INTERNATIONAL JOURNAL OF ACADEMIC RESEARCH IN ECONOMICS & MANAGEMENT SCIENCES

OPEN ACCESS JOURNAL

Vol 14, Issue 1, (2025) E-ISSN: 2226-3624

Cost-Benefit Elements of Construction Waste Management in China's Construction Sector

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To Link this Article: http://dx.doi.org/10.6007/IJAREMS/v14-i1/24373 DOI:10.6007/IJAREMS/v14-i1/24373

Published Online: 06 February 2025

Abstract

This study explores the cost-benefit elements of construction waste management (CWM) within China's rapidly expanding construction sector. As urbanization accelerates, the generation of construction waste has surged, posing significant environmental and economic challenges. This research analyzes various management strategies, including waste reduction, recycling, and sustainable disposal methods, to assess their economic viability and environmental impact. Through a combination of qualitative studies, the study identifies cost-benefit elements. The findings underscore the importance of integrating effective waste management practices in construction projects, highlighting potential cost savings and environmental benefits. This research aims to provide actionable insights for policymakers and industry stakeholders, promoting a more sustainable construction paradigm in China.

Keywords: Construction Waste Management, Cost-Benefit Analysis, Industrialized Building System, Sustainable Construction, Material Selection, Technology Adoption

Introduction

Considering the rapid development of China's construction industry and its vital role in global waste production, studies on construction waste management (CWM) are essential in the modern world. With urbanization at a fast pace, the volume of construction and demolition waste has been shooting up, causing environmental risks of resource depletion, greenhouse gas emissions, and soil and water bodies pollution (James, 2023). Challenges related to these issues go beyond environmental concerns because the need to address these issues has implications for the economic efficiency and long-term sustainability of the construction projects. Policymakers, construction firms, and environmental regulators need to know this research because it gives insight into how waste can be optimized for cost savings, improved operations efficiency, and meeting China's sustainability goals. We pursue a cost-benefit analysis to identify the viable waste management strategies in recycling, prefabrication and sustainable disposal, among others, and highlight practical mechanisms that can be factored

within policy frameworks and industry practices so that the sector can evolve with the global sustainability standards.

The construction industry is one of the major waste producers, contributing approximately 30% of total global production. As the world population, particularly that of developing countries such as China, continues to grow, and more people move to urban areas, construction activities and the quantity of waste produced have also risen. This surge brings about environmental effects regarding resource exploitation, polluting the soil and water, and emission of greenhouse gases. Controlling construction waste has, therefore, become crucial to enable the organization of sustainable development goals. Various approaches and policies, such as Lean construction and Building Information Modelling, have been implemented in construction organizations. However, many construction projects still have a poor waste management approach, worsening adverse environmental effects. Academicians have continued calling for best practices, including waste management and disposal, recycling, and other concepts like prefabrication technologies, to overcome these challenges. However, implementing such practices is still irregular due to the high costs, low awareness, and Lack of appropriate facilities. This research focuses on such dynamics in China's construction industry, where solving waste management challenges is vital to realizing the country's agenda on sustainability.

Recent research shows poor construction waste management has numerous environmental and economic implications. Construction and demolition waste comprises recyclable concrete, timber and steel, metal, and bricks. Nevertheless, inadequate sorting of waste on construction sites means that such items are disposed of by being taken to landfills or burned, damaging the environment and being costly. Guo et al. (2021) have pointed out that waste minimization saves material costs. Recognized by researchers as potentially beneficial, prefabrication has been shown in this study to decrease on-site waste by assembling components elsewhere. In China, the industrialized building systems (IBS) that involve prefabrication have received attention due to their sustainability factor. However, these systems have problems, such as higher start-up costs, Lack of stakeholder cooperation, and later physical problems. This paper looks into how such practices are received and applied within the construction industry in China.

