recycling; Renovation waste; Cross-stage coordination; Transaction cost theory; Shanghai; Cities in developing countries.

1. Introduction

Urbanization in developing countries involves not only the concentration of population and economic activities but also the continuous reconstruction of housing, infrastructure and the built environment. New construction, demolition and renewal jointly generate streams of C&D waste, so that cities face constraints on disposal space and demand for construction materials at the same time. The 2018 Revision of World Urbanization Prospects projected that the global urban population would increase by about 2.5 billion between 2018 and 2050, with nearly 90% of the increase concentrated in Asia and Africa. This historical projection reflects the long-term concentration of demand for urban construction and environmental services in these regions [1]. A field survey of construction and demolition projects in Dhaka, Bangladesh, further shows that the average waste generation intensities of the two types of activity are about 73.9 kg/m² and 575.0 kg/m² respectively [2]. Although specific intensities depend on project and material conditions, these field results indicate that the expansion of construction creates persistent waste management demands.

C&D waste governance is therefore a basic capability that must be configured in step with urban development. Mismanagement increases pressure on disposal space, environmental pollution and risks to urban operations, while the concrete, masonry and metals contained in the waste have reuse potential. Haque et al. [2] reveal the tension between construction expansion and management infrastructure; Ma and Hao [3] point out that the circular transition of C&D waste in China requires improving the quality and value of secondary materials and strengthening linkages among the actors involved. For cities in developing countries, the governance task includes both establishing formal collection, transportation and treatment capacity and converting recyclable materials into usable materials. As new construction coexists with the renewal of existing buildings, renovation waste, characterized by dispersed sources and mixed composition, further highlights the complexity of this task [4].

To delimit the scope of analysis, this paper divides the renovation waste recycling process into four stages: generation and source disposal; collection, transportation and transfer; resource recovery and recycled material production; and engineering procurement and use. A stage here is an operational phase with relatively independent tasks and responsible actors; cross-stage concerns the handover interface between adjacent stages, that is, whether the output of one stage can become an acceptable input for the next. Cross-stage coordination accordingly requires that material

quantity and composition, delivery timing, quality information, and cost and responsibility arrangements match one another. Equipment failure or process defects within a single stage do not in themselves constitute the coordination dilemmas discussed in this paper; a problem enters the scope of analysis only when it concerns delivery requirements, responsibility sharing or the handling of change between upstream and downstream stages.

The development of China's waste sorting institutions provides the policy background for discussing this transition. The 2017 Implementation Plan for the Household Waste Sorting System required the construction of systems for sorted disposal, collection, transportation and treatment, and introduced mandatory household waste sorting first in 46 key cities [5]. Qi et al. [6] place sorting-based recycling within the zero-waste society strategy and emphasize that governance measures should be configured according to waste type and stage of urbanization. Sorting thus concerns not only individual disposal behavior but also the organic connection between different governance stages. Household waste and C&D waste differ in sources and management institutions, but both face the question of how the achievements of sorting can be preserved in subsequent collection, treatment and utilization.

Shanghai is an important case for observing this question. The Shanghai Municipal Domestic Waste Management Regulations, effective from July 1, 2019, provide the local institutional basis for household waste sorting [7]. A survey of Shanghai residents by Tang et al. [8] shows that sorting facilities, recycling systems, and reward and penalty measures are associated with sorting behavior, indicating that institutional implementation depends on concrete organizational conditions. Household waste and C&D waste are governed by different institutions, but the sorted disposal, sorted collection and transportation, whole-process supervision and actor responsibility promoted by household waste sorting constitute the institutional environment in which Shanghai's solid waste governance is shifting from end-of-pipe disposal to whole-process sorting and resource circulation. Shanghai's dedicated C&D waste policies implement this governance orientation in the C&D waste sector: the construction waste disposal provisions promulgated in 2017 and effective in 2018 already addressed sorted treatment and the use of recycled products, and the 2023 notice on the whole-process governance of renovation and demolition waste further emphasized the connection of collection and transportation, facilities reaching design capacity, product quality and application promotion [9, 10]; the construction waste disposal provisions were further revised in 2025 to strengthen whole-process supervision and interdepartmental information sharing [9]. Together, these two policy tracks show that the problem facing C&D waste governance in Shanghai has shifted from simply making up for insufficient end treatment capacity to how the achievements of sorting can be preserved across the stages of collection, treatment and utilization.

The typicality of the Shanghai case lies in the coexistence of governance scale, facility foundations and operational contradictions. Public statistics on Shanghai renovation waste record that the declared volume of renovation waste in Shanghai was 6.2915 million tonnes in 2019 and remained 4.631 million tonnes in 2022; by the end of 2022, the combined treatment capacity for renovation and demolition waste was 11.21 million tonnes per year. At the same time, the actual daily throughput of Plant A was below its design capacity, the relevant sites in District B faced a tension between centralized hauling distance and dispersed impurity removal, and recycled aggregate also faced problems of connecting uses with destinations . This material makes Shanghai suitable for answering a question that goes beyond the capacity gap: as institutions and treatment capacity continue to be built, why may stable material intake and product use still fail to emerge?

This question is shared internationally. Lim et al. [11] find that actors across the Australian construction supply chain differ in their perceptions of governance barriers and strategies; Kleponė and Kovaitė [12] point out that a gap remains in Europe between relatively high C&D waste recovery rates and high-quality material circulation. Shanghai can provide concrete organizational process clues for this common problem. Its representativeness lies not in economic and administrative resources equivalent to those of all cities in developing countries, but in its ability to reveal the connection conditions that such cities need to consider in advance when expanding collection and treatment capacity and cultivating markets for recycled materials.

This paper accordingly poses its central research question: under conditions in which sorting management has been advanced and treatment facilities built, why does C&D waste recycling still face cross-stage coordination dilemmas, and how do transaction governance arrangements shape these dilemmas? The question is specified at three handover interfaces. First, among generation and disposal, collection and transportation, and resource recovery: why is it difficult for dispersedly generated renovation waste to be delivered stably as required by treatment facilities? Second, between source sorting on the one hand and resource recovery and recycled material production on the other: why is it difficult for front-end sorting requirements to be continuously converted into stable product quality? Third, between recycled material production and engineering procurement and use: why may qualified materials still fail to achieve predictable practical application? The three sub-questions correspond to intake coordination, quality coordination and application coordination respectively, and are linked by upstream-downstream feedback through facility intake, product inventory and supply capability.

