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ROBOTIC SYSTEMS FOR CLOSED-LOOP CONSTRUCTION: A BIBLIOMETRIC ANALYSIS OF CONSTRUCTION DEMOLITION WASTE MANAGEMENT

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ABSTRACT

Robotic and automated systems present transformative potential for addressing construction and demolition waste (CDW) challenges through enhanced sorting, deconstruction, and material recovery. However, research at the intersection of robotics and closed-loop construction remains fragmented, lacking a comprehensive synthesis of trends, collaboration patterns, and technological evolution. This study conducts a bibliometric analysis of 36 peer-reviewed articles (2015-2026) retrieved from Scopus and Web of Science following PRISMA guidelines, employing VOSviewer for keyword co-occurrence, bibliographic coupling, and collaboration network analysis. Results reveal exponential publication growth since 2021, with peak output in 2024-2025 driven by advances in artificial intelligence and computer vision. China, Australia, and Hong Kong emerge as leading contributors within Asia-Pacific and European collaborative networks. Keyword analysis identifies five primary research clusters: robotic sorting and grasping technologies, computer vision for waste recognition, deconstruction and disassembly systems, digital enablers (BIM, digital twins, IoT), and circular economy frameworks. Despite significant progress, critical gaps persist in perception robustness under real-world conditions, manipulation of heterogeneous materials, and deconstruction system integration for component reuse, human-robot collaboration frameworks, and economic validation. This review provides researchers, practitioners, and policymakers with a systematic foundation for advancing robotic closed-loop construction toward sustainable, intelligent waste management.

Keywords: *Automation; Bibliometric Analysis; Closed-Loop Construction; Construction and Demolition Waste; Robotics*

1. INTRODUCTION

The construction industry faces an unprecedented crisis of resource depletion and waste generation, with construction and demolition waste (CDW) constituting approximately 36% of total waste in the European Union and exceeding 10 billion tons annually worldwide (Dodampegama et al., 2024; Moschen-Schimek et al., 2023). Traditional waste management approaches, characterised by manual sorting and conventional

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demolition, prove increasingly inadequate due to occupational health risks, human error, and limited recovery rates (Ku et al., 2020; Chen et al., 2023).

Robotic and automated systems have emerged as transformative enablers of circular construction, offering consistent, precise material handling capabilities through advanced configurations incorporating computer vision, hyperspectral imaging, and deep learning (Xiao et al., 2020; Prasad & Arashpour, 2024). Integration with digital technologies, including building information modelling (BIM), digital twins, and the Internet of Things (IoT), creates unprecedented opportunities for closed-loop material management across the building lifecycle (Abd El-Hameed, 2025; Thakuri et al., 2024).

Despite technological enthusiasm, the literature remains fragmented, with isolated studies examining specific applications lacking a comprehensive synthesis of research trends and collaboration networks (Heuer et al., 2025; Ostapska et al., 2025). This study addresses this gap through a bibliometric analysis of robotic closed-loop construction systems for onsite recycling and material reuse. The objectives are: (i) to identify evolutionary publication patterns; (ii) to reveal primary research themes through keyword co-occurrence analysis; (iii) to map collaborative networks; and (iv) to identify future research directions.

2. METHODOLOGY

This study employs a comprehensive methodological approach, applying bibliometric analysis to identify the literature pertaining to robotic and automated systems for onsite recycling and material reuse in construction and demolition waste management. According to De Oliveira et al. (2019), bibliometric analysis constitutes a statistical instrument that represents the current state of scientific knowledge by analysing citations, authors, institutions, countries, and journals, thereby identifying research opportunities, trends, and voids while facilitating the development of scientific projects. The methodology followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure transparency, reproducibility, and rigour (Page et al., 2021). Scopus and Web of Science were employed due to their extensive coverage and high quality (Thelwall & Sud, 2022). The combination of Scopus and Web of Science follows the multi-database approach recommended by Abioye et al. (2021) and Kokkalis et al. (2025), serving to mitigate the risk of overlooking pertinent literature that might be indexed in only one database.

2.1 SEARCH STRATEGY DEVELOPMENT

The search strategy was structured around the following search string (Figure 1), in line with the methodologies established by Balogun et al. (2024), Shao et al. (2022), and Abd El-Hameed (2025).

