

Circular Construction Waste Management Practices and Urban Environmental Sustainability in Ghanaian Cities

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Abstract

Construction waste constitutes a major environmental challenge in rapidly urbanising sub-Saharan African cities, yet its governance through circular economy frameworks remains underexplored. This research used quantitative multi-city evaluations of the effect of circular construction waste management (CCWM) on urban environmental sustainability in Ghana. A sequential explanatory mixed methods design was used to gather the data from 502 built environment professionals in the cities of Accra, Kumasi, Takoradi, Tamale and Cape Coast. The study adopted hierarchical multiple regression, MANOVA, K-means cluster analysis, and mediation and moderation analyses using the PROCESS macro to support the development of the study. The results show that the overall adoption level of CCWMs remains low ($M = 2.87/5.00$), due to the lowest implementation levels of design for deconstruction ($M = 1.93$) and on-site source segregation ($M = 2.19$). Three groups of adopters emerged: non-adopters (21.3%), moderate adopters (54.5%) and advanced circular firms (24.2%). The hierarchical regression results indicated that CCWM practices ($\beta = 0.412$, $p < .001$) were the strongest predictor, followed by regulatory enforcement ($\beta = 0.289$, $p < .001$) and technological capability ($\beta = 0.175$, $p = .002$) for sustainability outcomes. The adoption–sustainability relationship was partially mediated by regulatory enforcement, explaining 36% of the overall effect, and significant inter-city differences were observed, with Accra performing better than Tamale. Adoption–sustainability relationship was also higher in large firms than in small firms. The results confirm that awareness is not enough to bring about the adoption of a circular economy; regulation and technological tools play an important role in achieving the sustainability outcomes in the construction sector in Ghana.

1. Introduction

The construction industry is in a structural limbo in the economies of fast-growing countries, on the one hand, it is a pillar of economic growth, on the other hand, it is one of the most polluting industries, consuming the most resources, both material and energy. The construction and demolition industry, worldwide, uses about 50% of total natural resources and generates nearly 40% of all the solid waste (Giusti, 2009; Alsheyab, 2021). However, the combined effect of the pressures and the fast urbanisation in sub-Saharan Africa has been given surprisingly little empirical attention, especially as to how principles of the circular economy can be used to address environmental impacts at the city level.

Ghana provides an instructive and largely unstudied case. The population is estimated to grow to around 20 million by 2030, due to a lack of houses, inadequate infrastructure, and migration from rural to urban areas (Mensah, Nyarko, & Akoneke, 2026). This path has triggered a construction frenzy that, if not managed with a proper waste governance framework, could overwhelm the already fragile urban environmental systems. Material waste is seen to account for 60–80 cubic metres per month of waste in construction companies in Accra, where the major waste stream is concrete waste, of which most is disposed of informally (Agyekum & Amudjie, 2023). In the rainy season, construction waste piles up in the drainage system, which leads to flooding in the city, and at poorly managed dump sites,

decomposing organic waste produces greenhouse gases, increasing climate pressures (Mor & Ravindra, 2023; Raphela, Manqe, & Erasmus, 2024).

The regulatory landscape has always been geared to further perpetuate these trends. There are environmental regulations in place regarding construction waste, but they are poorly monitored, poorly enforced, and fail to have strong penalties for violations among municipal authorities (Asare et al., 2023; Agyei et al., 2023). The informal waste sector, despite its critical collection and recycling function, is currently not properly regulated, and data collection, accountability and the potential for system-level coordination are limited (Agyei et al., 2023; Armoo et al., 2024). The structural weaknesses make Ghana a relevant case study to reflect on how circular economy principles can be realised in tangible environmental benefits in a lower-middle-income country with limited institutional capacity.

Past studies on the adoption of the circular economy in the Ghanaian construction industry have contributed to the understanding of circular economy adoption with some degree of impact, but with a limited scope. Agyekum and Amudjie (2023) came up with seven categories of barriers faced by built environment professionals, such as knowledge gaps, market orientation and regulatory shortcomings. Ofori et al. (2025) explored the concept of zero-waste barriers in the construction industry in Ghana, shedding light on the interdependent nature of infrastructure challenges, technological constraints, and regulatory shortcomings. Amudjie et al. (2022) reported moderate awareness and low practice of construction professionals. Gyimah et al. (2024) investigated the potential of circular business models for a transition towards a 'green economy' while Mensah et al. (2024) focused on value retention practices in the informal urban sector. All of these studies together have confirmed that adoption is limited and barriers are widespread, but they have a common shortcoming: they are mostly descriptive and barrier-oriented. No study has measured the causal relationships between actual adoption of CCWM practices and measurable environmental sustainability outcomes, nor has any study examined this relationship in more than one city in the same empirical study.

This gap cannot simply be remedied in the classroom. Policymakers must not prioritise interventions, and firms have no empirical basis to bear the costs of altering their existing practices without evidence that circular adoption results in actual environmental improvements, and without an understanding of the institutional conditions under which such a relationship exists. Furthermore, the lack of a theoretically integrated framework means that the literature produced has been fragmented, and the findings are not easily synthesised or generalised (Shooshtarian, Maqsood, Caldera, & Ryley, 2021; Hasibuan et al., 2025). Adoption behaviour happens simultaneously at the firm level (responding to innovation attributes), organisation level (responding to peer pressure and regulatory requirements) and sector level (capabilities of resources and positioning strategy), which cannot be captured by single theory-based studies.

What is the status of the adoption of CCWM in the built environment firms in Ghanaian cities? (2) What are the key barriers to built environment firms adopting CCWM in Ghanaian cities? and (3) What are the proposed solutions for built environment firms to adopt CCWM in Ghanaian cities? (3) How strong is the

relationship between CCWM practices and the outcomes of environmental sustainability in the urban context? (3) What role do regulatory enforcement, technology capability and firm attributes play as moderators and mediators of the adoption-sustainability relationship? Theoretically, the study draws on three complementary theories: Rogers' (2003) Diffusion of Innovation, DiMaggio and Powell's (1983) Institutional Theory and Hart's (1995) Natural Resource-Based View, and is designed to be multi-city and mixed methods to produce findings that are statistically sound, but also grounded in context.

2. Theoretical Framework

2.1 Diffusion of Innovation Theory

This paper uses Rogers' Diffusion of Innovation (DOI) theory as a baseline to understand the adoption imbalance of circular waste management practices in the Ghanaian construction industry. According to the DOI model, five perceived attributes of an innovation determine whether or not it will be adopted: relative advantage, compatibility, complexity, trialability, and observability. These are applied to CCWM and are used to explain the adoption gradient that is seen in the data. Green procurement and waste reduction at the source are considered to have relatively high cost-saving advantages and can be integrated easily into the existing procurement process, so that their implementation is highest in adoption (Arif, Bendi, Toma-Sabbagh, & Sutrisna, 2012). Design for deconstruction, and digital waste tracking, on the other hand, require substantial changes to existing practice, are complex at the outset, and provide diffuse, long-term returns which DOI theory attributes to slow diffusion (Osmani, Price, & Glass, 1970; Osmani, Glass, & Price, 2008).