Cross-stage coordination dilemmas are not attributed in advance to the failure of any particular actor, nor do they imply that every stage is problematic. They are identified by whether specific handovers persistently exhibit such phenomena as incoming materials that cannot be received, sorting results that cannot be preserved, quality that cannot be confirmed, or products that cannot enter engineering use. Drawing on transaction cost theory, the paper explains why these handovers require specific acceptance, responsibility, cost and adjustment arrangements, converts the operational contradictions found in the survey records into analytical propositions that can be further tested, and discusses their implications for cities in developing countries.

2. Literature Review and Research Questions

2.1. Behavioral Responses and System Performance in Sorting Research

Research on waste sorting first attends to actor behavior and its institutional conditions. Tang et al. [8] analyze

Shanghai residents' sorting behavior at the governmental, social and individual levels and find that rewards and penalties, facilities, recycling systems and environmental awareness all play associative roles. Weng [13] discusses sorting convenience, regulatory burden and differentiated services from the perspective of behavioral costs and utility. Together, these studies show that sorting behavior is embedded in concrete service and incentive conditions and cannot be explained by environmental awareness alone.

Managers in construction activities also play an important role. Shi and Hu [14] combine the theory of planned behavior with institutional pressure and find that attitude, subjective norms and perceived behavioral control are associated with project managers' sorting intentions, with institutional pressure affecting intentions through perceived behavioral control. This research extends the analysis from residents to actors in construction projects, but sorting intention, actual operation and final material utilization remain different outcomes. Explaining whether sorting achievements can extend downstream requires further study of the handovers between actors.

System-level environmental assessment emphasizes examining sorting effects across stages. Liu et al. [15] use life cycle assessment to analyze collection, transportation and treatment before and after household waste sorting in Beijing, estimating within their system boundary a 37.90% reduction in global warming potential, while noting that per-unit transportation impacts and overall system impacts may change in different directions. This indicates that sorting performance must be judged in combination with material composition, flows and treatment methods. The result cannot be used directly as evidence of emission reduction for Shanghai's renovation waste, but it supports extending the evaluative horizon from a single stage to the whole process.

2.2. Technical Potential and Organizational Conditions in Recycling Research

Studies of C&D waste generation, composition and recycling potential provide the basis for facility planning. Through field surveys in Dhaka, Haque et al. [2] identify waste generation intensities and recycling potential, demonstrating the link between construction activity and management demand. However, the presence of recyclable materials in a region does not mean that a given facility can obtain suitable feedstock within reasonable time and transport conditions. Converting material potential into stable operation still requires corresponding collection and intake arrangements.

Technical research continues to expand the feasibility of sorting and recycling. Dodampegama et al. [16] review artificial intelligence and robotic sorting and point out limitations arising from material complexity, insufficient public data and system application. Gao et al. [17] categorize machine learning applications into four domains, namely generation, on-site processing, transportation and disposal, and fifteen sub-domains, showing that technological innovation already covers multiple stages. These achievements improve identification and processing capabilities, but technical performance and cross-actor organization belong to different analytical levels: what materials a device can process is not the same question as who is responsible for delivering materials as required.

Research on renovation waste reveals this distinction. In a survey in Wuhan, Zhao et al. [4] find that insufficient tracking of sources and flows, together with low enterprise willingness to receive waste, jointly constrains governance, and they propose a policy framework of source responsibility, mid-stream transfer manifests and end capacity building. This study had already extended attention from end-of-pipe disposal capacity to the relations among sources, flows and enterprise intake, and it also suggests that renovation waste governance has an organizational complexity different from the recycling of waste from a single construction project. This paper further extends these relations to the engineering use end of recycled materials and examines its feedback on collection and treatment.

2.3. Actor Collaboration and Material Use in Circular Governance Research

Circular economy research extends C&D waste governance to value chains and inter-actor relations. Combining literature, interviews, questionnaires and causal loop diagrams, Ma and Hao [3] analyze closed-loop strategies for C&D waste in China, emphasizing that actor participation and key strategies are interrelated and highlighting the quality and value of secondary materials. A survey of 104 practitioners in the Australian construction supply chain by Lim et al. [11] shows that design consultants, general contractors and subcontractors perceive barriers and strategies differently. Whole-chain and multi-actor collaboration has been clearly discussed; further research should identify the concrete processes through which collaboration takes effect.

Alhawamdeh et al. [18] synthesize 55 papers and summarize governance drivers along political, economic, social, technological, legal and environmental dimensions. The study shows the diversity of influencing conditions and also raises the requirement of mechanism identification: when multiple conditions coexist, their operative processes must be distinguished, rather than treating all conditions simultaneously as causes in a particular case. Coordination research therefore needs to move from identifying participating actors to the content of handovers, the basis of acceptance, and procedures for handling change, in order to explain which organizational arrangements suit which transaction conditions.

Circular outcomes themselves also need careful definition. Using European data for 2010-2022, Kleponė and Kovaitė [12] examine the relationship between recycling performance and conditions such as innovation and markets, emphasizing the distinction between quantity and higher-value utilization; their proxy indicators remain insufficient to identify all differences in uses within recycling. This paper therefore defines effective utilization as the verifiable practical use of materials in suitable applications that meet quality and environmental requirements, and does not substitute plant-exit volume, selling price or the share of local absorption for this outcome.

2.4. Research Questions and Contributions of This Study

The literature reviewed above has answered the first two of three progressive questions: how behavioral and institutional conditions affect sorting [8, 14]; and how material characteristics and process conditions determine recycling potential [2, 16]. The third layer, namely when sorting management and facility construction are already under way, how the transactional requirements among actors are

implemented as executable arrangements, and why these arrangements may be insufficient to sustain stable intake, continuous quality investment and engineering procurement, remains relatively weak in existing research. The entry point of this paper is therefore not to treat whole-chain governance as an unresearched gap, but to build on existing knowledge and further interrogate the transaction governance of the handover interfaces between stages: by what agreements, acceptance and adjustment procedures the output of one stage enters the next, and why these procedures may fail.

