Ecological Economics 241 (2026) 108862

Contents lists available at ScienceDirect

Ecological Economics

journal homepage: www.elsevier.com/locate/ecolecon

“Local Heroes”: Construction firms pioneering circular innovation

Elisa Chioatto [a,b,c,*], Alessandro Montanaro [a,b,c], Massimiliano Mazzanti [a,b,c]

[a] University of Ferrara, Department of Economics and Management, V. Voltapaletto, 11, 44121 Ferrara, Italy
[b] SEEDS Sustainability, Environmental Economics and Dynamic Studies, Italy
[c] CERCIS CEntre for Research on Circular economy, Innovation and SMEs, Italy

ARTICLE INFO

Keywords:
Circular economy
Innovation
Construction and demolition sector
Local networks

ABSTRACT

Innovation in the construction sector is critical to reducing environmental impacts, yet the adoption of circular innovations remains poorly understood. This paper examines the determinants of circular innovation adoption among 376 construction firms in the Emilia-Romagna region of Italy, based on an original survey dataset. Our analysis reveals that R&D investments increase the likelihood of circular innovation adoption by 24 percentage points, while larger firm size raises it by 13 points. Local market orientation exerts a strong positive effect: firms generating at least 50 % of their turnover locally are 15 percentage points more likely to adopt a circular innovation. Regulatory factors are not significant in aggregate, but become decisive for specific circular practices such as selective demolition and the use of sustainable inputs. Theoretically, the study demonstrates that circular innovations follow different adoption dynamics than traditional innovations in the construction industry, with proximity-based networks and local material flows playing a central role. Policy-wise, findings highlight the need to support R&D, especially in smaller firms, strengthen targeted regulatory incentives, and foster local inter-firm collaborations to reduce transaction costs and overcome secondary material quality risks.

1. Introduction

Most research on innovation has focused on manufacturing, science and technology-driven businesses, and knowledge-intensive service firms, often overlooking construction firms as the primary unit of analysis. However, the innovating routines of construction firms differ from those in other sectors due to the unique characteristics of construction products and processes. These characteristics include immobility, complexity, durability, costliness, and a high degree of social responsibility (Nam and Tatum, 1988). As early as 1988, Nam and Tatum, and later Reichstein et al., 2008 highlighted the limited understanding of innovation development within the construction sector. This lack of understanding hinders policy-driven initiatives aimed at boosting innovativeness and firms’ capacity for innovation. In an era where innovation is key to embedding principles of a cleaner, safer, and circular economy into construction industry, addressing this gap is crucial. Innovative adjustments to products, processes, and the entire value chain are, indeed, essential to mitigate the environmental impacts associated with construction sector activities.

A significant share of these impacts stems from the large volumes of waste generated throughout the sector. On a global scale, the building and construction industry is responsible for 40 % of all waste generated, 40 % of all material resource use, and 33 % of all human-induced emissions. At the same time, the world’s demand for construction is growing and will continue to grow at an even faster pace due to population growth, urbanization, and economic progress (United Nations Environment Programme, 2012; Ness and Xing, 2017). As this global picture translates to Europe, the magnitude remains significant: in 2021, nearly 40 % of all waste generated within the European Union (from now on EU) originated from construction activities (Eurostat, 2023). This waste is produced throughout the entire life cycle of buildings, including the planning and design phases, but is particularly significant during the disposal of building materials at the end of a building’s life, most of which ends up in landfills (Benachio et al., 2020). Despite the explicit targets set by the EU Waste Framework Directive (Directive 2008/98/EC as amended by Directive (EU) 2018/851), the upward trend in construction and demolition (from now on C&D) waste generation is expected to grow, especially due to the ageing building stock in Europe. Approximately half of the building stock comprises structures over 50 years old, with a significant portion expected to undergo refurbishment or demolition (Pacheco et al., 2023).

In light of these trends, there is an urgent need to explore and

* Corresponding author at: University of Ferrara, Department of Economics and Management, V. Voltapaletto, 11, 44121 Ferrara, Italy.
E-mail address: elisa.chioatto@unife.it (E. Chioatto).

https://doi.org/10.1016/j.ecolecon.2025.108862
Received 2 January 2025; Received in revised form 18 September 2025; Accepted 9 November 2025
Available online 14 November 2025

promote more effective utilization of C&D waste through the role of innovation, and particularly circular-related innovation. This involves maximizing reuse and recycling by improving the quality of secondary materials and enhancing the environmental performance of treatment methods (Gálvez-Martos et al., 2018). Nonetheless, construction firms continue to face significant challenges in adopting circular practices as pointed out in Munaro and Tavares, 2023. Against this background, the research problem addressed in this paper concerns the limited understanding of why some construction firms adopt Circular Economy Innovations (hereafter CEI) while others do not. Our objective is indeed to examine the factors that promote or hinder the adoption of CEI in the construction sector, with particular attention to the Emilia-Romagna Region.

The exploration of CEI enablers has received limited attention, (Cainelli et al., 2020; Kiefer et al., 2021; Chioatto et al., 2024; Meili et al., 2024) and to our knowledge, no research has specifically addressed its adoption in the construction industry. Only Hazarika and Zhang (2019) have investigated green innovation in the construction sector, examining the causes of the technological phenomena primarily from a material-based industries perspective. In contrast, we link our research to the general innovation literature that seeks to extend theories on innovation to industries beyond the leading manufacturing sector, aiming to understand why some construction firms succeed in innovating. This body of work suggests that a deeper understanding of construction firms' unique characteristics and their products is essential for driving innovation in the industry (e.g. Nam and Tatum, 1988; Reichstein et al., 2008; Barata and Fontainha, 2017).

These earlier findings investigate how factors such as regulation, sources of knowledge, firm size, and market orientation influence construction firms' ability to innovate. This paper aims to determine whether and how these factors similarly impact the adoption of CEI. Further to this, we assume that circular innovation is more complex, involving the entire supply chain, from resource acquisition to after-use activities (Meili et al., 2024). Consequently, general innovation theories may not be fully transferable to circular innovation, which demands targeted analysis. So, we will contend, contrary to existing literature suggesting a negative impact of local market orientation on innovation adoption in construction, that this relationship might be positive for CEI. The transition to a circular economy (from now on CE) requires material flows likely facilitated by the creation of networks among firms (Bocken et al., 2016). This implies that the local relationships firms build could play a decisive role, especially in the adoption of specific CEIs within the C&D sector. This relates to the nature of C&D waste, which is characterized by large volumes, high transportation costs, and quality risk associated with reuse. Local networks can help overcome these obstacles by facilitating the exchange and reuse of waste materials.

This paper aims to provide a theoretical contribution to the still-scarce circular innovation literature, especially at the sectoral level. In addition, the paper responds to the call for increasing the understanding of innovation sources in the construction sector, an area that remains unaddressed for circular innovation adoption. In this sense, we want to learn more about the role of small-scale market orientation in facilitating the implementation of CEIs for construction firms.