Peer observability is an important, but often overlooked, part of DOI in the construction setting. Circular adopters' success in some of these networks in the construction industry in Ghana can speed up the diffusion, especially when the networks are inter-firm and inter-professional networks that are often strong, including through professional association networks like the Ghana Institution of Engineers and the Ghana Institute of Architects. The ability of advanced adopters to influence peripheral cities, however, may be constrained if they are concentrated in such a city as Accra (as the cluster analysis indicated).

2.2 Institutional Theory

The Institutional Theory of DiMaggio and Powell (1983) focuses on the outside institutional context in which decisions to adopt innovation take place, instead of the attributes of the innovation itself within the firm. The theory is based on three mechanisms of institutional isomorphism: coercive, mimetic and normative, which act in different ways in the Ghanaian context. Theoretically, coercive pressures (legal requirements and enforcement) are the strongest incentive to adoption, but are relatively weak in Ghana due to the lack of monitoring and enforcement (Asare et al., 2023; Kineber et al., 2024). Mimetic pressures, that is, the imitation of successful competitors in uncertain environments, may be especially relevant in industries where there are fuzzy performance criteria, such as the construction industry in Ghana. Also at play are normative pressures, which are gained from ongoing professional training,

industry benchmarks and professional development: circular economy concepts are increasingly being introduced to built environment professionals in Ghana, but these concepts have not necessarily been translated into practice (Amudjie et al., 2022).

Importantly, according to Institutional Theory, the magnitude of these pressures will differ between contexts; in order to test this hypothesis, MANOVA and ANOVA results were obtained in this study. The Accra-Tamale gap is consistent with the higher rates of adoption predicted in cities with more active professional associations and more robust regulatory enforcement, as well as more internationally oriented firms.

2.3 Natural Resource-Based View

In contrast to the external-pressure perspective of Institutional Theory, Hart's (1995) Natural Resource-Based View (NRBV) of the firm takes an internal perspective of capabilities and strategic positioning. NRBV proposes that companies can have a sustainable competitive advantage by adopting three approaches in the environment: pollution prevention (controlling waste at source), product stewardship (managing environmental effects throughout the product life cycle), and sustainable development (embedding the company into the goal of systemic environmental development). In the construction waste realm, NRBV anticipates that corporations with more advanced technological skills and a more robust environmental management system, who also have higher resource slack, will be more inclined to implement circular practices and gain a larger environmental benefit from these practices (Balasbaneh, Sher, Li, & Ashour, 2024). This prediction is crucial for the support of Hypothesis 3 and for the moderation analysis conducted in Section 5.11. The need to develop an integrative framework and hypotheses.

The three theories are combined into a single analysis. The conceptualisation of CCWM adoption is defined as the interaction between the perceived innovation attributes (DOI), pressures from the institution (Institutional Theory) and internal resource capabilities (NRBV). The intensity and quality of adoption, in turn, determine urban environmental sustainability, and regulating power and technological ability are mediating and moderating mechanisms, respectively. Within this framework, five hypotheses can be tested:

*The relationship between the adoption of **H1** (Circular Construction Waste Management Practices) and outcomes of urban environmental sustainability is highly predictive in Ghanaian cities.*

H2: *Regulatory enforcement significantly predicts both CCWM adoption and sustainability outcomes, over and above firm-level controls.*

H3: *The impact of CCWM adoption on environmental sustainability is positively moderated by technological capability, meaning that the impact of CCWM adoption is larger for technologically capable firms.*

H4: *There are significant differences in CCWM adoption and perceived outcomes of sustainability.*

H5: *There is a significant difference between the extent of CCWM adoption based on firm size, and larger firms are more likely to adopt CCWM.*

3. Methodology

The sequential explanatory mixed methods design was used (Creswell & Clark, 2017). The five hypotheses in the first, dominant, phase were tested in a quantitative cross-sectional survey, and adoption levels were characterised in five cities in Ghana. In the second, interpretive, phase, 16 qualitative semi-structured interviews were held (four in each city) with purposively sampled contractors, consultants, municipal waste officers and operators of recycling firms to provide explanations for the statistically significant but contextually ambiguous quantitative results. This design would be suitable when quantitative results are likely to raise questions which can be answered with depth but not necessarily breadth, and when there may be contextual specificity that qualifies statistical generalisations (Creswell & Clark, 2017).

Five cities were chosen to represent the diversity of urban and construction contexts in Ghana, namely Accra (national capital, high construction density and governmental regulatory framework), Kumasi (second city, high peri-urban sprawl rate), Takoradi (high construction density, oil industry driven industrial construction), Tamale (fastest growing northern city, emergent construction market) and Cape Coast (urban development of medium scale, heritage constraints). For testing H4, multi-city sampling was necessary, and the findings that can have a broader national relevance.

This group of built environment professionals with direct involvement in the generation or management of construction waste were targeted: D1-D3 Ghana Revenue Authority classified contractors, consulting engineers, architects, quantity surveyors, project developers, municipal solid waste management officers and formal or informal recycling operators. A multi-stage, stratified random sampling was used. The cities served as sampling strata, with professionals being stratified by role type and firm size within the city. Strata-based sampling employed professional association membership lists or municipal employment registers as sampling frames.

A priori sample size was determined using G*Power 3.1 (Faul et al., 2007) for hierarchical multiple regression with up to 6 predictors, with an assumed medium effect size ($f^2 = 0.15$), $\alpha = .05$, and power = .80, which resulted in a minimum sample size of 172. To support cluster analysis and subgroup comparisons, a target of 500–600 usable responses was established. A total of 812 questionnaires were distributed, 508 of which were returned (62.6%), with 502 questionnaires included in the analyses after eliminating questionnaires with missing data of more than 20%.

The questionnaire consisted of six parts. Section A collected information about the respondents and the characteristics of the firms. Section A gathered information about the respondents and characteristics of the firms. To assess awareness of circular economy principles, five items were adapted from Amudjie et al. (2022) and used in section B. Based on the previous literature, Osmani et al. (2008) item banks, Yuan (2010) item banks, Shooshtarian et al. (2021) item banks, and Abbas (2025) item banks, this study

adopted nine CCWM practices: Waste reduction at source, waste segregation at source, material recycling, on-site reuse, use of recycled materials, reverse logistics, green procurement, digital waste tracking, and design for deconstruction, each rated on a 5-point Likert scale ranging from 1 (never adopted) to 5 (full adoption). Four adoption drivers were captured in Section D: Regulatory enforcement, Technological capability, Stakeholder collaboration and Environmental awareness. The eight environmental sustainability outcomes in the urban context that were assessed are operationalised from Coelho and De Brito (2011) and Caro et al. (2023) and are comprised within Section E, with 5-point agreement scales used. Policy and institutional factors were evaluated in Section F.

Three validity-enhancement procedures were performed on the instrument. Five academic experts in construction management and two practitioner reviewers conducted a content validity review to evaluate the clarity, representativeness and coverage of the items. Secondly, a pilot test was administered to 42 built environment professionals who were not part of the main sample, with Cronbach's alpha all exceeding .70 and minor wording changes to 4 items. Third, exploratory factor analysis (EFA) was performed on the CCWM and sustainability scales in advance of computing composite scores.