This entry point differs from simply adding more barrier factors. Dispersed sources, complex materials and insufficient market demand may reflect physical and technical limits, but may also affect cooperation through searching, negotiation, verification and adjustment processes. Only by distinguishing these causal paths can one judge whether a problem calls for technical improvement, demand cultivation, or the reorganization of transaction relations. Table 1 summarizes the correspondence between existing research and the three sub-questions of this paper.

Table 1. Correspondence between the literature and the research questions

Literature stream	Representative studies	Established knowledge	Questions further asked in this paper
Sorting behavior and institutions	Tang et al. [8]; Shi and Hu [14]	Facilities, incentives and awareness influence sorting behavior or intention	How front-end input is confirmed and fed back at the back end
Materials and treatment technology	Haque et al. [2]; Dodampegama et al. [16]	Waste characteristics and process conditions influence recycling potential	How suitable materials are continuously delivered to facilities
Whole-process management of renovation waste	Zhao et al. [4]	Tracking, willingness to receive and disposal capacity are interrelated	How intake arrangements respond to changes in quantity and quality
Actor collaboration and circular quality	Ma and Hao [3]; Lim et al. [11]; Kleponė and Kovaitė [12]	Collaboration, material quality and markets influence recycling	How material output connects with engineering procurement and use

The contributions of this paper are as follows: taking cross-actor handovers as the unit of analysis, it specifies the general notion of insufficient coordination into three problems, namely intake coordination, quality investment and engineering procurement; it links transaction attributes to governance arrangements and proposes explanations that can be further tested through agreements and performance processes; and it incorporates the feedback of downstream application on upstream intake into the analysis, thereby providing a basis for cities in developing countries to identify the complementary governance conditions beyond facility construction. This paper is an exploratory, theory-guided qualitative case analysis that aims to propose empirically constrained conditional propositions and develop mechanism explanations, rather than to estimate the causal effects of policies.

3. Research Design and Theoretical Framework

3.1. Research Object and Material Sources

This paper adopts an exploratory, theory-guided qualitative case analysis, taking the mixed waste generated by housing renovation as its object. Shanghai was selected because institutional and facility foundations coexist with operational difficulties, which makes it possible to observe problems that a pure capacity-supply explanation cannot cover; this selection pursues analytical heuristic value rather than statistical representativeness of cities in developing countries. Renovation waste belongs to C&D waste, but differs from engineering spoil, demolition waste and relatively homogeneous waste concrete in composition, generation mode and recycled uses. Taking it as the entry point helps observe governance situations in which dispersed sources, multi-actor collection and transportation, and quality control act together. When extending the conclusions to other C&D waste categories, material and organizational conditions should be re-examined.

The paper draws mainly on survey records that assemble government disclosures, industry information and regulatory platform records on C&D waste recycling in Shanghai, covering declared volumes of C&D waste, destinations of recycled aggregate, facility capacity and conditions at certain related sites over a five-year period since 2016. These underlying sources are institutional and secondary rather than first-hand measurements taken by the author: the report does not contain independently sampled enterprise accounts, and figures such as facility throughput and disposal cost are used as they are recorded in the source documents. The material is organized by the collection, treatment and use stages and cross-checked against policies and the literature.

The policy analysis covers the 2017 construction waste disposal provisions (revised in 2025), the 2019 Shanghai household waste regulations, the 2023 notice on whole-process governance of renovation and demolition waste, the 2024 implementation opinions on strengthening construction waste management, the 2025 special action on renovation waste collection and transportation services, and the 2025 work plan for upgrading the renovation waste booking and hauling platform. Policies are used to identify institutional requirements and subsequent responses, the survey records to present operational phenomena, and theory to propose mechanism explanations; the three do not substitute for one another. The later issuance of policies does not prove that earlier problems have been solved, nor can the records of individual facilities directly represent all enterprises in the city.

It should be frankly acknowledged that this study relies mainly on secondary institutional sources, public policies and public statistics, and that no semi-structured interviews were conducted with generators, collectors and transporters, treatment enterprises or engineering purchasers. The analysis can therefore observe cross-stage operational phenomena and outcomes, but cannot directly confirm the behavioral motives and decision processes of the actors involved in handovers. This determines that the explanatory positioning of the paper is a theory-guided mechanism hypothesis rather than an empirical confirmation of actor motives; these limitations are further discussed in Section 6.

Data processing proceeded in three steps: first, the data, operational phenomena and recommendations obtained in the survey records were sorted separately, and only explicitly documented operating conditions were used as case clues; second, the clues were classified under intake coordination, quality linkage and engineering application, and the year, material category and statistical scope of the data were checked; finally, the clues were compared with policy provisions and theoretical explanations to distinguish observed phenomena, possible transaction mechanisms and competing explanations. Throughout this process, publicly released statistics, industry information and facility-level records were tagged by source type, so that each case clue can be traced back to its underlying document.

3.2. Transaction Attributes and Governance Arrangements

Transaction cost economics concerns the alignment between transaction attributes and governance arrangements. Asset specificity, uncertainty and transaction frequency affect the relative suitability of different organizational forms; market exchange, continuing cooperation and intra-organizational coordination have different incentive and adaptation characteristics [19, 20]. This perspective is suitable for turning insufficient collaboration into checkable questions: what materials or services are handed over, which conditions the two parties need to confirm, and how arrangements are adjusted when change occurs.

The unit of analysis in this paper is the handover with a clear responsibility boundary, including the delivery of waste from generators to collectors and transporters, the delivery of materials from collectors and transporters to facilities, and the delivery of products from processors to engineering users. Transportation, sorting, crushing and maintenance are mainly direct operating costs; searching for partners, negotiating terms, verifying performance and handling disputes constitute the transaction organization costs of concern here. Per-tonne treatment costs recorded in the survey records cannot serve directly as indicators of transaction costs. Testing may simultaneously serve production control and transaction acceptance functions and should be distinguished by actual use.

Uncertainty appears as the difficulty of predetermining quantity, composition, delivery time or demand; specificity refers to investments that may lose value when redeployed to other partners or uses, and does not simply mean expensive equipment; transaction frequency depends on the specific pairing of actors rather than on how often individual households renovate. Bounded rationality means that agreements cannot exhaust future changes, so governance must also provide adjustment and responsibility-confirmation procedures [21]. Opportunism is the contractual risk of concern to this theory, but this paper does not presume that the actors in the case concealed quality or strategically breached agreements; insufficient information and incomplete agreements cannot be directly equated with opportunistic behavior.