Some policies include the Green Building Evaluation Standards and the Circular Economy Promotion Law. These frameworks were drawn to encourage people to recycle and reduce the amount of waste they generate. Nevertheless, they are criticized due to poor compliance and little knowledge regarding such measures among interested parties. Although these policies form a good background, effective implementation of the policies can only be driven by construction firms, workers, and local governments. Some challenges include Inconsistent enforcement of the rules, Lack of skilled labour, and insufficient financial incentives for sustainable practices. The literature also reveals that stakeholders must come together to tackle these barriers to change. There is a need to enhance communication and make training programs for the workers inclusive while finances have to be provided for and regulations enforced. Extending from these features, this research examines how such factors affect waste management in the Chinese construction industries.

Another important area of interest identified in the literature is the implementation of green building practices. Green buildings are those structures constructed to reduce the effect on the environment by efficiently using energy, resources, and waste. According to Lee et al. (2021), the research shows that despite the increasing incorporation of green building certifications in China, its influence on waste management is minimal. The study also shows that most construction firms implement green buildings mainly because they are legally required and not as a business model. This becomes more of a reactive approach, leading to a box-ticking approach, which means minimal implementation of enhanced waste management practices. For example, some projects may attain the recycling threshold without considering other factors, such as material efficiency or sustainability across the lifecycle. This paper explores such practices in different project environments, commercial, residential, and infrastructure projects, as well as the findings about their efficiency and drawbacks.

Therefore, the literature is replete with the impact of financial incentives and technology on sustainable construction. Offering tax exemptions or subsidies for green technologies has been demonstrated to spur firms into green practices. Furthermore, the construction technologies today, like building information modelling (BIM) and automatically sorting wastes, are great solutions to the problem. From the work of Zhang et al. (2024), it is possible to infer that BIM can also contribute to minimizing over-ordering of materials as well as proper planning of the same. Likewise, automated sorting systems may help increase recycling efficiency by sorting out recyclable material from waste material. Nevertheless, since these technologies are expensive, SMEs do not quickly implement them.

Thus, implementing the following technologies entails various challenges that influence SMEs' uptake of these technologies. As a result, this paper investigates the impact of financial and technological factors on waste management in the construction industry in China. Moreover, social and cultural factors influence waste management in a particular society. There is limited consciousness or appropriate training of the workers and the site managers about sustainable working practices. Some of the earliest research has found that education and awareness-raising campaigns can lead to important changes in community waste segregation and recycling practices. There is a need for training methods that would fit the construction zone and close the gap in knowledge regarding sustainability among construction workers. For example, waste management programs have improved workers' posters, signs, and training session interactions. However, the effectiveness of these interventions still rests on the extent to which the program can be implemented and integrated into the worker's tasks. This paper explores the efficiency of different ways of communicating waste management practices to the workers to establish their efficiency in determining project performance.

Another consideration we have also seen is the extent of infrastructure for waste management, which is another important factor affecting sustainable construction. The large metropolitan areas are more likely to have access to recycling stations and waste disposal companies than the rural or suburban regions. This difference makes it difficult for projects in regions with low infrastructure development, which do not adopt the newest technologies in waste management. Liu et al. (2022) state that waste management services should be improved with a focus on the provision of funding in rural zones. The present research focuses

on the issue of regional differences in waste management policies and experiences in China and how they could impact waste management situations in various regions.

It is well known that resistance to change is one of the main problems in implementing sustainable practices. Since people do not see waste management as a long-term investment but a cost they bear, stakeholders also view waste management as an extra cost. This mentality is most rife in traditional construction activities because the primary focus is generally on profits, especially in the short term. The literature reveals no motivation and established culture and behaviour as significant challenges to change. If change initiatives, for example, the introduction of waste management practices into a workplace, are made systematically, it is easier to deal with resistance that may emerge. This paper aims to investigate how much resistance there is among the stakeholders in the construction industry in China and how it can be overcome.