(“robot*” OR “automation” OR “computer vision” OR “AI” OR “deep learning”)
AND
(“construction and demolition waste” OR “construction waste” OR “demolition waste” OR “CDW” OR “waste sorting” OR “deconstruction”)
AND
(“circular economy” OR “closed-loop” OR “recycling” OR “reuse” OR “material recovery”)

Figure 1: Search string (By Authors)

This approach ensured that retrieved articles addressed the intersection of robotics, construction waste, and circular economy principles. The search was applied to "Article title, Abstract, Keywords" fields across both databases. The search was conducted in February 2026, capturing the state of knowledge up to that date, with a focus on studies published between 2015 and 2026 to capture recent technological developments in this rapidly evolving field (Prasad & Arashpour, 2025a; Wang et al., 2020; Xiao et al., 2020).

2.2 SCREENING PROCESS

The screening process followed a systematic, multi-stage approach consistent with PRISMA guidelines (Page et al., 2021). Figure 2 presents the PRISMA flow diagram documenting the number of studies at each stage and the reasons for exclusion. Moreover, Table 1 represents the Exclusion and inclusion criteria established for article selection.

Initial database searches retrieved a total of 1,233 records (976 articles from Scopus and 257 articles from Web of Science). After removal of 216 duplicate records using reference management software (Mendeley), 1,017 unique records remained for screening. Titles and abstracts were screened against the inclusion and exclusion criteria. Articles were categorised based on their primary focus: robotic-related papers (137), construction-related papers (323), and papers addressing both areas (47), yielding 507 articles selected for full abstract review. The 507 articles underwent detailed abstract screening against all inclusion and exclusion criteria. This stage resulted in 139 articles selected for full-text retrieval.

Full-text articles were retrieved for all 139 studies passing abstract screening. Reasons for exclusion at this stage were documented, including insufficient technical detail on robotic systems (42 articles), lack of onsite applicability (31 articles), absence of closed-loop material flow considerations (18 articles), and focus on non-construction applications (10 articles). Following the full-text screening, 36 articles were selected for inclusion in the bibliometric analysis.

Table 1: Inclusion and exclusion criteria

Criteria	Inclusion criteria	Exclusion criteria
Year	Publication years from 2015 to 2026	Publications before 2015
Document Type	Articles and Conference Papers	Books, book chapters, reviews, notes, and editorials
Language	English language	Languages other than English
Subject Areas	Construction technology, computer science,	All other subject areas

2.3 DATA EXTRACTION AND BIBLIOMETRIC ANALYSIS

This study conducted a variety of bibliometric analyses using both manual techniques and VOSviewer software (version 1.6.20). The manual analysis concentrated on examining annual publishing patterns and identifying the most impactful journals and conferences in the sector. Additionally, keyword co-occurrence analysis was conducted using VOSviewer to reveal significant research topics and emerging areas of interest. Bibliographic coupling analysis was performed among journals, authors, and countries to identify influential publications and research groups, map the intellectual structure of the field, and visualise collaborative networks across geographic regions. Citation analysis was employed to examine citation networks, identify seminal works, and track the evolution of key concepts in robotic closed-loop construction (Balogun et al., 2024; Oluleye et al., 2023). Figure 2 illustrates the PRISMA flow diagram which summarises the process of identifying, screening, assessing eligibility, and selecting studies for inclusion in the bibliometric analysis.