To facilitate identification in the renovation waste context, this paper operationalizes the three transaction attributes as follows. Uncertainty appears as temporal fluctuations in the composition and generation of incoming materials, for example as renovation activity rises and falls with seasons and residential renewal cycles, as dispersion in delivery locations and times, and as fluctuations in downstream engineering orders; in the absence of notification, acceptance standards and abnormal adjustment procedures, such uncertainty requires repeated negotiation. Asset specificity refers to factors invested to undertake a specific handover that would depreciate significantly if redeployed, such as sorting process arrangements adjusted to the composition of local renovation waste, batch sorting arrangements organized for specific engineering orders, or dedicated service sites and personnel; general-purpose factors such as ordinary transport vehicles are not specific investments. Transaction frequency depends on the density of repeated handovers between specific actors; the occasional generation of renovation waste by households does not imply equally infrequent dealings between treatment enterprises and other actors. It should be emphasized that equipment purchase and process investment are not in themselves transaction-specific investments in the sense of this paper; the paper focuses on specific investments formed in the handover process between stages and their governance, not on the allocation of fixed assets within enterprises.

Comparing governance forms is an important part of this perspective. For handovers whose quality is easy to verify and for which alternative partners are plentiful, standardized short-term transactions may already be suitable; where continuous supply, joint adjustment or specific quality investment is required, framework agreements and continuing cooperation can provide different safeguards; highly interdependent tasks may also be accomplished through intra-organizational coordination. Each form carries its own administrative burden, and it cannot be presumed that vertical integration or long-term cooperation is necessarily superior [20]. Coordination among urban departments provides the institutional environment and enforcement support and should not be directly equated with hierarchical governance within firms in the theory.

3.3. Analytical Framework and Conditional Propositions for Cross-Stage Coordination

This paper constructs a framework of transaction attributes, governance alignment, handover reliability and recycling outcomes. Material and activity characteristics form specific transactional requirements; acceptance, cost, responsibility and adjustment arrangements determine how these requirements are organized; the degree of alignment may affect negotiation, verification and responses to change, and in turn continuous delivery, facility operation and material use. Governance alignment must be identified independently through rules and performance records and cannot be inferred merely from low utilization or inventory.

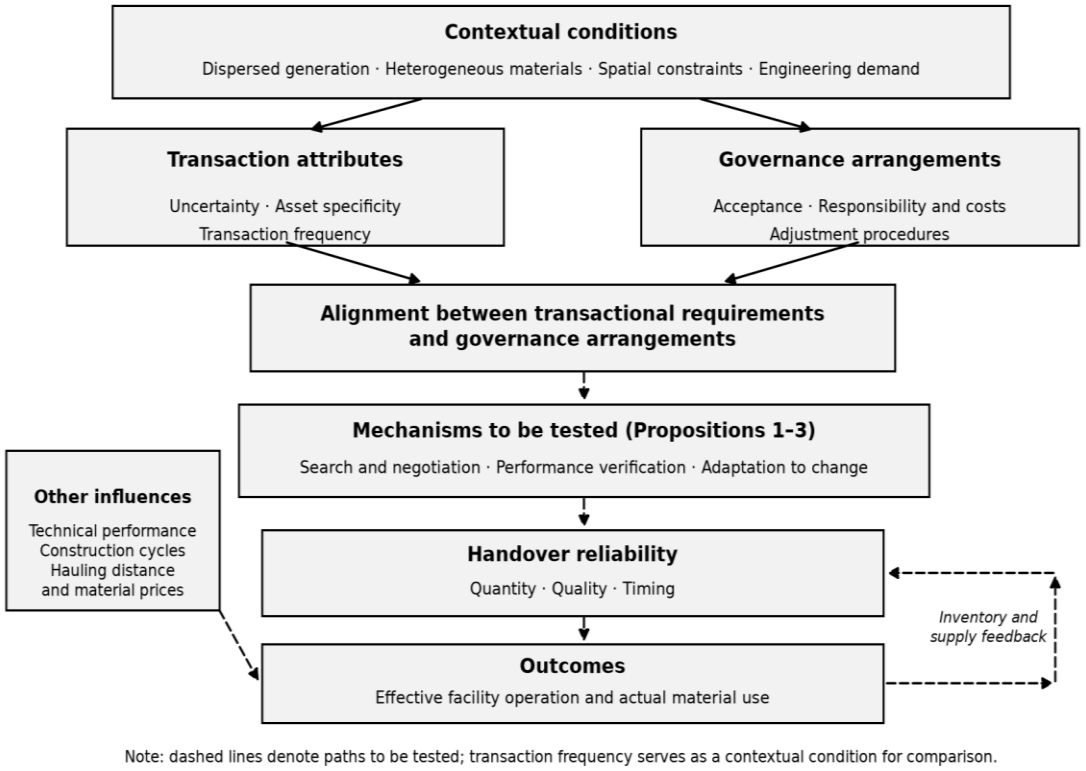


Figure 1. A transaction cost framework for cross-stage coordination in C&D waste recycling

Around the three sub-questions, the paper proposes three conditional propositions. They are formulated as to-be-tested interpretations supported by the case material rather than as verified results, and each is stated together with its scope conditions and competing explanations.

Proposition 1 (Intake coordination). Given that the receiving party has treatment conditions and suitable materials exist, the stronger the delivery uncertainty, the greater the need for clear notification, acceptance and abnormal adjustment arrangements; when these arrangements do not match the transactional requirements, the risks of repeated negotiation and delivery interruption may increase. This proposition concerns how existing materials are organized; it cannot explain pure material shortage or equipment downtime.

Proposition 2 (Quality investment). When source sorting or processing modification involves investments that are difficult to redeploy to other transactions, enforceable responsibility, cost and cooperation safeguards may strengthen the conditions for sustained investment. If investments are general-purpose and trading partners are easy to replace, long-term arrangements may not be necessary. What needs to be tested here is the alignment between investment specificity and safeguarding arrangements, not the amount of investment itself.