Therefore, the literature reveals that construction waste management is surrounded by various challenges, including environmental, economic, social, and technological challenges. The potential of sustainable practices, including prefabrication, recycling, and efficient material planning, are well understood from the advantages that accrue from their implementation; however, their implementation is hampered by many challenges, including} policies and regulations can be a strong environment for sustainability, but the main question is whether they are enforced or whether people are willing to participate. By investigating these factors in China's construction sector, this study enhances the existing literature by presenting a view on the inefficiencies and potential for waste management improvement. Therefore, while synthesizing review data with primary data, this study intends to offer implications for industry players and policymakers.

Research Method

Materials and Data Collection

This research used a structured questionnaire to obtain primary data from 253 construction professionals in the People's Republic of China. The survey focused on construction waste management practices, demographics, and emerging issues. Participants included civil engineers, site managers, environmental specialists, government officers, and procurement experts, representing the construction industry fairly well. The sampling method adopted in the study was purposive, targeting those with functional responsibilities in implementing waste management practices.

The basic demographics of the participants were obtained from the survey, which included questions about gender, age, highest educational level attained, work occupation, number of years of professional practice, and the kinds of projects they worked on. For example, the gender distribution of the sample was relatively equal; 50.5% of participants were females, while 49.5% were males. Participants were of diverse ages: 35-44 years (25.2%) and 55+ years (20.9%). By education, 22.1% of them had a master's degree, and 20.9% had a PhD, so the respondents could be considered professionals. The majority of the participants were very experienced, an average of 58% had more than 10 years of experience in the industry.

Therefore, the second part of the survey focused on the current construction waste management practices. It posed basic questions touching on difficulties in categorizing

wastes, methods of disposal of uncontrolled wastes, accessibility to waste management facilities, and issues of non-compliance to waste management. Additional items discussed the ways that could be used to educate the workers and steps taken to prevent wastage. The survey also included questions on the use and efficiency of Industrialised Building Systems (IBS) against traditional construction methods. IBS was of particular interest because of the possibility of minimizing waste generation on-site through prefabrication and material optimization.

The survey was conducted online and reached out to respondents involved in constructing a living, business, industrial, and infrastructural construction in China's urban, suburban, and rural areas. In this approach, we were able to capture a broad geographic distribution and reveal the differences in the practice and issues with waste management. Areas that experienced intense construction activity, including large cities and emerging suburbs, were considered. The study was explained to all participants, and they agreed to act as respondents in the study voluntarily. For purposes of anonymity, the responses received were de-identified.

Data Analysis

This quantitative data was then subjected to statistical tests in order to compare, correlate, and gain insight into construction waste management practices. To gain insight into the study's findings, the analysis process was performed in a descriptive and inferential manner. Frequency distributions were employed to present demographics and comprehensively illustrate regularities in construction waste practices. For example, 53% of the respondents indicated no implementation of green building in their project, indicating low sustainable construction. Consequently, on-site waste segregation was also common, but common issues were reported with the separation of waste types, the level of difficulties being occasionally, 35 percent of respondents mentioned.

Analytical tests comprised descriptive statistics and chi-square (χ^2) tests of independence to establish significant relationships between variables, the type of construction method (IBS vs. conventional), and waste management practices. For instance, the analysis showed that the method of waste disposal was significantly related to IBS adoption ($\chi^2 = 4.15$, $p = 0.04$), and, more specifically, IBS projects are likely to use incineration. Odds ratios (OR) were used to measure how likely outcomes of interest were to occur. On the one hand, for respondents in IBS projects, the percentage of project teams using effective material plans was higher, with an odds ratio of 1.35, CI=0.31. Other studies mainly focused on disposal practices, and findings on differences in the availability of waste management infrastructure and policies in different regions were also discussed. The developed cities enhanced more innovative waste separation and recycling forms than the rural areas because they lacked the necessary capital. These findings corroborate other research on geographic disparities in China’s construction waste disposal system (Li et al., 2020). The study also examined formal and informal channels of passing information on waste management to the workers. The survey found that training sessions were considered the most effective, used by 49.2% of IBS projects and 52.1% of conventional projects, while emails and signage were less effective. Recommendable measures for increasing waste management efficiency, including the development of infrastructures and monetary encouragement, were also assessed. Notably, of the projects

reported to have been implemented in IBS, there was a high index of having adapted to the use of prefabrication methods, which led to lower levels of wastage.