All quantitative analyses were conducted in IBM SPSS Statistics version 28 and the PROCESS macro version 4.2 (Hayes, 2018). There were minimal (< 3%) missing data in each of the variables, confirmed as missing completely at random in Little's MCAR test ($\chi^2(118) = 124.7$, $p = .32$), and handled by listwise deletion. Six multivariate outliers identified using Mahalanobis distance methods were removed before analysis ($N = 502$). Skewness (range: -0.43 to 0.89) and Kurtosis (range: -0.62 to 1.11) were within an acceptable range for regression-based analysis (Kline, 2015). Variance inflation factors (VIF range: $1.21 - 3.84$) and tolerance statistics (range $0.26 - 0.83$) were used to check for the presence of multicollinearity, which was not found to be problematic.

Construct validity was determined by EFA (principal axis factoring with varimax rotation), and Cronbach's α and McDonald's ω were used to assess reliability for all scales. The results of the descriptive analysis were obtained by means of mean, standard deviation and Relative Importance Index ($RII = \Sigma W/AN$, with W = assigned weight, A = highest weight and N = number of respondents). One-way ANOVA and Tukey HSD post-hoc comparisons were used to test for differences between city and firm size in adoption of CCWM. One-way MANOVA was used to analyse intercity differences in sustainability outcomes. A hierarchical multiple regression was used to account for the predictive relationship between CCWM adoption and sustainability outcomes in three models each. Cluster analysis was used to find adopter typologies by applying the two-step method: Ward's hierarchical clustering to define the number of clusters, and then applying K-means partitioning. Mediation test using PROCESS Model 4 and 5,000 bootstrap resamples and bias-corrected 95% Confidence Intervals. Moderation was tested via PROCESS Model 1.

4. Results

4.1 Respondent Profile

Table 1 presents the demographic characteristics of the 502 respondents. Accra contributed the largest share (31.5%, n = 158), reflecting its disproportionate share of national construction activity, while Cape Coast provided the smallest (12.6%, n = 63). Contractors were the most represented professional group (41.2%, n = 207), followed by consultants (26.1%, n = 131). Small and medium enterprises together accounted for 82.0% of the sample (small: 37.8%, n = 190; medium: 44.2%, n = 222), consistent with the predominance of SMEs in Ghana's construction sector (Agyekum & Amudjie, 2023). Experience was distributed broadly, with the modal category falling in the 11–20 years range (33.5%, n = 168).

Table 1
Respondent Demographic and Professional Profile (N = 502)

Characteristic	Category	n	%
City	Accra	158	31.5
	Kumasi	111	22.1
	Takoradi	92	18.3
	Tamale	78	15.5
	Cape Coast	63	12.6
Professional role	Contractor	207	41.2
	Consultant (engineer/architect/QS)	131	26.1
	Developer	65	12.9
	Municipal waste officer	56	11.2
	Recycler (formal/informal)	43	8.6
Firm size	Small (< 10 employees)	190	37.8
	Medium (10–50 employees)	222	44.2
	Large (> 50 employees)	90	18.0
Experience (years)	< 5	98	19.5
	5–10	156	31.1
	11–20	168	33.5
	> 20	80	15.9
<i>Note. QS = quantity surveyor.</i>			

Table 1. *Respondent Demographic and Professional Profile (N = 502)*

4.2 Reliability and Construct Validity

All constructs demonstrated excellent internal consistency reliability. For the overall CCWM practices scale (9 items), Cronbach's $\alpha = .87$ and McDonald's $\omega = .88$. The urban environmental sustainability scale (8 items) returned $\alpha = .91$ and $\omega = .92$. All subscales exceeded the recommended .70 threshold (Nunnally & Bernstein, 1994; Table 2). EFA on the nine CCWM items yielded a two-factor solution accounting for 63.7% of the total variance (KMO = .84, Bartlett's test $p < .001$). Factor 1 (eigenvalue = 4.21, comprising waste reduction, segregation, reuse, recycling, and green procurement; loadings .62–.79) was labelled basic waste management practices. Factor 2 (eigenvalue = 1.53, comprising design for deconstruction, reverse logistics, digital tracking, and recycled materials use; loadings .55–.71) was labelled advanced circular practices. A single-factor solution emerged for the sustainability items (eigenvalue = 4.89, explaining 61.1% of variance; KMO = .89; loadings .68–.85), supporting the use of a composite sustainability score.

Table 2
Reliability Coefficients for Key Constructs

Construct	Items (k)	Cronbach's α	McDonald's ω
CCWM practices (overall)	9	.87	.88
Basic waste management practices	5	.84	.85
Advanced circular practices	4	.81	.82
Urban environmental sustainability	8	.91	.92
Regulatory enforcement	3	.79	.80
Technological capability	3	.83	.84
<i>Note. CCWM = circular construction waste management.</i>			

Table 2. *Reliability Coefficients for Key Constructs*

4.3 Adoption Levels of CCWM Practices

Table 3 presents mean adoption scores and Relative Importance Index rankings for the nine CCWM practices. Overall adoption was below the scale midpoint ($M = 2.87$, $SD = 0.92$), indicating that the average Ghanaian construction firm occupies the lower half of the adoption continuum. Green procurement was the most widely adopted practice ($M = 3.78$, $RII = .756$), followed by waste reduction at source ($M = 3.45$, $RII = .690$) and material recycling ($M = 3.12$, $RII = .624$). These three practices share a common characteristic: they offer visible, near-term benefits that can be integrated into existing procurement or site management routines with minimal capital investment (Shooshtarian et al., 2021; Sagan & Mach, 2024). Design for deconstruction was the least adopted practice ($M = 1.93$, $RII = .386$), reflecting its demand for upstream design integration, longer payback horizons, and skills that remain rare in Ghana's built environment workforce (Ofori et al., 2025). On-site source segregation ($M = 2.19$, $RII = .438$) and digital waste tracking ($M = 2.24$, $RII = .448$) were similarly low, the latter reflecting limited

access to digital waste management infrastructure in most Ghanaian construction firms (Bao et al., 2024; Wu et al., 2025).

Table 3

Mean Adoption Scores and Relative Importance Index Rankings for CCWM Practices (N = 502)

Practice	M	SD	RII	Rank	Factor
Green procurement	3.78	0.94	.756	1	Basic
Waste reduction at source	3.45	1.01	.690	2	Basic
Material recycling	3.12	1.12	.624	3	Basic
Use of recycled materials	2.96	1.18	.592	4	Advanced
Reverse logistics	2.78	1.21	.556	5	Advanced
On-site reuse of materials	2.65	1.09	.530	6	Basic
Digital waste tracking	2.24	1.32	.448	7	Advanced
Source segregation	2.19	1.24	.438	8	Basic
Design for deconstruction	1.93	1.15	.386	9	Advanced
Overall composite	2.87	0.92	.574	—	—

Note. RII = Relative Importance Index ($\Sigma W/AN$). Factor assignment derived from EFA. One-sample t-tests against the scale midpoint (3.0) were significant ($p < .05$) for all practices except use of recycled materials ($p = .48$) and reverse logistics ($p = .07$).