Proposition 3 (Engineering procurement). Given that materials meet performance requirements and actual engineering demand exists, mutually recognized quality verification, delivery arrangements and responsibility allocation may reduce the confirmation and performance difficulties in procurement. When demand is insufficient or materials are unqualified, simply adding information cannot make application happen.

The three propositions correspond to different handover relations, but their outcomes may feed back on one another. Obstructed engineering procurement may increase inventory and affect facilities' continued intake, while unstable incoming materials may in turn weaken supply commitments. This feedback is the key to bringing collection-transportation and material use into a single explanatory framework in this paper.

Transaction cost economics here provides the mechanism explanation, while the circular economy provides the outcome criterion. Smoother organization does not necessarily mean greater environmental benefit; effective use must still meet quality, safety and application requirements. In particular, this paper distinguishes regulated disposal services from recycled material product production: the former is a basic public environmental service that a city must guarantee, while the latter is a product that can enter market transactions. The two are interrelated, but their tasks, beneficiaries and revenue sources are not identical, and it cannot be assumed that all regulated disposal costs can be recovered through material sales; this distinction runs through the analysis of the intake, quality and application dilemmas below and serves as a premise for judging complementary governance in cities of developing countries. The paper accordingly uses the three propositions to organize evidence and compare explanations; it does not build a formal model, nor does it substitute the contextualized application of classical theory for empirical verification.

4. Three Coordination Dilemmas in Shanghai's Renovation Waste Recycling

4.1. The Intake Coordination Dilemma and Its Adaptation Requirements

According to the survey records, by the end of 2022 Shanghai had 27 renovation and demolition waste recycling facilities with a combined treatment capacity of 11.21 million tonnes per year. This statistical scope cannot be directly compared with the declared volume of renovation waste alone to infer a citywide capacity surplus. Facility commissioning

status, service scope and feedstock suitability also affect actual operation, so aggregate capacity and the material actually available to an individual facility must be distinguished.

The design capacity of C&D waste recycling and disposal Plant A is 2,000 tonnes per day, while the survey records report an actual throughput of only 800-900 tonnes per day, roughly 40%-45% of the design daily capacity. This ratio compares daily throughputs reported in the survey records; it is not a capacity utilization rate verified against annual ledgers, but it shows the distance between facility scale and actual operation. What an enterprise needs is not the abstract citywide waste total, but material delivered at appropriate times, within reasonable hauling distances and at agreed quality.

The case of renovation waste recycling and disposal in District B further presents spatial constraints: for some areas the distance to centralized sites is long, while dispersed treatment makes it difficult to achieve good impurity removal. Centralized treatment facilitates the organization of professional sorting, while dispersed generation increases collection and transfer requirements; the two must be configured together. Physical hauling distance is not itself a transaction cost, but who organizes transportation, how allocation is carried out, and who receives material under abnormal conditions are matters that governance arrangements must address.

Corresponding to Proposition 1, low utilization suggests examining the material handover process rather than directly adding capacity or attributing the problem to insufficient regulation. Whether changes in incoming materials are notified in advance, whether intake standards are clear, and whether cross-district allocation is executable may all affect the reliability with which facilities obtain material. Product backlogs may also affect intake in reverse; the 2023 Shanghai notice already proposed establishing emergency arrangements for seasonal product backlogs and situations in which waste cannot enter plants [10], a point taken up again below.

The theoretical implication of the intake coordination dilemma is that material existing at the city level is not equivalent to material receivable at the enterprise level. A facility must obtain deliveries that are mutually compatible in quantity, timing and quality before it can schedule operations. Improvised searches for destinations, repeated confirmation of intake conditions and re-allocation may prevent physical accessibility from becoming a stable organizational link. It should be clear that this phenomenon can also be explained by non-transactional factors such as equipment downtime, material shortage or changes in transport conditions, and the available material is not sufficient to rule out these alternative paths; this paper accordingly treats transaction-governance misalignment as a theoretical lens for examining intake shortfalls, not as a confirmation of causes. Owing to data availability, the survey records did not record the frequency and duration of these activities, and the reverse effect of product backlogs on intake also lacks enterprise-level operating data; the paper therefore treats them as paths of Proposition 1 to be tested, and draws on policy texts to bring downstream use constraints into the same explanatory framework.

4.2. The Quality Coordination Dilemma and Its Investment Safeguards

Renovation waste contains a large share of light substances, powdery soil and other components, and some materials still rely on manual sorting. The survey records also show difficulties in equipment maintenance and process stability, and contrast renovation waste with relatively high-quality waste concrete, whose products sell more smoothly. This information suggests that processes and business arrangements formed around a single material may not adapt directly to mixed renovation waste.

The survey records show that the disposal cost of renovation waste is about 70-100 CNY per tonne, but they do not fully specify the cost ranges and periods of individual enterprises, so this paper does not use it to rank technical options. What calls for explanation is that mixed materials distribute quality control across the source, transport and treatment stages. Front-end sorting can reduce the back-end burden but requires additional labor, space and organizational input; relying entirely on end-of-pipe sorting may concentrate quality control pressure on facilities. Technical improvement and cross-stage division of labor are thus interrelated.

Corresponding to Proposition 2, it is necessary to examine who bears the investment in sorting or quality improvement and whether its effects can be fed back through service or procurement relations. If better sorting does not change intake, fees or service conditions, the investing party may find it difficult to obtain a direct return; if adding quality control still fails to secure predictable orders, treatment enterprises may also lack the business conditions for continuous improvement. At the same time, quality problems caused by mixed incoming materials can also be explained by equipment and process capability, manual sorting efficiency or the composition of incoming materials themselves, and do not necessarily point to an investment-incentive misalignment; expensive equipment does not prove asset specificity, nor do differences in product quality and sales necessarily stem from unclear cross-stage responsibilities. The available material hardly allows a causal discrimination between process conditions and transaction governance, so this paper limits Proposition 2 to a mechanism hypothesis to be tested by interviews and performance records.

Shanghai already has standards related to recycled products; the 2023 notice lists a catalogue of standards such as that for recycled aggregate from renovation waste used in engineering fill [10]. The question should therefore move from whether standards exist to whether standards suit specific materials, and whether source sorting, plant-entry acceptance and product conformity can form consistent requirements. The focus of quality assurance is to let each stage know what tasks need to be completed, how results are confirmed, and how nonconformity is handled.