Altogether, the analytical framework helped identify construction waste management's cost and benefit aspects. On this basis, prefabrication, good material management, and better worker training have been stressed to reduce waste and increase sustainability. Furthermore, the aspect of regional analysis pointed out the necessity of further differentiated approaches to infrastructure and resource scarcity. Due to the use of both descriptive and inferential statistics, the paper presents a strong background that can inform on the various issues surrounding waste management in the construction industry in China. It offers concrete advisory relevant to industry participants and policymakers.

Results

Demographic Section Table

Characteristic	Category	Frequency (N=253)	Percentage
Gender	Female	128	50.5
	Male	125	49.5
Age	18-24	39	15.4
	25-34	48	18.9
	35-44	64	25.2
	15-54	49	19.3
	55+	53	20.9
Occupation	Civil engineer	37	14.6
	Construction Worker	23	9
	Environmental Engineer	24	9.4
	Environmental Officers	27	10.6
	Environmental Specialist	28	11
	Government Officer	26	10.2
	Procurement Experts	30	11.8
	Site engineer	36	14.2
	Site manager	22	8.6
Education Level	Bachelor	49	19.3
	Diploma	51	20.1
	High school	44	17.3
	Master	56	22.1
	PhD	53	20.9
Years of experience	11-15 years	53	20.9
	16-20 years	56	22.1
	20+ years	58	22.9
	6-10 years	42	16.6

	<5 years	44	17.3
Types of Construction projects involved	Commercial	40	15.8
	Industrial	57	22.5
	Infrastructure	52	20.5
	Public building	56	22.1
	Residential	48	18.9
Size of construction project	1,000-5,000 sqm	55	21.7
	5,001-10,000 sqm	72	28.4
	<1,000 sqm	60	23.7
	>10,000 sqm	66	26
Green building practices	No	134	53
	Yes	119	47
Location	Rural	77	30.4
	Suburban	87	34.3
	Urban	89	35.3

Practices and Challenges in Construction Waste Management

The findings from this study on construction waste management practices in China reveal several critical themes: challenges in waste separation, disposal methods, availability of waste management facilities, resistance to sustainable practices, and communication and educational methods. These results reflect broader trends in the construction industry and are discussed below in existing literature.

Variable Analysis Table

Variable	IBS	conventional	OR	χ2, p value
Challenges in separating construction waste types			1.00	
Yes*	42 (31.3)	41 (34.4)	1.16 (0.63-	-
No	45 (33.5)	38 (31.9)	2.13)	0.22, p = 0.64
Sometime	47 (35)	40 (33.6)	1.15 (0.63-	0.2, p=0.95
			2.09)	
Disposal methods for unmanaged construction waste			1.00	
Incineration*	27 (20.1)	39 (32.7)	1.90 (1.01-	-
Landfill	54 (40.2)	41 (34.4)	3.59)	4.15, p=0.04
Other	53 (39.7)	39 (32.7)	1.96 (1.03-	4.29, p=0.03
			3.73)	
Availability of construction waste management facilities			1.00	
Yes *	51 (31.5)	35 (29.4)	0.64 (0.35-	-
No	42 (30.5)	45 (37.8)	1.17)	2.12, p = 0.12
Not sure	41 (38)	39 (32.7)	0.72 (0.39-	1.09, p=0.29
			1.33)	