For the empirical analysis we use an original dataset of 376 firms situated in the Emilia-Romagna region, collected by the Centre for Research on Circular Economy of the Department of Economics and Management, University of Ferrara, in 2022. The focus on a small-scale regional context is motivated by the belief that the obstacles and opportunities of the CE transition vary according to regional settings (Bourdin and Torre, 2024). Regional economies are recognized as distinct communities influenced by their own technological expertise, practices, and institutional setups, which consequently determine the conditions affecting the generation of innovation and the approach that each region need to take in implementing circular innovative practices (Balland et al., 2019; Losacker et al., 2023). This highlights the importance of identifying "*territorial dynamics linked to circular economy transformations*" (Tapia et al., 2021) in order to tailor local interventions and adapt policies and programs to the specific needs of each region (Bourdin and Torre, 2024).

The remainder of the paper is organized as follows: Section 2 discusses the determinants of innovation in the construction sector, outlining the theoretical framework and main hypotheses of this research. Section 3 details the data and methodology used. Section 4 presents and discusses the analysis results, and Section 5 concludes with general findings.

2. Theoretical background

2.1. Innovation in the construction sector: determinants of innovation

The construction industry is widely recognized as one of the leading sectors where the implementation of CE practices is essential (Damgaard et al., 2022). This is due to the large volumes of waste generated, resource depletion, and land deterioration associated with the sector's activities (Ruiz et al., 2020). Article 11(2)(b) of the EU Waste Framework Directive (2008/98/EC), mandates that by 2020, 70 % by weight of C&D waste must be prepared for re-use, recycling, and other forms of material recovery, including backfilling operations[1],[2]

In recent years, substantial progress has been made in terms of research and novel solutions for separation, processing and quality enhancement of C&D fractions. Examples include the application of artificial intelligence, machine learning, computer vision, and robotics for automated sorting and identification of waste streams, as well as the deployment of optical sorting and jigging methods to improve material purity and material recovery rates. These advances have raised the technical potential for recycling and reuse of C&D waste (Demetriou et al., 2023; Iyiola et al., 2024; Dodampegama et al., 2024). Accordingly, Cristóbal García et al. (2024) estimated recycling and reuse potential for each material fraction of C&D waste, indicating that (excluding excavated soils and dredging spoils due to their significant uncertainty) 83 % of European C&D waste could potentially be recycled, with up to 16 % of this being reusable. Achieving this, could result in a reduction of up to 48 million tonnes of greenhouse gas emissions annually, equivalent to the combined annual emissions of Estonia, Latvia, and Luxembourg, along with net savings of up to €7.3 billion. Nonetheless, while progress has raised technical potential, economic, organizational, and industry-structure barriers still prevent large-scale adoption. Indeed, recycling remains dominated by low-value recovery practices such as backfilling, and high-quality recycling and preparation for reuse often come at higher costs compared to incineration or landfilling, despite offering greater societal benefits when externalities are considered (Cristóbal García et al., 2024; European Environment Agency, 2022).

To overcome these challenges, substantial changes in both industry and societal structures are needed, especially in waste management and firms' capacity to innovate for improved construction and renovation processes (Chen, 2024). The construction sector has unique characteristics, including industry conservatism, complex structures with numerous interconnected attributes, diverse manufacturing techniques,

[1] In order to promote improved management practices and foster the circular economy within the construction and demolition sector, the European Commission has supplemented the Waste Framework Directive with guidance documents such as the EU Construction and Demolition Waste Management Protocol (European Commission, 2016), which provides non-binding guidelines for the proper handling of construction and demolition waste stream. Additionally, the Commission has issued guidelines for audits conducted prior to building demolition (European Commission, 2018) and Circular Economy Principles for Building Design (European Commission, 2020).

[2] The EU Commission is planning to exclude backfilling and naturally occurring materials in category 17 05 04 (European Environment Agency, 2022).

and multiple stakeholders throughout the supply chain (Barata and Fontainha, 2017). Given these features, it is necessary to examine and understand the barriers and motivators shaping sources of change and innovation within the construction industry to establish more precise CE initiatives (Benachio et al., 2020; Munaro and Tavares, 2023).

To investigate the factors driving the uptake of CEI in the construction sector, this paper draws on the literature on innovation (in its broader definition) within the industry. Most research on construction innovation has focused on the sector and project levels, often neglecting the firm-level perspective. This body of work, as previously noted, emerged from a need for specialized studies to comprehend the unique enablers of innovation in construction, considering the sector's distinct structural characteristics, products, and processes, thereby steering clear of the application of *one-size fits all* models.

To derive testable predictions, we draw on findings from this body of literature, which converges in suggesting several potential determinants of innovation within the sector. There is a general a consensus that regulation, Research and Development (from now on R&D) expenditure and firm size are likely to enhance innovation dynamics among construction firms.

Regulation is recognized as a significant factor influencing innovation, as noted by Reichstein et al. (2008) and Barata and Fontainha (2017). Firms in this sector face stringent regulatory requirements that impact material choices, technologies, and production processes. Reichstein et al. (2008) suggest that regulations may act as sources of information, prompting firms to develop new technologies and work practices. However, it is worth noting that Gann et al. (1998) found regulation can also hinder innovation, particularly when new materials require extensive time and financial investment to secure regulatory approval.

There is also evidence that increased *R&D expenditure* can positively impact innovation adoption in construction, although formal R&D investments in the sector remain low and often underestimated. Few construction firms have an R&D department, partly due to another important factor: *Firm Size.* Many construction firms are small and, as a result, experience the "liability of smallness." This is particularly true for process innovation rather than product innovation. Reichstein et al. (2008) found that while firm size does not significantly influence the likelihood of introducing product innovations, larger firms are more likely to introduce process innovations, a finding further supported by Barata and Fontainha (2017).

We expect these factors to similarly influence innovation adoption in the context of the CE and thus propose:

Testable Hypothesis H_1: *Regulations, R&D expenditure and firm size boost the adoption of circular innovations.*

The second research question addresses the role of market orientation. Reichstein et al. (2008) found out that construction firms operating at a local or regional level tend to innovate less compared to firms targeting national or international markets. Exposure to broader competition can drive firms to develop enhanced capabilities that promote innovation development. Nonetheless, sector-wide evidence indicates that CE adoption in construction encompasses design practices, material choices, supply-chain coordination and new business models, suggesting that CEIs adoption is inherently more complex than conventional innovations (Hossain et al., 2020). In addition, CEIs are subjected to specific market dynamics especially regarding the nature of construction and demolition waste. Munaro and Tavares (2023) observed that C&D waste often fails to be reinjected as secondary material into the market. C&D waste is bulky and heavy, with varied material fractions that differ in both economic value and environmental impact (Cristóbal García et al., 2024). Consequently, the primary barrier to circularity results from the lack of reintegration strategies for secondary materials. This is due to insufficient incentives for using recycled materials, higher transportation costs, lower reliability of secondary material flows, and the low cost of virgin materials, which often do not reflect the full environmental and social costs of C&D waste.