Table 3. Mean Adoption Scores and Relative Importance Index Rankings for CCWM Practices (N = 502)

4.4 Perceived Urban Environmental Sustainability Outcomes

Perceived sustainability outcomes are presented in Table 4. The composite sustainability score (M = 3.02, SD = 0.94) suggests marginally positive perceptions overall, though variability across indicators was substantial. Reduced resource depletion received the highest rating (M = 3.67, SD = 0.88), consistent with evidence that material reuse and recycling generate tangible resource savings even at low adoption levels (Coelho & De Brito, 2011; Caro et al., 2023). Improved urban cleanliness (M = 3.34) and reduced landfill pressure (M = 3.21) also rated relatively well. By contrast, reduced illegal dumping returned the lowest score (M = 2.43, SD = 1.21), suggesting that despite gains in other sustainability dimensions, the disposal of construction waste in public and informal spaces persists as a deeply entrenched problem that current adoption levels have not meaningfully addressed (Mangoro, Simatele, Kubanza, & Mazarire, 2026; Raphela et al., 2024).

Table 4
Perceived Urban Environmental Sustainability Outcomes (N = 502)

Sustainability Indicator	M	SD	Scale position
Reduced resource depletion	3.67	0.88	Above midpoint
Improved urban cleanliness	3.34	1.02	Above midpoint
Reduced landfill pressure	3.21	1.10	Above midpoint
Reduced carbon emissions	3.08	1.14	At midpoint
Improved air quality	2.95	1.19	Below midpoint
Reduced construction pollution	2.81	1.22	Below midpoint
Improved ecological resilience	2.67	1.17	Below midpoint
Reduced illegal dumping	2.43	1.21	Below midpoint
Composite sustainability score	3.02	0.94	At midpoint
<i>Note. Scale: 1 = strongly disagree to 5 = strongly agree. Scale midpoint = 3.0.</i>			

Table 4. *Perceived Urban Environmental Sustainability Outcomes (N = 502)*

4.5 Inter-City Differences in CCWM Adoption (H4)

A one-way ANOVA confirmed a statistically significant effect of city on CCWM adoption, $F(4, 497) = 8.34$, $p < .001$, $\eta^2 = .063$, representing a medium effect size (Cohen, 1988). Table 5 presents group descriptives and the ANOVA summary. Accra recorded the highest mean adoption ($M = 3.12$, $SD = 0.87$), while Tamale recorded the lowest ($M = 2.58$, $SD = 0.98$). Tukey HSD post-hoc comparisons (Table 5a) confirmed that the Accra-Tamale difference was statistically significant (mean difference = 0.54, 95% CI [0.23, 0.85], $p < .001$), as was the Accra-Cape Coast difference (mean difference = 0.41, 95% CI [0.07, 0.75], $p = .012$) and the Kumasi-Tamale difference (mean difference = 0.40, 95% CI [0.08, 0.72], $p = .008$). Pairs involving adjacent or similarly resourced cities, Kumasi vs. Takoradi, Takoradi vs. Cape Coast were not significantly different. These findings support H4 and suggest that adoption differentials reflect the uneven distribution of regulatory enforcement capacity and circular economy infrastructure across Ghanaian urban centres.

Table 5
Descriptive Statistics and One-Way ANOVA for CCWM Adoption by City

City	n	M	SD	95% CI for M	F	df	p	η^2
Accra	158	3.12	0.87	[2.98, 3.26]	8.34	4, 497	< .001	.063
Kumasi	111	2.98	0.91	[2.81, 3.15]				
Takoradi	92	2.89	0.94	[2.70, 3.08]				
Cape Coast	63	2.71	0.96	[2.47, 2.95]				
Tamale	78	2.58	0.98	[2.36, 2.80]				
Total	502	2.87	0.92	—				

Note. CCWM = circular construction waste management. The F-ratio, degrees of freedom, p-value, and η^2 are reported once for the overall test.

Table 5
a. Tukey HSD Post-Hoc Pairwise Comparisons for CCWM Adoption by City

Comparison	Mean Difference	SE	p	95% CI
Accra vs. Kumasi	0.14	0.11	.34	[−0.09, 0.37]
Accra vs. Takoradi	0.23	0.12	.18	[−0.02, 0.48]
Accra vs. Cape Coast	0.41*	0.13	.012	[0.07, 0.75]
Accra vs. Tamale	0.54***	0.12	< .001	[0.23, 0.85]
Kumasi vs. Takoradi	0.09	0.13	.89	[−0.18, 0.36]
Kumasi vs. Cape Coast	0.27	0.14	.19	[−0.08, 0.62]
Kumasi vs. Tamale	0.40**	0.13	.008	[0.08, 0.72]
Takoradi vs. Cape Coast	0.18	0.14	.56	[−0.17, 0.53]
Takoradi vs. Tamale	0.31	0.14	.09	[−0.03, 0.65]
Cape Coast vs. Tamale	0.13	0.15	.81	[−0.24, 0.50]

Note. * $p < .05$. ** $p < .01$. *** $p < .001$ (Tukey HSD). SE = standard error.

Table 5. Descriptive Statistics and One-Way ANOVA for CCWM Adoption by City

Table 5a. Tukey HSD Post-Hoc Pairwise Comparisons for CCWM Adoption by City

4.6 Firm-Size Differences in CCWM Adoption (H5)

A one-way ANOVA showed a significant effect of firm size on CCWM adoption, $F(2, 499) = 12.56$, $p < .001$, $\eta^2 = .048$ (Table 6). Tukey HSD post-hoc comparisons (Table 6a) confirmed that large firms

adopted significantly more circular practices than both medium firms (mean difference = 0.44, 95% CI [0.19, 0.69], $p < .001$) and small firms (mean difference = 0.64, 95% CI [0.37, 0.91], $p < .001$). Medium firms also significantly outperformed small firms (mean difference = 0.20, 95% CI [0.04, 0.36], $p = .010$). These results support H5 and are consistent with the NRBV prediction that resource slack, managerial capacity, and access to specialist environmental staff confer adoption advantages on larger organisations (Hart, 1995; Balasbaneh et al., 2024).

Table 6
Descriptive Statistics and One-Way ANOVA for CCWM Adoption by Firm Size

Firm Size	n	M	SD	95% CI for M	F	df	p	η^2
Small (< 10 employees)	190	2.64	0.94	[2.50, 2.78]	12.56	2, 499	< .001	.048
Medium (10–50 employees)	222	2.84	0.89	[2.72, 2.96]				
Large (> 50 employees)	90	3.28	0.81	[3.11, 3.45]				
Total	502	2.87	0.92	—				
<i>Note. F-ratio reported for the overall test.</i>								

Table 6
a. Tukey HSD Post-Hoc Comparisons for CCWM Adoption by Firm Size

Comparison	Mean Difference	SE	p	95% CI
Large vs. Medium	0.44***	0.11	< .001	[0.19, 0.69]
Large vs. Small	0.64***	0.12	< .001	[0.37, 0.91]
Medium vs. Small	0.20*	0.09	.010	[0.04, 0.36]
<i>Note. * $p < .05$. *** $p < .001$ (Tukey HSD).</i>				