Resistance to waste management practices					
Yes*	50	(37.4)	51	(42.8)	1.00
No	40	(29.8)	39	(32.7)	1.04(0.58-1.88)
Occasionally	44	(32.8)	29	(24.3)	1.54(0.84-2.85)
					-
					0.02, p=0.88
					1.98, p=0.16
Communication methods for educating workers					
Email Communication*	20	(14.9)	19	(15.9)	1.00
Posters and Signage	36	(26.8)	26	(21.8)	1.32 (0.59-2.94)
Training Sessions	66	(49.2)	62	(52.1)	1.01 (0.49-2.07)
Other	12	(8.9)	12	(10)	0.95(0.34-2.62)
					-
					0.45, p=0.50
					0, p=1
					0.01, p=0.92
Measures implemented to minimize construction waste generation					
Efficient Material Planning*	47	(35)	47	(39.5)	1.00
Prefabrication Techniques	50	(37.3)	37	(31)	1.35(0.75-2.43)
Reusing Material	19	(14.1)	23	(19.5)	0.83(0.39-1.71)
Other	18	(13.4)	12	(10)	1.5(0.65-3.46)
					-
					1.01, p=0.31
					0.26, p=0.61
					0.91, p=0.34
Improve construction waste management practices					
Enhanced Infrastructure*	21	(15.6)	29	(24.3)	1.00
Financial Incentives	19	(14.1)	14	(11.7)	1.87(0.76-4.56)
Increased Awareness Campaigns	48	(36.1)	34	(28.8)	1.95(0.96-3.97)
Policy Changes	43	(32)	35	(29.4)	1.69(0.82-3.47)
Other	3	(2.2)	7	(5.8)	0.59(0.14-2.56)
					-
					1.93, p=0.16
					3.4, p=0.65
					2.1, p=0.15

Discussion

Challenges in Waste Separation

The segregation of waste in construction sites is still a problem, though its implementation varies from project to project. The findings show that the percentage of respondents who sort waste correctly, “Yes,” is almost equal for IBS construction and conventional construction at 31.3 % and 34.4 %, respectively. Moreover, p-value = 0.64 and p-value = 0.95 indicate that this is an issue across most organizations which is also supported by other authors who have cited issues for doing with logistics and awareness as predominant challenges to achieving functional segregation (Yuan & Shen, 2011). To increase adherence to the waste separation policy, planned measures like enforcement of training activities and remunerations are required. This corresponds to research that points out the government's importance in fostering behavioral change in construction waste management (Ajayi et al., 2015).

Disposal Methods for Unmanaged Waste

A key finding of the analysis of disposal methods is that IBS has significant differences compared to conventional projects in incineration, landfill, and other methods. A noteworthy observation with statistical significance at a 95 % level is that landfill disposal is more preferred in IBS projects than the incineration type in conventional projects. However,

landfilling is one of the most common ways to dispose of waste, and it has many negative impacts on the environment, such as soil pollution and greenhouse gas emissions, according to Poon et al. (2004). These outcomes suggest a gap in Policy to encourage the practice of recycling and reuse, which can reduce the adverse impacts on the environment (Lu & Yuan, 2011). Implementing adequate technology, including automated sorting and recycling technologies, can decrease the overdependence on catastrophic disposal techniques (Ding et al., 2021).

Availability of Waste Management Facilities

This is because the readiness of waste management infrastructure affects the amount of sustainable waste handling practices. It is found that a significant proportion of IBS respondents, 31.5%, have access to facilities, conventional projects slightly behind 29.4%. The p-values are $p = 0.12$ and $p = 0.29$, which means there is no statistical significance to prove otherwise, hence widespread inadequate access. Prior literature also supports the role of facility availability in encouraging waste recycling and reuse, especially in areas with no infrastructure (Yuan et al., 2011). These gaps could be filled by increasing investment in developing new facilities in rural and suburban regions through outsourcing and government grant support for upgrading existing PP facilities (Tam et al., 2007).

Resistance to Waste Management Practices

This indicates that the main challenge persists in resistance toward sustainable waste management practices, especially in conventional construction projects. The results show that IBS respondents claim 37.4% stakeholder resistance to the conventional method, while conventional respondents report 42.8% resistance. As the null hypothesis is not quite significant with $p = 0.88$ and $p = 0.16$, this indicates that this problem occurs in all types of projects. They found that some reasons for resistance are costs, past practice, and even ignorance that sustainable processes are beneficial in the long run (Osmani et al., 2008). Mitigating this resistance means adopting broad-based interventions like legal measures, public sensitization, and financial motives that have previously litigated sustainable behaviors (Cheng et al., 2019). Another corresponding approach is the incremental approach, which allows stakeholders to get used to new waste management requirements.