In the Italian policy context, fiscal and regulatory instruments contribute to partially correcting these distortions. Since Law 549/1995, a disposal tax has internalised part of the environmental costs of landfilling (and, where applicable, incineration without energy recovery), thereby improving the relative competitiveness of reuse and recycling. Complementing this fiscal approach, non-tax measures such as the minimum environmental criteria for public works create demand for recycled materials and incentivise design-for-deconstruction practices. Yet, despite these initiatives, significant quantities of potentially recoverable resources continue to be landfilled, indicating that current instruments are necessary but not sufficient to close material loops in the construction sector.

These considerations lead us to argue that local market scope may facilitate networks creation, thereby enhancing access to secondary material flows, resource and knowledge exchange. In localized markets, the close-knit nature of business relationships can foster collaboration and information sharing among firms and decrease transaction costs associated with circular practices (e.g. transportation costs, quality uncertainties, knowledge development) (Zhang et al., 2022; Bourdin and Torre, 2024). Overall, local networks in construction and demolition extend beyond transactional exchanges, enabling firms to build trust, share knowledge, and develop collaborative relationships. When supported by platforms that integrate design, materials, and processes, these networks can reduce adoption risks and function as innovation ecosystems rather than mere transactional marketplaces (Wielopolski and Bulthuis, 2023).

Testable Hypothesis H_2: *Local market orientation is expected to encourage the adoption of circular innovations.*

3. Empirical analysis

3.1. Dataset description

The hypothesis put forward in *Section 2* are tested empirically on a sample of construction firms operating in the Emilia-Romagna region (Italy). Although focusing on a single sub-national area may limit the external replicability of our analysis, the chosen region stands out as one of the most advanced in Italy and Europe. In 2022, its GDP per capita was close to 40,000 euros, exceeding the EU average by 17 %. While Emilia-Romagna shows moderate green economic performance compared to other European regions (Silvestri et al., 2020), it has taken a distinctive approach to implementing CE principles. Notably, it was the first Italian region to enact dedicated CE legislation (Law No. 16 of 5 October 2015). This makes Emilia-Romagna an interesting model to study.

The dataset comes from a regional survey conducted in 2022 by CERCIS, the Centre for Research of the Department of Economics and Management, University of Ferrara in collaboration with the General Directorate for Land and Environment Protection, Emilia-Romagna Region. The survey targeted construction firms in Emilia-Romagna using CATI/CAWI methodologies. The reference years for the collected information is the triennium 2018–2020 and in some cases questions refers to the previous period. The initial sample consists of 408 respondents stratified by geographical location (Istat), sector (technological intensity, following the Eurostat taxonomy of low-tech, medium-low-tech, medium-high-tech and high-tech), and firm size (small: 10–49 employees; medium: 50–249 employees; large: ≥ 250 employees). A small fraction of firms in the sample are involved in the manufacturing of construction products (cement, concrete, bricks), which were excluded to maintain a focus solely on the construction industry, yielding a final sample of 376 firms.

Notably, in this sample, micro and small firms are more represented compared to previous studies that utilized Eurostat Community Innovation Survey (CIS) data, which only includes firms with more than 10 employees. This representation is significant in the context of the construction sector, as it consists of a large number of small and micro firms.

The questionnaire collected information on firm characteristics, standard innovation metrics, and the adoption of innovative practices related to the reuse and recovery of C&D waste. To assess CEI adoption, firms were asked to indicate their implementation of six specific practices between 2018 and 2020: 1) Replacement of natural inert materials with high environmental impact with sustainable materials; 2) Reduction of construction waste produced; 3) Selective demolition[3]; 4) Decontamination[4]; 5) Reuse of C&D waste in firms own production processes; 6) Transfer of C&D waste to other companies for reuse in their production processes.

Table 1 presents the sample averages, showing that reducing waste and transferring it to other companies were the most common practices, while decontamination was undertaken by only 9 % of firms.

Table 2 provides additional details on the main characteristics of the sample. As shown, over half (53.5 %) of the firms are classified as circular innovators, having adopted at least one of the six CEI practices. In contrast, less than a third (29.5 %) are categorized as standard innovators, reflecting a relatively lower prevalence of conventional innovation activities. Firm size is evenly distributed, with approximately one-third of the sample consisting of micro-firms (33.8 %) and another third comprising enterprises with 11 to 50 employees (35.6 %). Medium-sized firms with six to ten employees account for 28.4 % of the sample, while larger firms with more than 50 employees represent just over 2 %. Despite the notable adoption of circular practices, formal R&D activities remain limited; only 12.5 % of firms reported investing in R&D. This suggests that much of the innovation in this sector likely stems from practical, process-oriented approaches rather than structured R&D programs. Finally, in terms of industry segments, the sample is predominantly composed of firms involved in specialized construction activities (55.3 %), with the construction of buildings (34.8 %) and civil engineering (9.8 %) making up the remainder.

Table 1
Adoption rate of circular innovations ($N = 376$).

Circular innovation	Sample average
Replacement of natural inert materials with high environmental impact with sustainable materials	15 %
Reduction of construction waste	26 %
Selective demolition	19 %
Decontamination	9 %
Reuse of C&D waste in firms' own production processes	14 %
Transfer of C&D waste to other companies for reuse in their production processes	24 %

[3] Dismantling buildings to separate and preserve valuable materials for reuse, rather than demolishing everything indiscriminately.

[4] Cleaning and removing hazardous substances from construction sites or materials to make them safe for reuse or disposal.

Table 2
Sample characteristics.

Classification	Frequency	Percentage
Circular innovator		
Yes	201	53.5 %
No	175	46.5 %
Standard innovator		
Yes	111	29.5 %
No	265	70.5 %
Size		
1–5 employees	127	33.8 %
6–10 employees	109	28.4 %
11–50 employees	133	35.6 %
50+ employees	7	2.2 %
Formal R&D		
Yes	47	12.5 %
No	329	87.5 %
Industry		
Construction of buildings	131	34.8 %
Civil engineering	37	9.8 %
Specialized construction activities	208	55.3 %

3.2. Variables and methodology

The dependent variable employed to test the two research hypothesis regard the introduction of CEI. We define one generic dichotomous variable *CEI*, which takes value 1 if the firm declares to have introduced at least one circular innovation from the six categories surveyed. Considering the dichotomous nature of the dependent variables, the empirical analysis makes use of logistic estimation with the following model:

$$Y_i = f\left(GR\_REGULATION_i, R\&D_i, SIZE_i, LOCAL_i, X_i\right).$$

Where Y_i is a dummy variable that takes value 1 if the firm i introduces a circular innovation and 0 otherwise.