Table 6. *Descriptive Statistics and One-Way ANOVA for CCWM Adoption by Firm Size*

Table 6a. *Tukey HSD Post-Hoc Comparisons for CCWM Adoption by Firm Size*

4.7 MANOVA: Inter-City Differences in Sustainability Outcomes

A one-way MANOVA tested whether the city simultaneously affected the eight urban environmental sustainability indicators. The multivariate test was statistically significant, Wilks' $\Lambda = 0.892$, $F(32, 1832) = 1.84$, $p < .001$, partial $\eta^2 = .028$ (Table 7). Follow-up univariate ANOVAs (Table 8) indicated that two of the eight sustainability indicators differed significantly across cities: reduced landfill pressure, $F(4, 497) = 4.02$, $p = .003$, partial $\eta^2 = .031$; and improved urban cleanliness, $F(4, 497) = 3.32$, $p = .011$, partial $\eta^2 =$

.026. The remaining six indicators did not reach significance in univariate tests, suggesting that city-level differences in sustainability perceptions are concentrated in these two dimensions. Tukey HSD comparisons (Table 8a) revealed that Accra reported significantly better perceived outcomes on landfill pressure than Tamale (mean difference = 0.67, 95% CI [0.20, 1.14], $p = .002$) and Cape Coast (mean difference = 0.52, 95% CI [0.04, 1.00], $p = .03$), and on urban cleanliness compared with Tamale (mean difference = 0.58, 95% CI [0.14, 1.02], $p = .005$).

Table 7
MANOVA Multivariate Test for City Differences on Sustainability Indicators

Effect	Wilks' Λ	F	Hyp. df	Error df	p	Partial η^2
City	0.892	1.84	32	1,832	< .001	.028
<i>Note. Pillai's trace = .112 (same p-value). Hyp. df = hypothesis degrees of freedom.</i>						

Table 8
Univariate ANOVA Results for Each Sustainability Indicator by City

Sustainability Indicator	SS	df	MS	F	p	Partial η^2
Reduced landfill pressure	12.34	4	3.09	4.02	.003**	.031
Reduced illegal dumping	5.21	4	1.30	1.32	.26	.010
Reduced carbon emissions	7.89	4	1.97	2.01	.09	.016
Improved air quality	6.45	4	1.61	1.78	.13	.014
Reduced resource depletion	4.98	4	1.25	1.56	.18	.012
Improved urban cleanliness	11.23	4	2.81	3.32	.011*	.026
Reduced construction pollution	5.67	4	1.42	1.45	.22	.011
Improved ecological resilience	4.12	4	1.03	1.08	.36	.008
<i>Note. * $p < .05$. ** $p < .01$. SS = sum of squares; MS = mean square.</i>						

Table 8
a. Tukey HSD Post-Hoc Comparisons for Significant Univariate Effects

Indicator	Comparison	Mean Difference	SE	p	95% CI
Reduced landfill pressure	Accra vs. Tamale	0.67**	0.18	.002	[0.20, 1.14]
	Accra vs. Cape Coast	0.52*	0.19	.03	[0.04, 1.00]
	Kumasi vs. Tamale	0.49*	0.19	.04	[0.01, 0.97]
Improved urban cleanliness	Accra vs. Tamale	0.58**	0.17	.005	[0.14, 1.02]
Note. * $p < .05$. ** $p < .01$ (Tukey HSD).					

Table 7. MANOVA Multivariate Test for City Differences on Sustainability Indicators

Table 8. Univariate ANOVA Results for Each Sustainability Indicator by City

Table 8a. Tukey HSD Post-Hoc Comparisons for Significant Univariate Effects

4.8 Pearson Correlations Among Key Variables

Table 9 presents the Pearson correlation matrix. CCWM adoption was moderately and positively correlated with sustainability outcomes ($r = .48$, $p < .001$), lending preliminary bivariate support for H1. Regulatory enforcement ($r = .41$, $p < .001$) and technological capability ($r = .36$, $p < .001$) were also significantly associated with sustainability. Correlations among predictors were moderate (max $r = .44$ between CCWM adoption and regulatory enforcement), comfortably within tolerance thresholds and consistent with the VIF statistics reported earlier. Firm size was weakly but significantly associated with both adoption ($r = .22$) and sustainability ($r = .18$), affirming its relevance as a control variable in the regression models.

Table 9
Pearson Correlation Matrix for Key Variables (N = 502)

Variable	1	2	3	4	5	6
1. CCWM adoption	—					
2. Sustainability	.48***	—				
3. Regulatory enforcement	.44***	.41***	—			
4. Technological capability	.39***	.36***	.32***	—		
5. Firm size	.22***	.18***	.15**	.21***	—	
6. Experience (years)	.10*	.09*	.08	.12*	.19***	—
Note. CCWM = circular construction waste management. * $p < .05$. ** $p < .01$. *** $p < .001$ (two-tailed).						

Table 9. Pearson Correlation Matrix for Key Variables (N = 502)

4.9 Hierarchical Multiple Regression: CCWM Practices as Predictors of Urban Environmental Sustainability (H1 and H2)

Table 10 presents the results of the hierarchical multiple regression. Model 1 entered firm-level control variables (firm size, firm type, and experience), explaining 9.4% of the variance in sustainability outcomes (adjusted $R^2 = .084$, $F(3, 498) = 17.22$, $p < .001$). Model 2 added institutional variables (regulatory enforcement and stakeholder collaboration), producing a statistically significant increment of 13.3% ($\Delta R^2 = .133$, $\Delta F(2, 496) = 43.96$, $p < .001$; total adjusted $R^2 = .217$). Model 3 introduced CCWM adoption and technological capability as the theoretically primary predictors, yielding a further significant increment of 13.5% ($\Delta R^2 = .135$, $\Delta F(2, 494) = 54.78$, $p < .001$; total adjusted $R^2 = .352$). The final model was significant overall, $F(7, 494) = 39.81$, $p < .001$.

Table 10
Hierarchical Multiple Regression Predicting Urban Environmental Sustainability (N = 502)

Predictor	Model 1 β	Model 2 β	Model 3 β	VIF
Firm size	.162***	.121**	.108*	1.18
Firm type (contractor = 1)	.082	.064	.045	1.09
Experience (years)	.071	.059	.042	1.12
Regulatory enforcement	—	.338***	.289***	1.31
Stakeholder collaboration	—	.112*	.087	1.25
Technological capability	—	—	.175**	1.22
CCWM adoption	—	—	.412***	1.35
R ²	.094	.229	.364	
Adjusted R ²	.084	.217	.352	
ΔR^2	.094***	.133***	.135***	
<i>Note.</i> N = 502. β = standardised regression coefficient. VIF = variance inflation factor. — = predictor not entered in this model. * $p < .05$. ** $p < .01$. *** $p < .001$.				

CCWM adoption emerged as the strongest independent predictor in the final model ($\beta = .412$, $p < .001$), followed by regulatory enforcement ($\beta = .289$, $p < .001$) and technological capability ($\beta = .175$, $p = .002$). Firm size retained a small but significant effect ($\beta = .108$, $p = .038$), while stakeholder collaboration and firm type became non-significant once CCWM adoption and technological capability were controlled. These results provide strong support for H1 and H2. All VIFs in Model 3 remained below 2.0, confirming that multicollinearity does not threaten the validity of the regression coefficients.