Communication and Education for Workers

The results of the current study indicate that it is crucial to implement educational interventions to foster desired sustainable behaviors of construction workers. The study reveals that the training sessions are the most utilized type of information delivery, as 49.2% of the IBS participants and 52.1% of the conventional participants reported it. Although the p-values (>0.05) suggest no significant differences, the need for worker training has been and will continue to be supported in the literature. Yuan and Shen (2011) also posit that workers gain more knowledge about sustainability through interactive and hands-on training. Other facilities that support waste management may include posters and signs, mainly when used with training to enhance adherence to waste management measures (Ajayi et al., 2015).

Measures to Minimize Waste Generation

Improved procurement and prefabrication practices have the most significant impact on preventing construction waste. According to the results, 35% of IBS and 39.5% of conventional respondents consider efficient material planning the most important factor, whereas 37.3%

of IBS specialists prefer prefabrication. The small sample size of 65 and 90, respectively, did not show any significant difference in the participant's knowledge of these practices ($p = 0.31$ and $p = 0.61$), which could be due to the recognition of these practices as part of industry best practices. Of these, prefabrication has the most significant waste-saving advantages, where construction material wastage on site is minimized through off-site construction of the elements (Tam et al., 2007). Still, high start-up costs and organizational issues are problems that have yet to be solved. It could be possible to overcome these challenges by subsidizing and providing technical assistance to adopt prefabrication techniques (Osmani et al., 2008).

Improving Waste Management Practices

Respondents identified enhanced infrastructure and increased awareness campaigns when considering strategies to improve waste management practices as the most critical measures. The data reveal that 36.1% of IBS and 28.8% of conventional respondents prioritize awareness campaigns, while 15.6% and 24.3% emphasize infrastructure improvements. These findings align with existing research emphasizing the importance of stakeholder engagement and infrastructure investments for sustainable construction waste management (Ding et al., 2021). Awareness campaigns should focus on educating stakeholders about sustainable practices' environmental and economic benefits, while infrastructure investments should aim to bridge gaps in recycling and disposal capacity (Lu & Yuan, 2011).

Conclusion

Among the measures considered the most important for increasing the efficiency of waste management practices, the respondents mentioned better infrastructure and more awareness campaigns. The results show that 36.1% of IBS and 28.8% of conventional respondents value awareness campaigns more than the latter, while 15.6% of IBS and 24.3% of conventional respondents value improvement of the related infrastructures. These results are consistent with previous studies on the role of stakeholders and infrastructure investing in sustainable construction waste management (Ding et al., 2021). Information and awareness initiatives should highlight the efficiency of sustainable practices in terms of environmental returns on investment, economic return on investment, and return on aspiration, respectively (Lu & Yuan, 2011).

Conclusion and Recommendations

This paper discusses the major issues of construction waste management in the growing construction industry in China. The research highlights the issues of necessary changes in the waste sorting processes and practices, further development of environmentally friendly disposal methods, and the accessibility of waste management services. Lack of commitment to undertake sustainable initiatives and variability in training emphasizes the need for policies and training in an organization. Analysis of the study revealed that measures such as prefabrication and proper planning of the material were found to reduce waste throughput. In contrast, developing better infrastructure and effective awareness creation positively influenced waste management. These findings concord with the global tendencies and show the necessity of the multisector approach in partnership with policymakers, representatives of the concerned industries, and people living in the region. The barriers to sustainable construction waste management would help the industry contribute considerably to environmental conservation and economic efficiency. Subsequent research should focus on

combining the latest technologies in construction and circular economy to improve further the sustainability of construction projects in China and other countries.

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