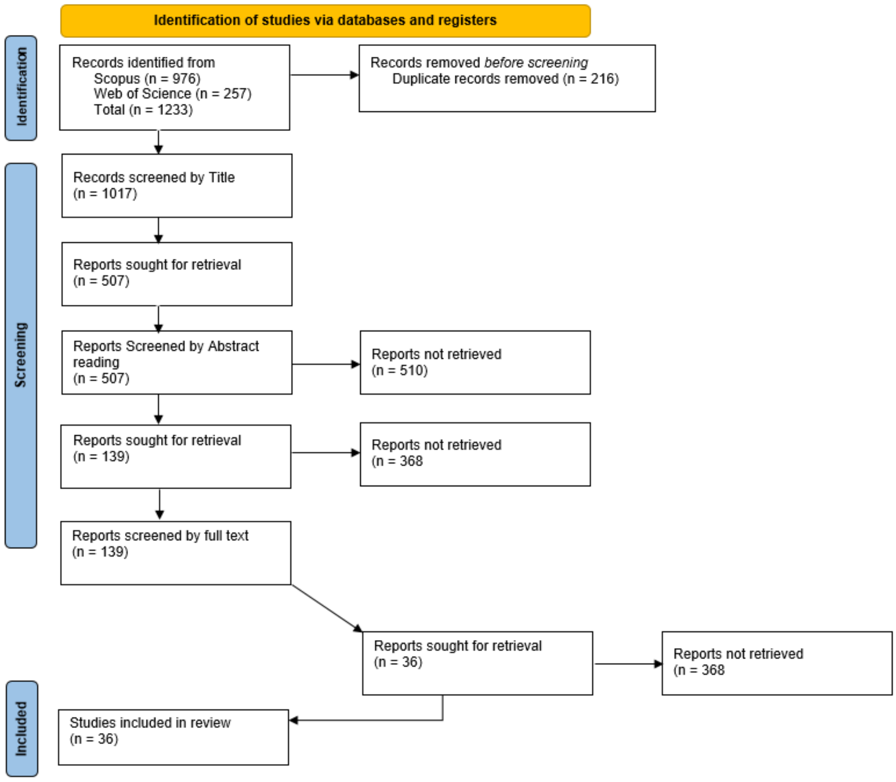

Figure 2: PRISMA FLOW diagram (By authors)

3. RESULTS AND DISCUSSION

This section presents the results of the bibliometric analysis with relevant interpretations while addressing the objectives of the study.

For keyword co-occurrence analysis, a minimum threshold of four occurrences for keywords was established. In the generated networks, the diameter of each circle represents the frequency of the term, while the thickness of the connecting lines denotes the strength of the association between keywords. Furthermore, the closeness of nodes demonstrates the extent of linkage, with nearer nodes indicating more closely connected phrases. These analyses jointly facilitated a qualitative interpretation of the bibliometric data, providing significant insights into the developing research landscape of robotic closed-loop construction in the context of CDW management.

Figure 3 presents the keyword co-occurrence network generated through the VOSviewer. The central positioning of terms such as “construction and demolition waste”, “robotic sorting” and “computer vision” indicates that the field remains strongly technology driven. However, the peripheral position of terms such as “human-robot collaboration” and “generative AI” suggests that socio-technical integration and advanced AI-enabled decision-making are still emerging rather than mature research areas.

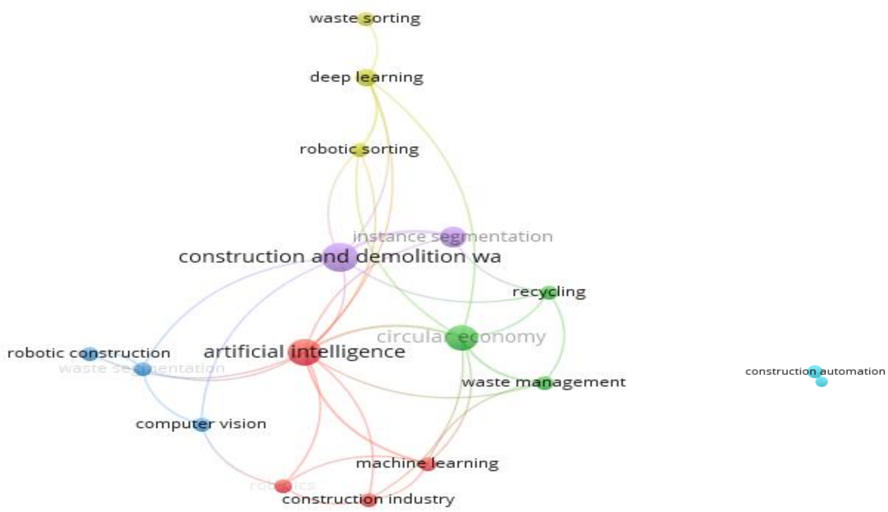

Figure 3-Keyword co-occurrence

The network therefore implies that future research should move beyond technical recognition accuracy and examine how robotic systems can be safely, economically and practically integrated into real construction waste environments.