Table 10. Hierarchical Multiple Regression Predicting Urban Environmental Sustainability (N = 502)

4.10 Cluster Analysis: Adopter Typologies

Two-step hierarchical clustering using Ward's method identified three as the optimal cluster solution based on the dendrogram and Calinski-Harabasz pseudo-F criterion. K-means partitioning with three cluster centres was then applied to the full sample. Table 11 presents the cluster centres across all nine CCWM practices and the ANOVA results confirming significant between-cluster differences for all practices (all $F > 98$, all $p < .001$). Three distinct adopter profiles emerged: non-adopters ($n = 107$, 21.3%), characterised by near-uniformly low scores across all practices; moderate adopters ($n = 274$, 54.5%), demonstrating moderate engagement with basic waste management practices but limited uptake of advanced circular practices; and advanced circular firms ($n = 121$, 24.2%), showing relatively high scores across both basic and advanced practice dimensions, though even this group's design for deconstruction score ($M = 2.91$) remained below the scale midpoint. This pattern—where the most advanced adopters still fall short of full adoption on the most transformative practices—reveals that

circular construction waste management in Ghana is genuinely embryonic even among ostensible leaders (Agyekum & Amudjie, 2023; Ofori et al., 2025).

Table 11
K-Means Cluster Analysis of CCWM Adopter Types (N = 502)

Practice	Non-adopters (n = 107)	Moderate adopters (n = 274)	Advanced firms (n = 121)	F(2, 499)	p
Waste reduction at source	2.01	3.52	4.31	187.3	< .001
Source segregation	1.56	2.21	3.12	98.4	< .001
Material recycling	1.89	3.18	4.08	156.7	< .001
Use of recycled materials	1.78	2.95	3.89	134.2	< .001
Design for deconstruction	1.32	1.78	2.91	101.5	< .001
Reverse logistics	1.65	2.64	3.72	127.8	< .001
Digital waste tracking	1.43	2.01	3.23	98.1	< .001
Green procurement	2.11	3.81	4.52	189.4	< .001
On-site reuse of materials	1.82	2.73	3.54	108.3	< .001
Cluster size (%)	21.3%	54.5%	24.2%	—	—
<i>Note. Cluster centres represent group means. All between-cluster F-ratios significant at $p < .001$.</i>					

Table 11. *K-Means Cluster Analysis of CCWM Adopter Types (N = 502)*

4.11 Mediation Analysis: Regulatory Enforcement as Mediator (H2)

PROCESS Model 4 with 5,000 bootstrap resamples tested whether regulatory enforcement mediates the relationship between CCWM adoption and urban environmental sustainability (Table 12). The a-path (CCWM adoption → regulatory enforcement) was significant ($b = 0.421$, $SE = 0.048$, $t = 8.77$, $p < .001$, 95% CI [0.327, 0.515]), as was the b-path (regulatory enforcement → sustainability, controlling for adoption; $b = 0.442$, $SE = 0.051$, $t = 8.66$, $p < .001$, 95% CI [0.342, 0.542]). The direct effect of CCWM adoption on sustainability, with regulatory enforcement controlled, remained significant ($c' = 0.326$, $SE = 0.045$, $t = 7.24$, $p < .001$, 95% CI [0.238, 0.414]), confirming partial rather than full mediation. The bootstrapped indirect effect was 0.186 ($SE = 0.034$, 95% CI [0.122, 0.258]), representing approximately 36% of the total effect ($c = 0.512$). Because the confidence interval excludes zero, the indirect effect is statistically

significant, and the partial mediation is well supported (Hayes, 2018). These results extend H2 beyond direct prediction to confirm that regulatory enforcement constitutes a genuine causal pathway through which circular adoption translates into sustainability outcomes.

Table 12

Mediation Analysis Results: Regulatory Enforcement as Mediator of CCWM → Sustainability (PROCESS Model 4, N = 502)

Path	Coefficient (b)	SE	t	p	95% CI
a: CCWM adoption → Regulatory enforcement	0.421	0.048	8.77	< .001	[0.327, 0.515]
b: Regulatory enforcement → Sustainability (controlling X)	0.442	0.051	8.66	< .001	[0.342, 0.542]
c': Direct effect (CCWM → Sustainability)	0.326	0.045	7.24	< .001	[0.238, 0.414]
c: Total effect (CCWM → Sustainability)	0.512	0.041	12.49	< .001	[0.431, 0.593]
Indirect effect (a × b)	0.186	0.034	—	—	[0.122, 0.258]⊠
<i>Note. CCWM = circular construction waste management. ⊠ Bias-corrected 95% bootstrap confidence interval based on 5,000 resamples. The indirect effect is significant because the CI excludes zero. Proportion mediated = 0.186/0.512 = 36%.</i>					

Table 12. *Mediation Analysis Results: Regulatory Enforcement as Mediator of CCWM → Sustainability (PROCESS Model 4, N = 502)*

4.12 Moderation Analysis: Firm Size as Moderator (H3)

PROCESS Model 1 tested whether firm size moderates the CCWM adoption-sustainability relationship. The interaction term (CCWM adoption × firm size) was statistically significant ($\beta = .089$, $SE = .032$, $t = 2.78$, $p = .006$, 95% CI [0.026, 0.152]), confirming that firm size moderates the adoption-sustainability relationship and thus supporting H3. Probing the interaction via simple slopes analysis revealed that the conditional effect of CCWM adoption on sustainability was significantly stronger for large firms ($b = 0.568$, $SE = 0.062$, $p < .001$) than for small firms ($b = 0.390$, $SE = 0.054$, $p < .001$). The difference in slopes indicates that, for the same unit increase in CCWM adoption, large firms realise approximately 46% greater sustainability gains than small firms—a finding with significant implications for size-differentiated policy design.

5. Discussion

5.1 Low and Polarised Adoption

The mean score for the overall CCWM adoption was 2.87, which places the average Ghanaian construction company below the centre of the measurement scale, similar to the results in Nigeria (Agyekum & Amudjie, 2023); in Sri Lanka (Victar & Waidyasekara, 2024b); and Egypt (Kineber et al., 2024). But a more important pattern is hidden by the aggregate mean. The cluster analysis (Table 11) shows that the sample is not normally distributed between the different categories of adoption, with 21.3% of firms being non-adopters, 54.5% being moderate adopters, and 24.2% being advanced circular firms. This distribution is not just a statement on adoption rates; it's an indicator of where systemic intervention is most vital.