The main variables of interest in the analysis capture the driving factors for CEI adoption in construction firms. $GR\_REGULATION_i$, captures the effect of regulatory instruments. It is a binary variable taking a value of 1 if the firm has participated in public tenders involving green public procurement contracts and 0 otherwise. RED_i, measures the impact of formal R&D investments and absorptive capacity on firms' innovation performance. It is a binary variable that takes value 1 if the firm invested in R&D during the 2018–2020 triennium, and 0 otherwise. $SIZE_i$ is a continuous variable that indicate the firm's size, calculated as the logarithm of the number of employees. $LOCAL_i$ captures the effect of market orientation in shaping CEI activities. It is expressed as the percentage of the firm's turnover generated from local markets, as opposed to regional, national, or international markets.

The model is saturated by a vector of control variables, X_i, drawn from the broader eco-innovation and innovation literature, to account for observable characteristics that may further influence firms' propensity to adopt CEI. $GR\_MANAGER_i$ a binary variable that equals 1 if the firm declares awareness of the EU Protocol on the management of C&D waste (September 2016).[5] Managerial commitment to environmental issues is recognized driver of sustainable innovation practices, particularly for smaller firms (Hojnik and Ruzzier, 2016). Hazarika and Zhang (2019) found that in the construction sector, managerial commitment significantly influences environmental initiatives and benchmarks performance improvement. Firms whose managers

[5] The EU Protocol on the Management of Construction and Demolition Waste was developed as part of the broader framework outlined in the contract titled *"Accompanying actions following the Communication: Strategy for the sustainable competitiveness of the construction sector and its enterprises."* This protocol aims to promote resource efficiency and sustainable waste management practices across the construction sector, aligning with the EU's strategic goals for competitiveness and environmental sustainability.

prioritize environmental conservation are thus more likely to adopt eco-innovative practices.

ORGANIZATION$_i$ is an ordinal variable ranging from 0 to 3, capturing firms' adoption of different certifications. Category 1 includes firms with ISO 9001certification; category 2 includes firms with ISO 14001 certification; and category 3 includes firms registered under the EMAS (Eco-Management and Audit Scheme) voluntary program. The ranking reflects the expected impact of these certifications on a firm's adoption of CE practices, with higher levels indicating stronger commitments to environmental standards. ISO 9001, the most prevalent certification in the construction industry (Wielopolski and Bulthuis, 2023), emphasizes quality control through process and resource management. In contrast, ISO 14001 and EMAS focus on environmental management, with EMAS as a voluntary program indicating the highest level of environmental commitment (Demirel and Kesidou, 2011). Organizational capabilities in environmental and quality management are thus pivotal in driving eco-innovation, influencing areas such as resource efficiency, pollution prevention, eco-design, and recycling to support circular economy principles (Wagner, 2007). *MARKET$_i$* is a binary variable that takes the value 1 if the firm has perceived an increased market demand for recycled building materials, serving as a proxy for traditional market pull effects.

We finally included the following control variables: *LICENSE$_i$* which indicates whether the firm possesses a permit for the recovery of inert C&D waste, and *GROUP$_i$* a binary variable indicating whether the firm is part of an industrial group, to account for potential supplier effects.

A visual representation of our conceptual model is represented in Fig. 1.

Apart from the usual parametric results, several global statistics are reported in Table 3 These statistics allow for a general evaluation of the model in terms of overall fit and explanatory power.

4. Results

Results of the Logit model for the dependent variable *CEI* are reported in Table 4. Values represent average marginal effects, while corresponding odds ratios are provided in Table A.1 in the Appendix.

Both firm size (*SIZE*) and investments in R&D (*RED*) show positive and highly significant effects on CEI adoption. Among the two, *RED* displays the stronger marginal effect (0.239) compared to *SIZE* (0.126). By contrast, the regulatory driver (*GR_REGULATION*) is not statistically significant. A plausible explanation may lie in the heterogeneous influence of regulation which often target specific CE practices, we will test this in Section 4.1. Taken together, these results provide partial support for H_1: firm size and R&D enhance CEI adoption, but regulation does not exert a significant effect.

Moving to our second research hypothesis, the variable *LOCAL* is positive and highly significant, indicating that a stronger local market orientation increases the probability of adopting circular practices. For example, if 50 % of turnover is generated in local markets, the likelihood of CEI adoption increases on average by 15 percentage points. Therefore, H_2 is not rejected.

Regarding the control variables, we observe that green managerial consent (*GR_MANAGER*) capturing internal commitment to environmental issues exhibit a positive and highly significant impact on construction firms' propensity to innovate in the CE. Similarly, the *MARKET* variable, capturing market pull effects, is also positive and significant. Other controls, such as *ORGANISATION* and *GROUP*, do not display significant effects.

4.1. Robustness and heterogeneity

To validate the robustness of our findings and to explore potential heterogeneous effects, we estimated alternative models. First, we replicated the benchmark logit specification of Table 4 replacing the dependent variable with a proxy for traditional innovations (*INNO*). *INNO* is a binary variable equal 1 if the firm introduced product or process innovation between 2018 and 2020.[6] The results, presented in Table A.2 (in the Appendix), indicate that local market orientation does not significantly affect traditional innovations, but in contrast, these last are positively and significantly affected by R&D investment and firm size. This approach allows us to assess that *LOCAL* specifically facilitates CEIs, as hypothesized in H_2, rather than general innovation dynamics, but the other determinants retain their significance and expected signs, in line with the existing literature. As a second robustness test, we run the benchmark logit specification, using *LOCAL* as a continuous variable that captures all four types of market orientation (local, regional, national, international) through a weighted average method.[7] The results were consistent with those presented in the main model of Table 4, as reports Table A.3 in the Appendix.

Finally, to examine potential heterogeneous effects of our main explanatory variables, we apply the same model to a set of dichotomous dependent variables representing specific CEIs, namely *SUST_INPUT* (Replacement of natural inert materials with high environmental impact with sustainable materials); *REDWAS* (Reduction of construction waste produced); *SDEMOL* (Selective demolition); *DECONT* (Decontamination); *REUSWAS* (Reuse of C&D waste in firms own production processes); and *TRANSWAS* (Transfer of C&D waste to other companies for reuse in their production processes). Table 5 presents the results of the econometric analysis. Each column indicates the average marginal effect from logit estimates for the full sample regarding the introduction of the six CEIs typologies (Table A.4 in the Appendix shows Logit estimates results).

Interestingly, the regulatory driver becomes significant and positively associated with the adoption of specific CEIs, such as the use of sustainable materials to replace natural inert materials with high environmental impact (*SUST_INPUT*), selective demolition (*SDEMOL*), decontamination practices (*DECONT*), and the transfer of C&D waste to other companies for reuse in their production processes (*TRANSFWAS*).

Investments in formal R&D show a significant and positive effect on the introduction of innovation aimed at reducing the amount of C&D waste produced (*REDWAS*) and implementing selective demolition practices (*SDEMOL*). Firms size, on the other hand, is significantly and positively associated with the implementation of selective demolition, decontamination and the transfer of C&D waste to other companies.

As for the *LOCAL* effect, firms oriented toward the local market are significantly more likely to adopt selective demolition and waste transfer. The magnitude of the effect is particularly pronounced for selective demolition (approximately twice as large).