3.1 Evolution of Publications and Top Contributing Sources

Moreover, Figure 4 represents the analysis of publication trends from 2015 to 2026. During the initial period of 2015-2018, publications remained minimal, with only two contributions in 2015, including foundational works on robot-oriented construction management (Bock & Linner, 2015) and framework development for robot-assisted deconstruction (Lee et al., 2015). No publications were recorded between 2016 and 2019.

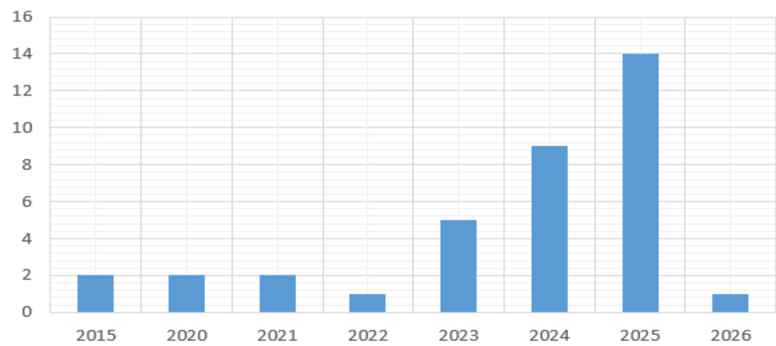

Figure 4: Annual publication trend

The period 2020-2021 witnessed gradual growth. Notable contributions included vision-based robotic systems for onsite CDW sorting (Wang et al., 2020), deep learning approaches for grasping detection (Ku et al., 2020), and automatic sorting robots employing hyperspectral imaging (Xiao et al., 2020). A significant inflexion point occurred in 2022-2023, with publications increasing from one to five annually. This acceleration coincided with advances in deep learning architectures substantially improving waste recognition capabilities (Chen et al., 2022; Lu et al., 2022), the emergence of human-robot collaboration frameworks (Chen et al., 2023), and increased digital technology integration (Abd El-Hameed, 2025).

The years 2024-2025 represent peak research activity, with nine and fourteen publications, respectively. This rapid increase after 2021 can be linked to wider advances in artificial intelligence, computer vision and automated material recognition. However, the relatively small number of studies before 2020 indicates that robotic CDW management is still an emerging research niche rather than a fully established field.

Table 2 presents the top contributing sources in the domain. The concentration of publications in Automation in Construction, Journal of Building Engineering and Waste Management demonstrates that robotic closed loop construction is interdisciplinary, requiring integration across construction engineering, environmental management, computer vision and circular economy research.

Table 2: Top contributing sources

Source Name	No of publications
Automation in Construction	5
Journal of Building Engineering	4
Waste Management	3
Buildings	2
Journal of Environmental Management	2

The distribution implies that future progress will depend on stronger collaboration between technical robotics researchers and construction waste management specialists.

3.2 LEADING COUNTRIES UNDERTAKING RESEARCH ON ROBOTIC CLOSED-LOOP CONSTRUCTION

Figure 5 illustrates the geographic distribution of research contributions advancing robotic closed-loop construction. Australia leads with six documents, demonstrating high research intensity and international collaboration. Hong Kong and China contribute four documents each, reflecting significant investment in construction automation driven by rapid urbanisation and policy support for circular economy initiatives (Chen et al., 2022, 2023; Ku et al., 2020; Xiao et al., 2020). Germany also contributes four documents, while the United Kingdom follows with three publications. The United States, despite substantial research infrastructure, contributes only one document, suggesting a domestically focused approach.

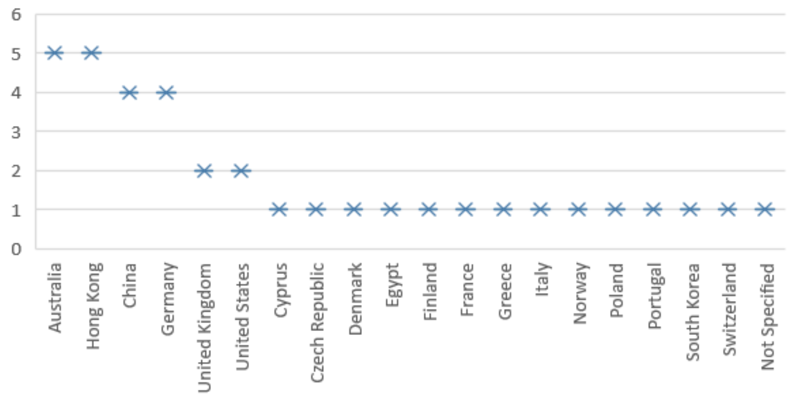

Figure 5: Global research frontier (Publication trend over geographical locations)