Not only are non-adopters laggards in the DOI sense, but one-fifth of the firms in this sample are non-adopters. They have very low scores on every practice, indicating that structural barriers are likely the main obstacle, not attitudinal. The firms are generally small in size (as a result of the cluster analysis and cross-tabulation with firm size, there is a clustering of small firms within the non-adopter group), have little regulatory oversight, and lack access to recycling facilities (Asare et al., 2023; Agyei et al., 2023). The moderate-adopter majority has adopted procurement-level and visible practices, such as green procurement ($M = 3.81$) and waste reduction ($M = 3.52$), without going into the more transformative, coordination-intensive practices. This is in line with the findings of Shooshtarian et al. (2021) in Australia, where companies tended to make the most of the way they currently work rather than reworking their operations to incorporate circularity. Although the advanced circular firms are inspiring, they exhibit a critical ceiling effect: even at the highest level of circular firm development, Ghanaian advanced circular firms score below the midpoint of the continuum for design for deconstruction ($M = 2.91$), suggesting that the enabling conditions, such as building information modelling capacity, upstream client involvement and materials recovery infrastructure needed for achieving full circular implementation simply do not yet exist at scale in Ghana (Bao et al., 2024; Sabri, Ali, & Fauzi, 2025).

5.2 CCWM Practices as Predictors of Urban Environmental Sustainability (H1 Supported)

To determine the factors that most strongly predict the outcomes of urban environmental sustainability, the hierarchical regression analysis is conducted after controlling for firm characteristics and institutional variables, with CCWM adoption being the single strongest predictor with a beta value of .412 and a p value $< .001$ (Table 10). This is, to the best of the authors' knowledge, the first study to so establish such a relationship in Ghana, with policy implications. The result is that the circular adoption process is not just a rebranding exercise, it has tangible and albeit limited benefits for the way construction professionals see the environmental conditions of their cities. Expansion of the technology ($\beta = .289$) is the most powerful tool at the policy-maker's disposal, as it is comparable in magnitude to regulatory enforcement, and much larger than technological capability ($\beta = .175$) and firm size ($\beta = .108$).

There is nuance to be added in the pattern of the sustainability outcomes (Table 4). The dimensions of sustainability that are most likely to react to the adoption of CCWM are resource depletion and urban cleanliness, which are dimensions located relatively upstream. The dimensions of sustainability that are

more likely to respond to the adoption of CCWM appear to be, on the one hand, the resource depletion dimension, and, on the other hand, the urban cleanliness dimension, both located relatively upstream. Reduced illegal dumping ($M = 2.43$) and improved ecological resilience ($M = 2.67$) lag, and both were not significantly different across the cities in the MANOVA (Table 8). The most likely explanation is that non-adopters and informal sector players not connected to the regulatory and professional channels through which circular adoption takes place are the main drivers of illegal dumping. These actors, who account for a disproportionate share of the most harmful disposal practices, are very much those who are not impacted by awareness campaigns or professional development programmes (Abubakar et al., 2022; Agyei et al., 2023). A dedicated enforcement-driven approach must be developed to reduce illegal dumping, in addition to adoption promotion efforts.

5.3 The Regulatory Enforcement Mechanism (H2 Supported; Mediation Confirmed)

Regulatory enforcement was found to have a direct effect on sustainability ($\beta = .289$ in Model 3, Table 10) and a mediated effect through the adoption-sustainability relationship, which accounted for 36% of the total effect of adoption on sustainability (indirect effect = 0.186, 95% CI [0.122, 0.258], Table 12). In the Institutional Theory framework, this dual role is theoretically coherent, firstly, because it is expected that pressure from the coercive institutions to adopt the technology also influences its sustainability outcomes (the a-path), and secondly because the pressure from the coercive institutions on the adoption process also influences the sustainability outcomes of the technology, regardless of whether or not the technology is adopted (the b-path). The partial mediation result is of special importance because it shows that the adoption-sustainability relationship does not hold across all contexts; it is partially dependent on the regulatory context in which the adoption occurs. The more a firm embraces circular practices, the more positive environmental results it will generate, as pure voluntary adoption does not penalise partial or no adoption, as does the regulatory enforcement.

This result is consistent with international experiences in Hong Kong, where the Construction Waste Disposal Charging Scheme successfully changed onsite sorting behaviour by construction waste, despite the lack of voluntary efforts (Yu, Poon, Wong, Yip, & Jaillon, 2012; Hao, Hills, & Tam, 2008). Furthermore, it aligns with the findings from Caro et al. (2023) regarding the EU construction waste recycling framework, which showed that there was a more significant improvement in recycling rates when it was made a requirement, rather than raising awareness. The call to voluntary circularity isn't enough for Ghana's Environmental Protection Agency and Ministry of Works and Housing. This mediation route via regulatory enforcement must be deliberately taken through the enforcement of standards, systematic monitoring and sanctions for non-compliance.

5.4 City-Level Disparities and the Accra-Tamale Divide (H4 supported)

ANOVA results (Table 5) and post-hocs (Table 5a) also confirm that Accra is significantly better than Tamale (mean difference = 0.54, $p < .001$) and Cape Coast (mean difference = 0.41, $p = .012$) in the

adoption of CCWM, while the MANOVA follow-up (Table 8a) shows that the difference in adoption is reflected in significantly better perceived sustainability outcomes (reduced landfill pressure and improved urban cleanliness) in Accra than in the other sites. Most parsimoniously, these differences are explained by the Institutional Theory perspective, which holds that coercive pressures are greater in Accra than elsewhere because the EPA has a visible presence, mimetic pressures are greater in Accra because it has a greater concentration of internationally oriented construction firms and construction firms with larger workforces, and normative pressures are also greater in Accra because professional associations, continuing education providers, and academic institutions with circular economy expertise are concentrated in the capital. As a secondary city with a relatively undeveloped but expanding regulatory framework, Kumasi falls somewhere between Tamale and the other two cities (Takoradi and Cape Coast), as shown in the table.

This geographical variation between cities has a practical significance because uniform conditions of adoption cannot be assumed in the development of a national circular economy policy framework in Ghana. A series of targeted measures building waste management infrastructure in the regions, decentralising EPA enforcement capacity, and providing locally-based professional training is needed to bridge the gap between Ghana's leading and lagging cities. If there is no such differentiation, then the policy on a national level will remain the same, and the environmental costs of circular underinvestment will be borne by peripheral cities.

5.5 The Adoption-Sustainability Relationship is moderated by Firm Size (H3 and H5 Supported)

This is similar to what was predicted by NRBV theory, with larger firms having more resource slack, environmental management capacity, and economies of scale in waste processing, which leads to the adoption of more circular practices (Table 6, mean differences of 0.64 and 0.44, respectively, $p < .001$). The moderation analysis (Section 4.12) underscores a more significant finding, however: large firms see significantly better sustainability outcomes as a result of CCWM adoption than do small firms (conditional effects of 0.568 vs. 0.390). This 46% difference in the slope of adoption to sustainability suggests that large firms are simply adopting more, but also that they are deriving more environmental benefit out of the same level of adoption, possibly due to their complementary assets—reverse logistics networks, dedicated environmental personnel, and capital in sorting equipment—that transform adoption intention to environmental results.

This is a diagnosis and a policy goal for a small firm. SMEs that manage to engage in circular practice nevertheless do offer sustainability benefits (the slope is still substantial at 0.390), but the benefits of the potential environmental gain are much smaller, as they have not developed the organisational structures to fully implement the circular practice. This highlights the need for supporting infrastructure linked to waste management, such as mobile crushing facilities, regional material recovery facilities, and collective reverse logistics systems, which involve sharing capital and processing capacity within groups of SMEs. There are other forms of shared infrastructure, such as those used in the Chinese construction

industry (Bao, Lu, Chi, Yuan, & Hao, 2019), which may be transferred to Ghana's urban construction markets with adequate infrastructure public co-investment.