Quality coordination thus involves an investment problem that crosses boundaries: the actor who bears sorting costs may not be the actor who obtains back-end sorting convenience or product revenue. Only if quality improvements can be identified and enter intake, billing or procurement arrangements does front-end investment have a channel for feedback. Whether such feedback actually exists, and whether quality improvement involves relationship-specific investment, determines the explanatory power of Proposition 2 in the case.

4.3. The Application Coordination Dilemma and Procurement Performance

In 2021, Shanghai produced about 3.4362 million tonnes of recycled aggregate from renovation waste, of which about 39.7% was absorbed in blocks or bricks, about 2.0% in sidewalk and curb masonry, and about 58.3% required out-of-province absorption or stockpiling. The last item includes cross-regional destinations that may already have been used and inventory awaiting use, and cannot be entirely classified as unutilized. This record suggests that actual uses should be further identified rather than judging recycling outcomes solely from material output.

Recycled materials entering engineering works must pass procurement decisions. Users care about performance, acceptance, delivery time and quality responsibility, while treatment enterprises need clear uses and predictable orders. If the two parties lack mutually recognized quality bases and delivery conditions, technically feasible uses may not translate into stable demand. The difficulties in market acceptance and supply-sales information found in the survey records should be analyzed within this relationship.

Corresponding to Proposition 3, flow tracing and procurement confirmation are different information tasks. The former answers where materials went; the latter must also answer whether they can be used in a given project, who confirms this, and how responsibility is borne. Shanghai's 2024 implementation opinions already address product quality, application in eligible government-invested projects and data interconnection [22]. Further work should examine how these arrangements are implemented for batches of material and procurement projects, rather than substitutingthe existence of a platform for actual transactions.

The survey records show that emerging application directions such as fluidized fill have appeared, providing clues for demand expansion, but potential capacity does not equal orders that can be fulfilled. Actual demand still depends on engineering schedules, performance verification, permitted usage ratios and delivery costs. Expanding use should be premised on meeting existing engineering functions; unnecessary construction should not be created merely to absorb waste. Cross-regional use may also constitute a reasonable division of labor; the key to its evaluation is suitability of use and traceability, rather than insisting that all material be absorbed locally.

The application coordination dilemma shows that between qualified products and executable procurement there remains a layer of organizational work. Material performance needs to be recognized by specific projects, delivery times need to match construction schedules, and quality responsibility needs to be clarified between suppliers and users. It should be noted that this explanation also retains competing factors such as price, performance and real demand, avoiding attributing all sales difficulties to information asymmetry; when material demand is insufficient or products are unqualified, simply adding information cannot make application happen. The available material mainly reflects product destinations and market acceptance difficulties and is not sufficient to quantify the relative influence of each factor on procurement decisions, so the scope of Proposition 3 still needs to be tested batch by batch and project by project.

Table 2. Evidence and explanatory boundaries of the three coordination dilemmas

Coordination dilemma	Survey clues	Transaction cost explanation	Competing explanations or evidentiary boundaries
Intake coordination	Plant A throughput of 800-900 t/day against a design of 2,000 t/day; tension between hauling distance and impurity removal in District B	Alignment of uncertain delivery with adjustment arrangements	Downtime, material shortage or transport conditions may also affect operation
Quality coordination	Mixed incoming materials, manual sorting and maintenance burden	Linkage of sorting investment, acceptance and cost responsibility	Expensive equipment does not prove asset specificity
Application coordination	Limited aggregate uses; out-of-province absorption and stockpiling total 58.3%	Quality confirmation, supply commitment and engineering responsibility	Out-of-province absorption cannot all be classified as unutilized; real demand remains the premise

5. Governance Responses to Cross-Stage Coordination Dilemmas

5.1. From Stage Management to Governing Handover Relations

The three dilemmas show that collection-transportation, treatment and use are linked by both technical continuity and responsibility boundaries. Even when each stage meets its own standards, connections must still be established through intake rules, quality confirmation and procurement arrangements. This paper accordingly proposes governance responses corresponding to the three problems: improving material linkage through intake allocation, preserving sorting achievements through quality responsibility and investment arrangements, and connecting material output with practical use through engineering procurement conditions. Information and responsibility coordination provides common support for these arrangements (Figure 2). These recommendations are proposed in combination with Shanghai's existing policies and the case analysis.

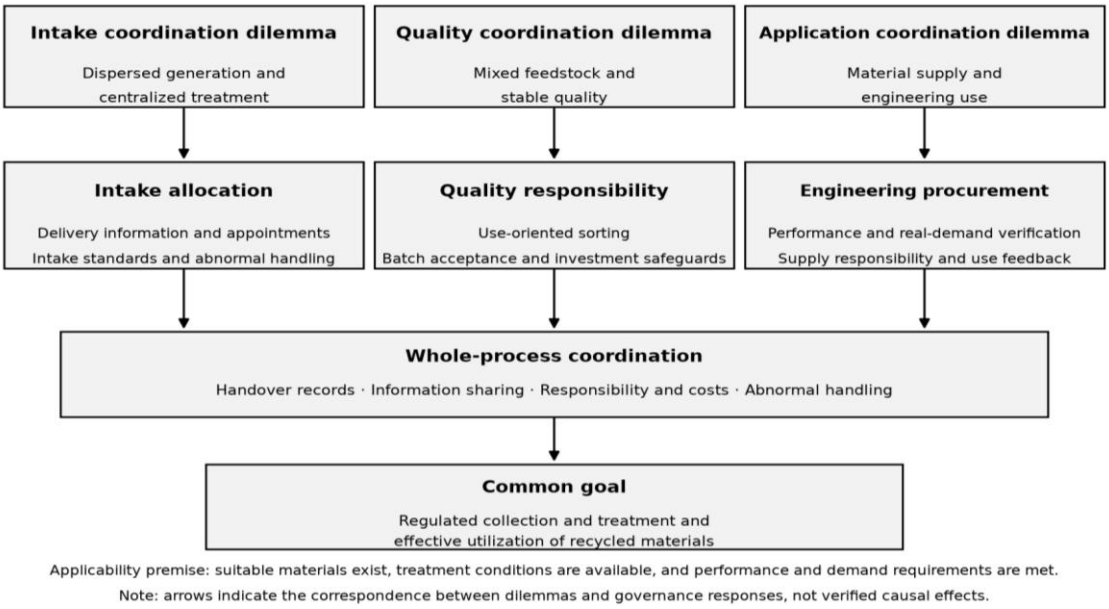


Figure 2. Correspondence between coordination dilemmas and governance responses

As noted in Section 3.3, governance responses must first distinguish regulated disposal services from recycled material production, whose tasks, beneficiaries and revenue sources are not identical. It cannot be assumed that all regulated disposal costs can be recovered through material sales, nor that different waste streams need the same subsidies. A city should first identify actual service tasks, costs and responsibilities, and then choose suitable fee and cooperation arrangements.