The collaborative landscape reveals two primary research clusters: the Asia-Pacific cluster centred on Australia, China and Hong Kong, and the European cluster encompassing diverse nations with dense collaborative networks. However, the limited representation of developing countries indicates a geographical research gap. This is important because CDW generation and informal recycling practices are significant in many developing economies, where low-cost and adaptable robotic solutions may offer considerable practical value.

3.3 TERMS CO-OCCURRENCE ANALYSIS

Figure 6 illustrates the results of terms co-occurrence analysis conducted using VOSviewer software, with a minimum threshold of four occurrences per term. Terms co-occurrence analysis is essential in academic research as it illustrates linkages between study subjects, uncovers temporal patterns, and assists researchers in comprehending the evolution of knowledge domains, thereby informing future research paths (Zhao, 2024).

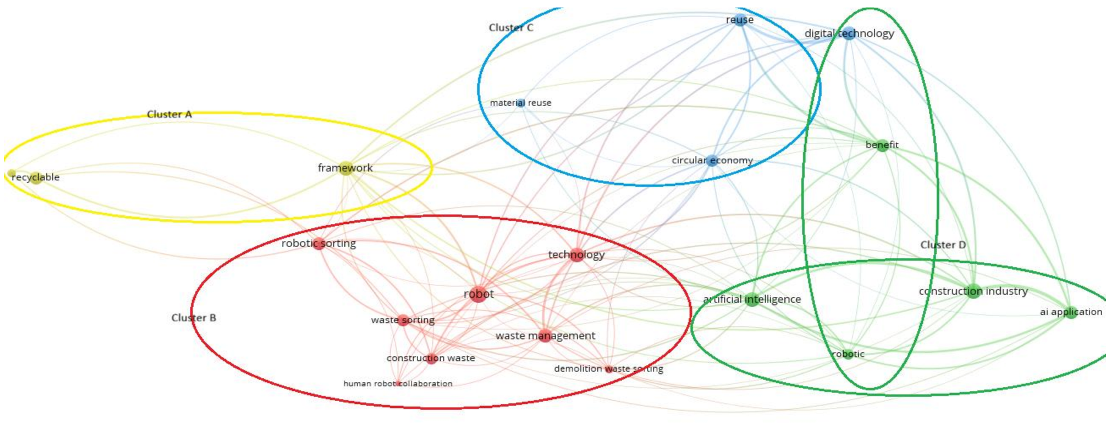

Figure 6-Terms Co-occurrence network

The network visualisation identifies four distinct research clusters (Table 3) in robotic closed-loop construction, each representing a coherent thematic area with characteristic terminology and conceptual focus.

Table 3: Summary of Terms Co-Occurrence Analysis

Cluster	Thematic Focus	Key Terms	Research Emphasis
A	Robotic sorting and HR collaboration	Recyclable, robot sorting, waste sorting, framework, human-robot collaboration	Development of structured sorting frameworks integrating robotic automation with human expertise to improve efficiency, safety, and adaptability in waste sorting processes.
B	Circular economy and intelligent technologies	Material reuse, circular economy, artificial intelligence, robotic technology, demolition waste sorting	Application of AI-driven robotic systems to enable sustainable material recovery and support circular construction practices.
C	Construction industry implementation	Construction industry, AI application, robotics	Translation of robotic and AI technologies into real-world construction environments highlights limited but growing implementation-oriented research.
D	Foundational perception technologies	Deep learning, computer vision	Core enabling technologies for automated waste recognition, classification, and robotic manipulation across closed-loop construction systems.

The four thematic clusters show that the literature has progressed from basic robotic sorting towards more integrated themes involving artificial intelligence, circular economy, and construction implementation. Nevertheless, the separation between technology-focused terms and implementation-focused terms suggests that many studies remain at the prototype or laboratory level. This highlights the need for field-based validation, standardised datasets, and operational studies that evaluate performance under unstructured site conditions.