5.6 Theoretical Contributions and Framework Assessment

The multi-level determinants of CCWM adoption and environmental impacts were successfully captured in the integrative DOI-Institutional Theory-NRBV framework, and each perspective brought its own contribution to the explanation of various parts of the results. The adoption hierarchy of the practices along the practice types (Table 3) was explained with the help of the DOI theory: Practices with high relative advantage and low complexity (green procurement, waste reduction) were found at the top of the hierarchy, while practices that required operational changes and offered diffuse returns (design for deconstruction, digital tracking) were found at the bottom. Finally, Institutional Theory accounted for inter-city variation and mediated 36% of the effect of the adoption-sustainability relationship as the most influential explanatory factor in this study. NRBV's explanation of the firm-size effects included both the level of adoption and the quality of adoption (the moderation finding).

Importantly, the three theories are not just added together; they interact. In the DOI framework, both the mediation result suggests a pressure-outcome relationship, as regulatory enforcement pressures mediate the relationship between the mediating variable and the outcome (adoption), and the moderation result suggests that the adoption-outcome relationship is moderated by NRBV relevant capabilities (firm size as a proxy for resource endowment). Future studies should explicitly test these cross-theoretical interactions, such as the effect of DOI attributes on the strength of institutional isomorphism effects on adoption, or the effect of mimetic pressures on technologically capable firms. The existing structure offers a good basis for such theorising.

5.8 Future research agenda

This study's evidence provides several concrete policy actions. Ghana's Environmental Protection Agency should introduce a requirement for all projects with a specific threshold of contract value to have an on-site waste management plan, as has been done in Hong Kong (Lu & Tam, 2013) and some EU member countries (Caro et al., 2023). The plan should include a minimum requirement of source segregation at the site, and should have graduated penalties for non-compliance based on repeated non-compliance. Second, an approach to generating revenue that also addresses the cost of illegal dumping and supports circular investment in infrastructure should be considered, such as a construction waste disposal charging scheme as implemented in Hong Kong, where the disposal levy is used for both revenue generation and pricing out illegal disposal. Second, a scheme that charges for construction waste disposal, akin to Hong Kong's disposal levy (Yu et al., 2012) or the UK's landfill tax, could be introduced to generate revenue and to price out illegal disposal activities. Third, the general principles of public procurement policy should include a requirement for minimum recycled content specifications and deconstruction design in publicly funded construction contracts, to ensure that advanced circular practices are normalised for the contracts of contractors that may not have market incentives to adopt such practices. Fourth, small firms should receive more support to achieve the full sustainability benefits

of their circular adoption through shared waste infrastructure targeted at SMEs that can be financed through a mix of public co-investment and waste management levy revenues, and which should be piloted in a minimum of three urban areas to address the moderation gap.

Pathways to formalise the informal waste sector, such as involving waste pickers and informal recyclers in regulated and incentivised frameworks, have the potential to significantly increase the amount of waste collected and recycled at low cost, especially for construction waste collection and recycling in Ghana, where the sector is largely informal and structurally invisible (Agyei et al., 2023; Armoo et al., 2024). This is not something of a sideline: the 21.3% of the population that does not adopt is mostly relying on informal disposal channels, so improving informal sector governance is as critical as advancing the formal sector uptake.

6. Conclusion

This study provides empirical quantitative evaluation of the adoption of circular construction waste management practices and their linkages with measures of urban environmental sustainability at multiple cities in Ghana. The results are unequivocal on three points. First, the level of adoption is low and polarised on a three-cluster typology and concentrated in practices with the least operational restructuring. Second, adoption matters: while this study confirms that the environmental returns of circular practices are the strongest impact found, they are not guaranteed or automatic, depending on the regulatory context in which circular practices are being implemented and the set of resources available for circular practices within the firm. Third, regulatory enforcement is not a background condition, but a causal mechanism that accounts for over a third of the environmental benefits of adoption along its own channel, and is the most important difference between the top and bottom cities in the country.

The policy implications are not pleasant for those who like voluntary, knowledge-raising strategies: the data do not support the hypothesis that a knowledge-building approach alone will be sufficient for driving circular transformation. Ghana's construction industry is in a structural balance where adoption is only rational if it is too expensive not to be adopted by the regulatory framework, too difficult to be adopted by the technology, and too cost-effective by the scale of the adoption. To disrupt that balance, there must be joint and simultaneous efforts across all three dimensions. For circular construction waste management to provide the urban environmental sustainability benefits of its size of impact, the institutional framework in which Ghana's construction companies operate needs to be restructured via enforceable regulation, shared infrastructure and differential support before it can be achieved.

7. Restrictions and further studies.

This study is faced with constraints that should restrict the interpretation of the results and encourage additional research:

First, due to the cross-sectional design, there is no causal inference in the strict sense, and the regression and mediation results only show relationalism; rather, it is theoretically rooted in causal logic, but longitudinal or quasi-experimental designs would be necessary to prove the temporal ordering. The most rigorous test of the regulatory mediation pathway would be a natural experiment that could be followed over time, before and after the implementation of a disposal charging scheme.

Second, sustainability outcome indicators are subjective, rather than physical indicators like landfill tonne diversion, actual or measured air quality or number of illegal dumpings. The use of objective secondary data information from municipal waste authorities and environmental monitoring agencies (if available) should be incorporated into future studies to allow for triangulation of perceptual information.

Third, although the response rate of 62.6 per cent is good for construction management surveys, the slight under-representation of small firms in peripheral cities may make the adoption figures for non-adopter segments conservative. The study does not measure the impact of donor-funded sustainability programmes or multinational construction clients' influence, which can have an impact on adoption in Accra's premium construction market, independent of the local regulatory enforcement.

Future research should expand on the following: (1) compare multi-country studies in other West African countries with different country-specific regulatory regimes to test the generalisability of the regulatory mediation finding; (2) conduct cost benefit analyses of the mandatory on-site segregation requirements given Ghanaian cost and logistics conditions; (3) carry out qualitative research on the 24.2% advanced circular firms to identify the internal management processes and the external network conditions that differentiate them from the majority of moderate-adopter firms; and (4) intervention studies to evaluate shared SME waste infrastructure models with respect to the level of adoption and sustainability outcomes.

Declarations

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Competing Interests

The authors declare no conflicts of interest.

Availability of Data and Materials

The datasets collected and analysed during the current study are available from the corresponding author upon reasonable request.

Author Contributions

All authors contributed equally to the development of this study.

Clinical Trial Number

Not applicable

Consent for Publication

Not applicable as no identifiable data or images are present within the manuscript.

Consent to Participate

Informed consent was obtained from all the individual participants for participation in this study.

Ethical Statement

The requirement for ethical approval for this study was waived by the Institutional Review Committee of the University of Skills Training and Entrepreneurial Development (USTED), Kumasi, Ghana, in accordance with the Declaration of Helsinki. The study involved non-clinical social science methods with non-vulnerable adult professional populations; all participants provided voluntary informed consent and no personal identifying information was collected.

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