4.2. Discussion of the results

The results indicate that the likelihood of a construction firm adopting circular innovations in Emilia-Romagna increases with its

[6] For product innovation, firms are asked whether they "have introduced products or services that are technologically new or significantly improved compared to those previously available, considering technical and functional characteristics, performance, ease of use, etc.". For process innovation, firms are asked whether they "have introduced new or significantly improved processes compared to those previously adopted by the enterprise, in terms of technical and functional characteristics, performance, ease of use, etc." Both variables are dichotomous and the dependent variable *INNO* takes value 1 if the firm has adopted at least one product or process innovation.

[7] The continuous variable LOCAL (range 1–3.7 in our sample) is constructed using information on the geographical distribution of firms' sales. We assign increasing weights to different market horizons according to their distance from the local market (1 = local, 2 = regional, 3 = national, 4 = international). The index is obtained by weighting these categories with the percentage share of turnover in each market, so that higher values of LOCAL indicate a greater orientation beyond the firm's local market. Formally, $LOCAL = \frac{1\times\%Local+2\times\%Regional+3\times\%National+4\times\%International}{100}$

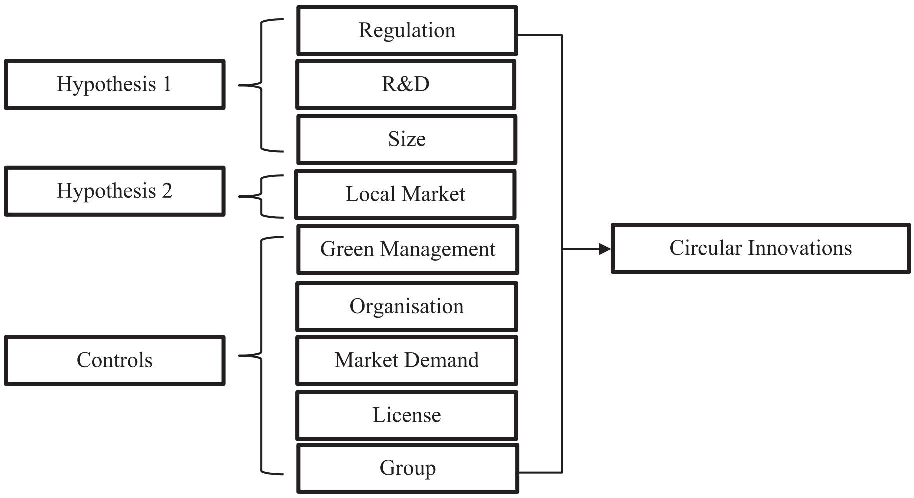

Fig. 1. Conceptual model of the study.

Table 3
Descriptive statistics and correlation matrix ($N = 376$).

Variables	Mean	SD	Min	Max	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
i. *CEI*	0.53	0.49	0	1	1.00									
ii. *GR_REGULATION*	0.19	0.39	0	1	0.15	1.00								
iii. *RED*	0.12	0.33	0	1	0.17	0.09	1.00							
iv. *SIZE*	2.18	0.83	0.6	4.7	0.22	0.25	0.03	1.00						
v. *LOCAL*	69.1	38.7	0	100	0.05	−0.15	−0.07	−0.30	1.00					
vi. *GR_MANAGER*	0.26	0.44	0	1	0.21	0.02	0.04	0.04	0.00	1.00				
vii. *ORGANISATION*	0.48	0.78	0	3	0.14	0.28	0.02	0.34	−0.17	0.09	1.00			
viii. *MARKET*	0.30	0.46	0	1	0.19	0.18	0.11	0.04	−0.07	0.07	0.05	1.00		
ix. *LICENSE*	0.19	0.39	0	1	0.15	0.10	0.05	0.09	0.05	0.02	0.13	0.06	1.00	
x. *GROUP*	0.07	0.26	0	1	0.07	0.08	0.01	0.10	−0.09	0.03	0.15	0.15	0.00	1.00

Table 4
Determinants of circular economy innovation.

Estimation Method	Logit
Dependent variables	CEI (Circular Innovations)
GR_REGULATION	0.0768
	(0.0672)
RED	0.239***
	(0.0760)
SIZE	0.126***
	(0.0299)
LOCAL	0.0020***
	(0.0005)
GR_MANAGER	0.209***
	(0.0525)
ORGANISATION	0.0263
	(0.0342)
MARKET	0.155***
	(0.0517)
LICENSE	0.121**
	(0.0615)
GROUP	0.0493
	(0.0866)
N.Obs.	376

Notes: Reported coefficients are average marginal effects calculated at the mean of all other covariates. Robust standard errors in parentheses. *** significant at the 1 % level; ** significant at the 5 % level; * significant at the 10 % level.

capacity to invest in R&D, its size, and its orientation toward local markets. When the analysis disaggregates CEI types, these effects appear heterogeneous, and also the role of regulation becomes significant. We interpret these findings as evidence that CEI adoption is multidimensional, and not all drivers are equally effective across different types of practices. To the best of our knowledge, this is the first study to investigate the determinants of CEI adoption at the firm level in the construction sector and with a local focus, thereby offering a novel contribution to the literature.

First we found out that firm size and R&D investments emerge as strong predictors of CEI adoption. Larger firms, equipped with greater resources and capabilities, are better positioned to implement CEI practices, especially those more complex such as selective demolition, decontamination and transfer of waste to other firms. Similarly, firms that invest in R&D also demonstrate a higher likelihood of adopting CEIs (especially those targeting waste reduction and selective demolition), suggesting that absorptive capacity and formal R&D activities play a critical role in driving innovations within the sector. In this regard, several national measures exist to support firms' research capacity, underscoring the relevant role of R&D. For instance, the Ministry of Enterprises and Made in Italy (MIMIT) launched the "Economia Circolare" call in 2020, which financed industrial R&D projects on resource efficiency and waste valorisation, directly relevant to CDW flows. Such initiatives are particularly significant for Small and Medium Enterprises (SMEs), which often face resource constraints and depend more heavily on public support to undertake R&D activities.

Table 5
Determinants of specific typologies of circular innovations.