3.4 Application of Robotic Systems in CDW Management

The bibliometric analysis reveals substantial diversity in robotic system configurations, perception technologies, and application contexts within CDW management.

Selected studies reveal substantial diversity in robotic system configurations, perception technologies, and application contexts within construction and demolition waste management. The analysis identifies distinct evolutionary trajectories in robotic CDW research. Early systems (2019-2021) focused on demonstrating technical feasibility through proof-of-concept prototypes, establishing baseline capabilities for automated sorting and grasping with impressive accuracies approaching 100% (Xiao et al., 2020; Wang et al., 2020). Mid-period research (2022-2023) addressed challenges of material heterogeneity, occlusion, and adhesion through deep learning-based grasping optimisation (Ku et al., 2020) and human-robot collaboration frameworks (Chen et al., 2023). Recent studies (2024-2026) demonstrate maturation through vision foundation models for robust waste segmentation (Heo & Na, 2024), robot-agnostic planning frameworks (Kokkalis et al., 2025), and field-validated deconstruction systems (Heuer et al., 2025).

3.5 END-EFFECTOR TECHNOLOGIES AND GRASPING STRATEGIES FOR ROBOTIC CDW MANIPULATION

End-effector design emerges as a critical determinant of robotic construction and demolition waste (CDW) system performance. The reviewed literature identifies two primary gripper categories dominating waste sorting applications.

1. Finger grippers with force control offer versatility for irregular, heavy materials including concrete fragments, bricks, and timber sections (Ku et al., 2020; Xiao et al., 2020).
2. Vacuum grippers provide gentle handling for lightweight materials with smooth surfaces but face limitations with porous construction materials (Chen et al., 2023; Raptopoulos et al., 2020).

Emerging research integrates sensor-based adaptive control with global information-based strategies (Ku et al., 2020) and boundary-guided grasp detection (Prasad & Arashpour, 2025a), substantially improving performance with cluttered, heterogeneous waste streams.

3.6 INTEGRATION WITH DIGITAL TECHNOLOGIES

The synthesis of the reviewed literature, as reflected in Figure 7, demonstrates that the effectiveness of construction robotics in achieving circular economy objectives is fundamentally contingent upon its integration with advanced digital technologies. Rather than operating as isolated systems, robotic applications are increasingly embedded within a broader digital ecosystem that enables data-driven decision-making, real-time coordination, and closed-loop material management. In this context, BIM emerges as a foundational platform, providing structured representations of building geometry and material attributes while enabling the development of material passports that support reuse, remanufacturing, and lifecycle tracking (Abd El-Hameed, 2025; Honic et al., 2019).

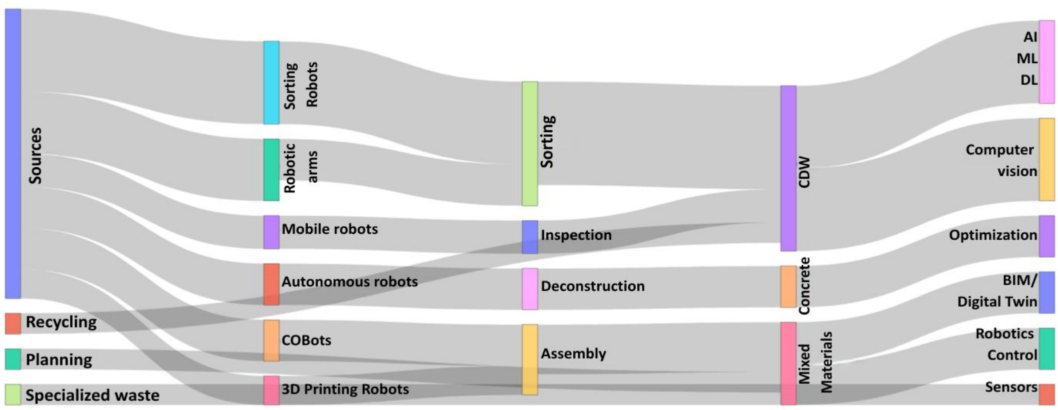

Figure 7: Robotics in construction

Beyond static data environments, Digital Twin technologies extend BIM capabilities by integrating real-time sensor inputs, thereby enabling dynamic monitoring of material conditions and predictive decision-making for deconstruction and recovery processes (Thakuri et al., 2024). IoT and Radio Frequency Identification (RFID) systems provide the necessary data infrastructure to support continuous tracking, identification, and provenance verification of materials across the construction lifecycle, ensuring traceability within circular value chains (Bock et al., 2015; Santos et al., 2024).