5.2. Responding to Delivery Uncertainty through Intake Allocation

The focus of source organization is to establish an executable delivery relationship from generators to treatment facilities. Shanghai's practices of fixed drop-off sites, dedicated recycling bins and appointment-based collection, institutionalized in the notice on the management of renovation waste release and hauling whose validity has been extended to 2027 [24], provide organizational forms for different scenarios; the 2025 special action on renovation waste collection and transportation further addresses appointment linkage, service agreements and fee transparency [23]. These experiences can be distilled into functional requirements: generators know where to deliver, whom to book with and what fees to bear; collectors and transporters are clear about service scope and destinations; and facilities can obtain the necessary information about incoming materials.

For cities in developing countries, the specific form of facilities should depend on community space, road accessibility and service capacity. Areas with adequate conditions can provide dedicated temporary storage and appointment services, while areas with weaker conditions should first establish clear delivery points, fixed service arrangements and basic records. Sorting requirements must balance operability with subsequent uses, preventing the front end from imposing overly detailed requirements that are re-mixed during transportation.

Facility planning should also proceed together with feedstock organization. For existing facilities, a distinction should be made among low utilization caused by insufficient collection, downtime, unsuitable materials or product demand, and collection-transportation, processes or capacity should then be adjusted accordingly. Spatial configuration needs to balance transport and impurity removal conditions, without presuming that more centralization or more dispersion is better. Cross-regional allocation can be an option, but intake standards, fees and responsibility for abnormal situations should be clarified.

5.3. Supporting Sorting Investment through Quality Responsibility and Cooperative Arrangements

Quality assurance runs through source identification, preservation in transport, plant-entry acceptance and product testing. Requirements should be established for different materials and uses, with a particular need to distinguish relatively homogeneous waste concrete from mixed renovation waste. Shanghai's existing recycled material standards and product application systems show that capacity building needs to proceed in step with use specifications; the improvement priority is to implement requirements in each handover, not merely to increase the number of documents.

A demonstration can start from one specific use, with generators, collectors and transporters, processors and users jointly confirming which components need to be separated in advance, how acceptance at the plant gate is conducted, how products are tested, and how nonconforming material is disposed of. By checking with actual batches whether sorting results can be preserved through to the product end, processes and organization can then be adjusted. This approach of deriving sorting tasks from uses helps avoid disconnection between source operations and end demand.

For additional sorting and quality control tasks, the bearers and fee arrangements should be clarified. If the relevant investments are specific, continuing cooperation and enforceable procurement or service agreements can serve as supporting arrangements; if investments are general-purpose and alternative partners are plentiful, complex long-term relations need not be established across the board. Quality and safety bottom lines must not be lowered on the grounds of cost savings, and incentive arrangements should serve compliant performance.

5.4. Linking Material Supply and Engineering Application through Procurement Conditions

Demand cultivation should begin with clarifying uses and engineering responsibilities. Shanghai's promotion of recycled building materials in eligible government-invested projects provides a policy basis for connecting public demand with material circulation [22]. Following this approach, applicable projects, testing and acceptance, and supply and quality responsibilities need to be clarified so that users can judge whether materials meet project requirements.

Product promotion should follow the sequence of verification, application, feedback and expansion. New uses should first complete the necessary performance and environmental verification before entering actual engineering works, with delivery and use results recorded. Scale estimates should distinguish one-off engineering stock from sustainable annual demand, and theoretical capacity should not be treated directly as a market. Product selection should also be based on functional substitution and comprehensive conditions, without automatically equating higher prices or more complex technology with higher circular value.

The operating records of treatment enterprises should be extended to inventory and material uses. Descriptive information on actual intake, downtime, product inventory, rejected deliveries and engineering use can help identify bottlenecks without being synthesized into a single score. Evaluation should distinguish plant-exit, temporary storage, cross-regional use and accepted application, preventing the completion of logistics from being regarded as the completion of circulation.

5.5. Supporting Cross-Stage Coordination with Enforceable Records

Whole-process coordination should organize information around the decisions that actors need to make. Generators need sorting and delivery guidance; facilities need composition and timing information; purchasers need performance and supply data; and management departments need records of regulated disposal and actual destinations. Shanghai's experience in platform integration and data interconnection, most recently the 2025 work plan for upgrading the renovation waste booking and hauling platform [25], can be transformed into shared rules, record standards and responsibility confirmation, rather than requiring all cities to replicate the same digital platform.

A minimum necessary record can be established first, connecting material sources, handover parties, quantities, batch quality and final uses. When information capacity is insufficient, one can start with key materials and key projects, and expand cross-departmental interconnection when conditions mature. Records should correspond to actual deliveries and the handling of abnormal situations, avoiding data concentration that cannot be used for procurement, allocation or enforcement.

Coordination must ultimately be embodied in enforceable agreements: who inspects and accepts, who undertakes additional tasks, who pays, and how changes are handled when they occur. Multi-departmental collaboration provides institutional support, while service and procurement relations between enterprises implement concrete responsibilities. Only when the two work together can source organization, quality assurance and engineering application form a continuous feedback loop.

6. Theoretical Discussion and Implications for Cities in Developing Countries

6.1. Incremental Value and Applicability of the Coordination Explanation

This paper supplements existing collaboration research by further specifying multi-actor participation as handovers with clear responsibility boundaries. Ma and Hao [3] emphasize the interrelation of actors and key strategies, and Lim et al. [11] reveal differences in how different actors perceive governance problems. Shanghai's empirical material provides clues for refining these relations into intake, quality and procurement problems. The transaction cost perspective enables the analysis to ask how the two parties to a handover confirm requirements, share investments and handle change, rather than summarizing coordination as adding participating actors or strengthening communication.