Estimation Method	Logit	Logit	Logit	Logit	Logit	Logit
Dependent variables	SUST_INPUT Sustainable Inputs	REDWAS Reduction of waste	SDEMOL Selective demolition	DECONT Decontamination	REUSWAS Reuse of waste	TRANSWAS Transfer of waste
GR_REGULATION	0.1180***	0.0347	0.1040**	0.0518*	0.00791	0.1010*
	(0.0380)	(0.0533)	(0.0443)	(0.0300)	(0.0438)	(0.0538)
RED	0.0166	0.2000***	0.1160**	0.0422	0.0605	0.0899
	(0.0537)	(0.0555)	(0.0509)	(0.0359)	(0.0488)	(0.0584)
SIZE	0.0163	0.0441	0.0439**	0.0451**	0.0225	0.0546**
	(0.0208)	(0.0297)	(0.0217)	(0.0200)	(0.0223)	(0.027)
LOCAL	0.0006	−0.0002	0.0023***	0.0002	0.0002	0.0013**
	(0.0005)	(0.0005)	(0.0006)	(0.0004)	(0.0004)	(0.0006)
GR_MANAGER	0.1340***	0.1360***	0.0920**	−0.0128	0.0952***	0.1450***
	(0.0357)	(0.0459)	(0.0378)	(0.0313)	(0.0348)	(0.0414)
ORGANISATION	0.0338	0.0416	0.0690***	0.0101	0.0060	−0.0073
	(0.0225)	(0.0258)	(0.0218)	(0.0170)	(0.0221)	(0.0261)
MARKET	0.0069	0.0271	−0.0124	0.0103	−0.0209	0.1040**
	(0.0405)	(0.0470)	(0.0434)	(0.0328)	(0.0409)	(0.0438)
LICENSE	0.0036	0.1200**	0.0980**	0.0557*	0.1420***	0.0097
	(0.0431)	(0.0478)	(0.0416)	(0.0315)	(0.0347)	(0.0499)
GROUP	−0.0170	0.0156	−0.0410	0.1300*	−0.0052	−0.0139
	(0.0677)	(0.0805)	(0.0746)	(0.0695)	(0.0669)	(0.0754)
N.Obs.	376	376	376	376	376	376

Notes: Reported coefficients are average marginal effects calculated at the mean of all other covariates. Robust standard errors in parentheses. *** significant at the 1 % level; ** significant at the 5 % level; * significant at the 10 % level.

Secondly our analysis reveals that regulation does not exert a statistically significant effect when CEIs are considered collectively, but becomes decisive for specific innovations. Regulatory influence is particularly strong for sustainable inputs, selective demolition, decontamination, and waste transfer. These effects can be attributed to Italian green public procurement legislation (currently, CAM Edilizia - DM 23 June 2022, n. 183[8]), which explicitly rewards firms that employ the use of sustainable inputs, such as recycled inert materials, employ highly skilled workers, and engage in collaborative contracting for both the design and execution of projects. This provides empirical evidence that regulatory frameworks designed around measurable criteria can catalyze CEI adoption in construction, thereby partially supporting H_1.

Taken together, these findings align with prior research linking regulation, R&D and firm size with innovation capacity in the construction industry (Nam and Tatum, 1988; Reichstein et al., 2008; Barata and Fontainha, 2017), while extending its validity to CE-specific practices.

Third, the most original and novel contribution of this study concerns local market orientation. Firms with a greater share of turnover from local markets are significantly more likely to adopt CEIs, especially selective demolition and the transfer of C&D waste to other companies for reuse. This finding contrasts with prior studies that associated local market focus with lower innovation capacity (Reichstein et al., 2008). In the case of CEIs, localization has been recognized (e.g. Bourdin and Torre, 2024) as an advantage because material flows and knowledge exchange are most effectively organized through close firm relationships and short supply chains. This become especially true for C&D waste that incur in high transportation costs and quality risks of secondary raw materials, as noticed in Zhang et al., 2022; Munaro and Tavares, 2023 among the others. At confirmation of this, both innovations resulting significant in our model entail the transfer or exchange of waste between firms, a processes that, as hypothesized, can be facilitated by local market dynamics. Moreover, these innovations are interdependent: selective demolition involves carefully dismantling buildings to segregate and preserve valuable materials for reuse, which can then be transferred to other companies for incorporation into their production processes. It is worth noting that, Emilia-Romagna has introduced funding schemes and strategic plans (e.g. Programma Operativo Regionale – POR, "Asse 1 – Ricerca e Innovazione")[9] that explicitly encourage collaboration between research actors and construction SMEs, with a focus on CE goals. More specifically, the region supported the development of *Clust-ER networks* (such as the Edilizia e Costruzioni cluster), which are designed to foster structured collaboration between firms, universities, and research centres around innovation in construction and CE practices.

Finally, our analysis highlights the role of managerial and market factors in CEI adoption. Green managerial commitment positively influences nearly all CEI types, except decontamination,[10] emphasizing the importance of managerial awareness and strategic prioritization of environmental protocols, as suggested in Hojnik and Ruzzier, 2016; Hazarika and Zhang, 2019. Organizational certifications (e.g., ISO 9001, ISO 14001, EMAS) increase the likelihood of adopting selective demolition, suggesting that formal management systems support resource-intensive circular practices. Market demand for recycled materials also emerges as a key driver, particularly for C&D waste transfer, emphasizing the role of market incentives in fostering demand for secondary materials within the CE.

5. Conclusion

The contribution of our paper is the enrichment of research on the determinants of circular innovation in the construction sector, a still understudied area within the innovation literature.

[8] In the EU, public procurement in the construction sector is significantly represented. Directive 2014/24/EU was implemented to harmonize procurement processes across European countries. Italian legislation transposed this European directive with DM 11 ottobre 2017, n. 259, and later updated it with DM 23 giugno 2022, n. 183.

[9] The current Regional Operational Programme (POR) is the 2021–2027 cycle; at the time of our survey, the POR 2014–2020 was in force.

[10] This may be closely linked to how the variable is built: managers were asked whether they were aware of the EU Protocol of September 2016 for the management of C&D waste. While the protocol covers a broad range of practices related to the CE, including selective demolition and the reuse of materials, it does not explicitly focus on decontamination activities. Decontamination, which involves the removal of hazardous substances from construction materials, is typically addressed under different regulations and guidelines specific to hazardous waste management and environmental protection, such as the Waste Framework Directive (2008/98/EC) and the Seveso III Directive (2012/18/EU).

It has been shown that the distinctive features of construction processes and products, such as immobility, complexity, durability and a project-based nature, result in innovation patterns that differ from those in manufacturing or knowledge-intensive industries. Hence understanding how innovation takes shape within the construction industry is critical, given the sector's urgent need to face deep renovations to address its environmental impact and waste generation.

Through an analysis of 376 Emilia-Romagna's construction firms, our study identifies that firm size, R&D investments, regulatory frameworks and local market orientation, all play significant roles in shaping firms' adoption of CEIs, although their impact varies across specific types of innovations.

The most significant and original finding of this paper is that the success of circular initiatives in the construction sector relies not just on regulatory and economic factors (e.g. policy push, market push/pull effects), but also on the capacity of territories to mobilize and organize proximity relationship among the involved stakeholders. The reuse and recycling of construction waste is still constrained, and proximity and collaboration between firms may help reducing transportation costs, facilitating the exchange of secondary raw materials and knowledge, while ensuring improved quality control through shorter supply chains.