The feedback of downstream application on upstream intake is another important insight. Shanghai's 2023 policy already listed product backlogs alongside waste being unable to enter plants as matters for emergency support [10], suggesting that the recycling chain cannot be understood as a one-way material flow. On this basis, the paper proposes that the operation of the treatment end must connect feedstock organization with product use, and that arrangements at either end may constrain the functioning of the other. This is an explanatory direction supported by case and policy clues, not yet a feedback effect identified from longitudinal records.

The value of this framework for cities in developing countries lies in highlighting the complementary organizational conditions that facility construction requires. The Dhaka study reveals a context of weak management infrastructure, while the Shanghai case presents coordination problems that remain even where facilities exist [2]. The two cannot be directly compared in governance quality, but together they show that cities should consider capacity supply and transaction organization at the same time, rather than dealing with feedstock and sales only after facilities are built. The core theoretical insight distilled here is that one cannot assume that building treatment facilities amounts to achieving recycling: handover rules, acceptance standards, responsibility sharing and adjustment procedures should be designed in step at the facility planning stage, rather than remedied after operations are blocked. This is the fundamental implication of treating hardware facility investment and cross-actor transaction governance building as separate matters; specific policy choices are given for each stage in Section 5.

International applicability requires specific conditions: waste sources are relatively dispersed, treatment depends on cross-actor aggregation, and recycled materials need to enter an independent engineering use system. Where materials are mainly reused on site, trading partners are very few, or the public service foundation is weak, the constraint structure may differ. What can be borrowed are functions such as intake, verification and responsibility configuration; specific facility forms, cooperation durations and digital investment need to be chosen in light of local conditions.

6.2. Stepwise Implementation According to Urban Conditions

The primary constraints facing different cities are not the same. When the collection and transportation foundation is weak, priority should be given to ensuring regulated delivery and clear destinations; when facilities have been built but operate unstably, the constraints among feedstock, processes and demand should be identified; and when supply can be stabilized, uses can be gradually expanded and procurement feedback improved. This is the configuration of actions according to conditions, not a fixed sequence of stages that all cities must go through.

Table 3. Coordination priorities for cities in developing countries under different governance conditions

Primary urban condition	Priority actions	Minimum necessary evidence	Adaptation points
Insufficient collection, transportation and disposal foundation	Clarify delivery points, service providers and compliant destinations	Records of generation, clearance and intake	Give priority to the accessibility of basic services
Facilities exist but incoming materials are unstable	Verify the causes of low utilization and adjust intake and allocation	Records of feedstock, downtime and rejected deliveries	Do not directly equate low utilization with insufficient capacity
Product quality or sales limited	Improve testing and procurement arrangements around specific uses	Batch performance, orders and inventory	Confirm real uses and demand first
Multiple stages already established	Connect data, responsibilities and use feedback	Handovers, acceptance and engineering destinations	Expand the system step by step according to shared rules

Resource input must also balance service burdens with enforceability. Overly complex sorting, certification or data requirements may increase the participation costs of small-scale actors. Basic requirements should therefore be distinguished from enhancement measures, first solving the key problems that affect regulated delivery and reliable use, and then expanding according to effects. The combination of public investment, regulation and market arrangements needs to be determined according to local legal, fiscal and industrial conditions.

6.3. Evidentiary Boundaries and Future Testing

As stated in Section 3.1, the material combines public statistics, public policies and related studies. It can present operational contradictions, but it is not yet sufficient to identify the causal effects of the three propositions, nor can it directly confirm actor motives. Equipment performance, construction cycles, market prices and business differences may all affect outcomes, and governance misalignment cannot be inferred from low utilization or product backlogs; the data in the survey records are historical point-in-time information that only reflects the operational contradictions of the period examined, does not represent Shanghai's current governance performance, and records of individual facilities do not represent the citywide situation.

Future testing should track one or two complete material paths, connecting generation, collection and transportation, treatment and actual use, and cross-validate with agreements, performance records and participant information. The focus should be on comparing how changes are handled, whether investments are difficult to redeploy, how quality is confirmed, and whether these processes affect intake and procurement. Cases that do not support the propositions should also be retained to clarify the scope of the theory.

What this paper proposes is an exploratory, case-grounded conditional governance framework, not a universal measure tested across cities. Effective utilization does not amount to demonstrated net environmental benefit; specific uses still need to be judged in combination with performance, transport and environmental impacts. These boundaries determine that international borrowing should take the form of adaptation and verification rather than direct copying.

7. Conclusion

This paper has analyzed why C&D waste recycling still faces cross-stage coordination dilemmas after sorting management and treatment facilities have been established. The Shanghai survey records show that intake, quality and application are interrelated but non-substitutable tasks: the existence of materials in a city does not mean that facilities can stably receive them; front-end sorting requirements do not mean that quality can be preserved downstream; and the output of recycled materials does not mean that engineering procurement has formed. These three gaps constitute the coordination dilemmas identified in this paper.

Transaction cost theory provides a conditional explanation for these dilemmas. The uncertainty of material delivery calls for intake and adjustment arrangements; cross-actor quality investment requires acceptance, cost and responsibility allocation and appropriate cooperation safeguards; and engineering procurement requires reliable confirmation of performance, supply and responsibility information. The common mechanism is that the alignment between transactional requirements and governance arrangements may affect handover reliability and, through upstream-downstream feedback, the operation of the recycling chain. These explanations should be examined together with process capability, hauling distance, price and real demand, and institutional factors cannot replace all techno-economic constraints.

For cities in developing countries, the Shanghai experience suggests that C&D waste governance should plan treatment capacity building and cross-stage transaction arrangements in step. Policy priorities can fall on intake allocation, quality responsibility or engineering procurement according to the primary constraint, and implementation results can be tested through traceable handover and use records. The contribution of this paper is an exploratory analytical framework grounded in public statistics that connects real problems with theoretical explanation; its cross-city applicability and specific mechanisms remain to be tested by finer-grained performance records, actor interviews and comparative cases.

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