By shedding light on these determinants, our study fills a relevant gap in the literature while providing valuable insights for policymakers, aiming to strengthen CEI frameworks within the construction industry and to tailor local interventions. In particular, policies could increase the public support to R&D investments especially in smaller firms, through funding programs, tax incentives, or innovation grants targeting resource-intensive CEIs, such as selective demolition and decontamination. Regulatory frameworks should also account for the multidimensional nature of CEIs to ensure targeted interventions, as exemplified by the role exerted by the Italian green public procurement legislation. In addition, regulation should reinforce actions toward the creation of inter-firm networks/collaborations or clusters to leverage local market, thereby reducing transaction costs and improving quality control in the flow of secondary materials. Our study also highlights the importance of managerial awareness and market-driven stimuli that can complement regulatory measures. Managerial awareness can be strengthened through dedicated training or information programs, while market-based incentives can focus on creating stronger demand signals for recycled materials. More robust pricing of virgin material extraction would narrow the cost gap with secondary aggregates, while mechanisms that mitigate the perceived risks linked to the heterogeneous quality of C&D waste would further encourage uptake.

This study is not without limitations. Although the dataset is rich and original, it covers only a single period, which constrains our ability to capture the dynamic impact of circular innovation determinants over time. Furthermore, the evidence is limited to Emilia- Romagna construction firms restricting the generalizability of the findings to other territorial spaces. These limitations highlight the need for future research to expand both the temporal and geographical scope in order to provide a more comprehensive and robust understanding of the drivers of CEI adoption.

CRediT authorship contribution statement

Elisa Chioatto: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Alessandro Montanaro:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Massimiliano Mazzanti:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Investigation, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We acknowledge the funding within University of Ferrara project “Dipartimenti di Eccellenza 2018-2022” (coordinator M. Mazzanti).

Appendix A. Appendix

Table A.1
Determinants of circular innovation– Estimated Odds Ratio.

Estimation Method	Logit
Dependent variables	CEI (Circular Innovations)
GR_REGULATION	0.378
	(0.335)
RED	1.177***
	(0.385)
SIZE	0.622***
	(0.158)
LOCAL	0.00993***
	(0.00307)
GR_MANAGER	1.031***
	(0.277)
ORGANISATION	0.129
	(0.169)
MARKET	0.764***
	(0.264)
LICENSE	0.595*
	(0.310)
GROUP	0.243
	(0.427)
Constant	−2.772***

(*continued on next page*)

Table A.1 (*continued*)

Estimation Method	Logit
Dependent variables	CEI (Circular Innovations)
	(0.478)
N. Obs.	376

Notes: All coefficients are estimated with a Logit regression. Standard errors in parentheses. *** significant at the 1 % level; ** significant at the 5 % level; * significant at the 10 % level.

Table A.2
Robustness test on standard innovation adoption.

Estimation Method	Logit
Dependent variables	INNO (Innovations)
GR_REGULATION	−0.0614
	(0.0611)
RED	0.387***
	(0.0528)
SIZE	0.0609**
	(0.0301)
LOCAL	0.0005
	(0.0005)
GR_MANAGER	0.0740
	(0.0484)
ORGANISATION	−0.0007
	(0.0308)
MARKET	0.0476
	(0.0468)
LICENSE	−0.0300
	(0.0578)
GROUP	0.149*
	(0.0760)
N.Obs.	376

Notes: Reported coefficients are average marginal effects calculated at the mean of all other covariates. Robust standard errors in parentheses. *** significant at the 1 % level; ** significant at the 5 % level; * significant at the 10 % level.

Table A.3
Robustness test on circular innovation adoption.

Estimation Method	Logit
Dependent variables	CEI (Circular Innovations)
GR_REGULATION	0.0728
	(0.0677)
RED	0.248***
	(0.0768)
SIZE	0.128***
	(0.0303)
LOCAL	−0.124***
	(0.0428)
GR_MANAGER	0.201***
	(0.0520)
ORGANISATION	0.0306
	(0.0342)
MARKET	0.158***
	(0.0515)
LICENSE	0.121**
	(0.0616)
GROUP	0.0630
	(0.0877)
N.Obs.	377

Notes: Reported coefficients are average marginal effects calculated at the mean of all other covariates. Robust standard errors in parentheses. *** significant at the 1 % level; ** significant at the 5 % level; * significant at the 10 % level.

Table A.4
Determinants of specific typologies of circular innovations– Estimated Odds Ratio.

Estimation Method	Logit	Logit	Logit	Logit	Logit	Logit
Dependent variables	SUST_INPUT Sustainable Inputs	REDWAS Reduction of waste	SDEMOL Selective demolition	DECONT Decontamination	REUSWAS Reuse of waste	TRANSWAS Transfer of waste
GR_REGULATION	1.003***	0.204	0.827**	0.674*	0.0741	0.613*
	(0.338)	(0.315)	(0.356)	(0.393)	(0.410)	(0.330)
RED	0.142	1.181***	0.929**	0.549	0.567	0.546
	(0.457)	(0.346)	(0.410)	(0.466)	(0.454)	(0.357)
SIZE	0.139	0.260	0.350**	0.587**	0.211	0.331*
	(0.177)	(0.176)	(0.175)	(0.255)	(0.210)	(0.169)
LOCAL	0.00563	−0.00161	0.0184***	0.00269	0.00275	0.00800**
	(0.00448)	(0.00323)	(0.00540)	(0.00539)	(0.00439)	(0.00389)
GR_MANAGER	1.143***	0.801***	0.733**	−0.167	0.891***	0.877***
	(0.313)	(0.277)	(0.312)	(0.404)	(0.331)	(0.265)
ORGANISATION	0.288	0.245	0.550***	0.131	0.0565	−0.0447
	(0.192)	(0.154)	(0.177)	(0.222)	(0.206)	(0.159)
MARKET	0.0590	0.160	−0.0991	0.134	−0.196	0.630**
	(0.345)	(0.277)	(0.347)	(0.425)	(0.385)	(0.270)
LICENSE	0.0311	0.709**	0.781**	0.724*	1.328***	0.0591
	(0.367)	(0.291)	(0.338)	(0.407)	(0.337)	(0.303)
GROUP	−0.145	0.0922	−0.327	0.093	−0.0485	−0.0844
	(0.577)	(0.474)	(0.595)	(0.863)	(0.626)	(0.457)
Constant	−3.268***	−2.323***	−4.693***	−4.333***	−3.259***	−3.152***
	(0.603)	(0.488)	(0.722)	(0.839)	(0.660)	(0.583)
N. Obs.	376	376	376	376	376	376

Notes: All coefficients are estimated with a Logit regression. Standard errors in parentheses. *** significant at the 1 % level; ** significant at the 5 % level; * significant at the 10 % level.

Data availability

Data will be made available on request.

References

Balland, P.A., Boschma, R., Crespo, J., Rigby, D.L., 2019. Smart specialization policy in the European Union: relatedness, knowledge complexity and regional diversification. Reg. Stud. 53 (9), 1252–1268.
Barata, J.M., Fontainha, E., 2017. Determinants of innovation in European construction firms. Technol. Econ. Dev. Econ. 23 (6), 915–936.
Benachio, G.L.F., Freitas, M.D.C.D., Tavares, S.F., 2020. Circular economy in the construction industry: a systematic literature review. J. Clean. Prod. 260, 121046.
Bocken, N., Miller, K., Evans, S., 2016. Assessing the environmental impact of new circular business models. In: Proceedings of the "new business models"—exploring a changing view on organizing value creation, Toulouse, France, 1, pp. 16–17.
Bourdin, S., Torre, A., 2024. Economic geography's contribution to understanding the circular economy. J. Econ. Geog. 25 (2), 293–308.
Cainelli, G., D'Amato, A., Mazzanti, M., 2020. Resource efficient eco-innovations for a circular economy: Evidence from EU firms. Res. Policy 49 (1), 103827.
Chen, C., 2024. Development of green business strategies through green dynamic capabilities and environmental regulation: empirical evidence from the construction sector. J. Clean. Prod. 438, 140826.
Chioatto, E., Zecca, E., D'Amato, A., 2024. Which innovations for circular business models? A product life-cycle categorisation. Ind. Innov. 1–23.
Cristóbal García, J., Caro, D., Foster, G., Pristerà, G., Gallo, F., Tonini, D., 2024. Techno-Economic and Environmental Assessment of Construction and Demolition Waste Management in the European Union. Publications Office of the European Union, Luxembourg.
Damgaard, A., Lodato, C., Butera, S., Fruergaard Astrup, T., Kamps, M., Corbin, L., Tonini, D., Astrup, T.F., 2022. Background Data Collection and Life Cycle Assessment for Construction and Demolition Waste (CDW) Management, EUR 31323 EN. Publications Office of the European Union, Luxembourg.
Demetriou, D., Mavromatidis, P., Robert, P.M., Papadopoulos, H., Petrou, M.F., Nicolaides, D., 2023. Real-time construction demolition waste detection using state-of-the-art deep learning methods; single–stage vs two-stage detectors. Waste Manag. 167, 194–203.
Demirel, P., Kesidou, E., 2011. Stimulating different types of eco-innovation in the UK: Government policies and firm motivations. Ecol. Econ. 70 (8), 1546–1557.
Dodampegama, S., Hou, L., Asadi, E., Zhang, G., Setunge, S., 2024. Revolutionizing construction and demolition waste sorting: insights from artificial intelligence and robotic applications. Resour. Conserv. Recycl. 202, 107375.
European Commission, 2016. EU Construction and Demolition Waste Management Protocol. Publications Office of the European Union.
European Commission, 2018. Guidelines for the Waste Audits before Demolition and Renovation Works of Buildings. Publications Office of the European Union.
European Commission, 2020. Circular Economy Principles for Building Design. Publications Office of the European Union.
European Environment Agency, 2022. Modelling the Renovation of Buildings in Europe from a Circular Economy and Climate Perspective.
European Parliament and Council, 2008. Directive 2008/98/EC of the European Parliament and of the council of 19 November 2008 on waste and repealing certain directives. Offi. J. Eur. Union, L 312, 3–30.
Eurostat, 2023. Waste statistics: waste generation by economic activities and households (env_wasgen). Last access September 2024. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Waste_statistics.
Gálvez-Martos, J.L., Styles, D., Schoenberger, H., Zeschmar-Lahl, B., 2018. Construction and demolition waste best management practice in Europe. Resour. Conserv. Recycl. 136, 166–178.
Gann, D.M., Wang, Y., Hawkins, R., 1998. Do regulations encourage innovation? The case of energy efficiency in housing. Build. Res. Inf. 26 (5), 280–296.
Hazarika, N., Zhang, X., 2019. Factors that drive and sustain eco-innovation in the construction industry: the case of Hong Kong. J. Clean. Prod. 238, 117816.
Hojnik, J., Ruzzier, M., 2016. What drives eco-innovation? A review of an emerging literature. Environ. Innov. Soc. Trans. 19, 31–41.
Hossain, M.U., Ng, S.T., Antwi-Afari, P., Amor, B., 2020. Circular economy and the construction industry: existing trends, challenges and prospective framework for sustainable construction. Renew. Sust. Energ. Rev. 130, 109948.
Iyiola, C.O., Shakantu, W., Daniel, E.I., 2024. Digital technologies for promoting construction and demolition waste management: a systematic review. Buildings 14 (10), 3234.
Kiefer, C.P., del Río, P., Carrillo-Hermosilla, J., 2021. On the contribution of eco-innovation features to a circular economy: a microlevel quantitative approach. Bus. Strateg. Environ. 30 (4), 1531–1547.
Losacker, S., Hansmeier, H., Horbach, J., Liefner, I., 2023. The geography of environmental innovation: a critical review and agenda for future research. Rev. Regi. Res. 43 (2), 291–316.
Meili, R., Stucki, T., Kissling-Näf, I., 2024. Learning from the best: how regional knowledge stimulates circular economy transition at company level. Camb. J. Reg. Econ. Soc. rsae011.
Munaro, M.R., Tavares, S.F., 2023. A review on barriers, drivers, and stakeholders towards the circular economy: the construction sector perspective. Clean. Responsib. Consumption 8, 100107.
Nam, C.H., Tatum, C.B., 1988. Major characteristics of constructed products and resulting limitations of construction technology. Constr. Manag. Econ. 6 (2), 133–147.
Ness, D.A., Xing, K., 2017. Toward a resource-efficient built environment: a literature review and conceptual model. J. Ind. Ecol. 21, 572–592.
Pacheco, J., de Brito, J., Lamperti Tornaghi, M., 2023. Use of Recycled Aggregates in Concrete: Opportunities for Upscaling in Europe. Publications Office of the European Union, Luxembourg.
Reichstein, T., Salter, A.J., Gann, D.M., 2008. Break on through: sources and determinants of product and process innovation among UK construction firms. Ind. Innov. 15 (6), 601–625.
Ruiz, L.A.L., Ramón, X.R., Domingo, S.G., 2020. The circular economy in the construction and demolition waste sector–a review and an integrative model approach. J. Clean. Prod. 248, 119238.

Silvestri, F., Spigarelli, F., Tassinari, M., 2020. Regional development of circular economy in the European Union: a multidimensional analysis. J. Clean. Prod. 255, 120218.

Tapia, C., Bianchi, M., Pallaske, G., Bassi, A.M., 2021. Towards a territorial definition of a circular economy: exploring the role of territorial factors in closed-loop systems. Eur. Plan. Stud. 29, 1–20.

United Nations Environment Programme, 2012. Sustainable Resource Efficiency Cities — Making it Happen. UNEP, Paris.

Wagner, M., 2007. On the relationship between environmental management, environmental innovation and patenting: Evidence from German manufacturing firms. Res. policy 36 (10), 1587–1602.

Wielopolski, M., Bulthuis, W., 2023. The better building initiative—a collaborative ecosystem involving all stakeholders as catalyst to accelerate the adoption of circular economy innovations in the construction sector. Circ. Econ. Sustain. 3 (2), 719–733.

Zhang, C., Hu, M., Di Maio, F., Sprecher, B., Yang, X., Tukker, A., 2022. An overview of the waste hierarchy framework for analyzing the circularity in construction and demolition waste management in Europe. Sci. Total Environ. 803, 149892.