At a higher level of integration, the convergence of robotics with digital systems gives rise to Cyber-Physical Systems (CPS), where AI-driven computer vision systems are combined with robotic manipulators to enable autonomous material identification, segmentation, and handling (Konstantinidis et al., 2023; Sirimewan et al., 2025).

Furthermore, digital marketplaces, supported by BIM, IoT and blockchain can support the matching of reclaimed material supply with demand while improving quality assurance, certification and trust in secondary material markets (Çetin et al., 2022; Abd El-Hameed, 2025). Despite these advancements, the literature indicates that the integration of robotics with digital technologies remains uneven. While BIM and digital twins are widely adopted in design and planning stages, their linkage with physical robotic execution is still limited, reflecting a persistent gap between digital modelling and on-site implementation (Abioye et al., 2021; Abd El-Hameed, 2025). Additionally, challenges such as high implementation costs, interoperability issues, and the lack of standardised datasets constrain large-scale deployment, particularly in complex and unstructured on-site environments (Balogun et al., 2024; Dodampegama et al., 2024).

Among the 36 studies considered 50% were on site, 22.2% were off site and the rest were conducted focusing both on site and off site context. For instance, 53.8% of the studies were closed loop status, and the rest were in open loop robotic stage. Moreover, a clear academic evolution towards the integration of robotics within a digitally enabled construction ecosystem is driving the transition from conventional linear construction practices to intelligent, closed-loop material systems, wherein CDW is not treated as waste but as a valuable resource stream governed through interconnected digital and robotic infrastructures.

3.7 GAPS IN THE EXISTING BODY OF KNOWLEDGE

Figure 8 summarises six interrelated gaps that currently restrict the transition from isolated robotic applications to fully integrated circular construction systems: deconstruction, perception, manipulation, policy, integration and human-robot collaboration. Robotic deconstruction remains limited because most studies focus on sorting after waste has already been generated rather than selective dismantling for component reuse. Perception systems have improved through computer vision and deep learning, but real CDW streams remain dusty, damaged, heterogeneous and visually cluttered.

Manipulation also remains challenging because construction waste varies widely in size, weight, shape, texture and fragility. Policy gaps are equally important because quality assurance standards, liability arrangements and certification procedures for recovered materials remain underdeveloped. Integration gaps persist because BIM, digital twins, IoT, RFID and blockchain are often discussed separately from physical robotic execution. Finally, human-robot collaboration requires further investigation because construction sites are dynamic and safety-critical environments where full autonomy may not yet be feasible.

4. CONCLUSIONS

This bibliometric analysis systematically maps the research landscape of robotic closed-loop construction, revealing exponential growth since 2021 driven by advances in artificial intelligence, computer vision, and robotic technologies. Publication output peaked at 12 articles in 2025, with China, Australia, and Hong Kong emerging as leading contributors within Asia-Pacific and European collaborative networks.

Keyword co-occurrence analysis identifies five primary research clusters: robotic sorting and grasping technologies, computer vision for waste recognition, deconstruction and disassembly systems, digital enablers (BIM, digital twins, IoT), and circular economy frameworks. Despite substantial progress, significant challenges impede widespread adoption. Perception systems remain vulnerable to real-world variability, robotic manipulation struggles with material heterogeneity, deconstruction systems for component reuse remain experimental, and economic validation across diverse contexts is limited.

Future research should prioritise large-scale datasets for robust perception, adaptive manipulation strategies for heterogeneous waste, comprehensive deconstruction systems for component reuse, human-robot collaboration frameworks, and integrated economic-environmental assessment. The convergence of robotics, computer vision, and circular economy principles offers transformative potential for transitioning from linear disposal to closed-loop resource systems, requiring sustained investment and cross-disciplinary collaboration.

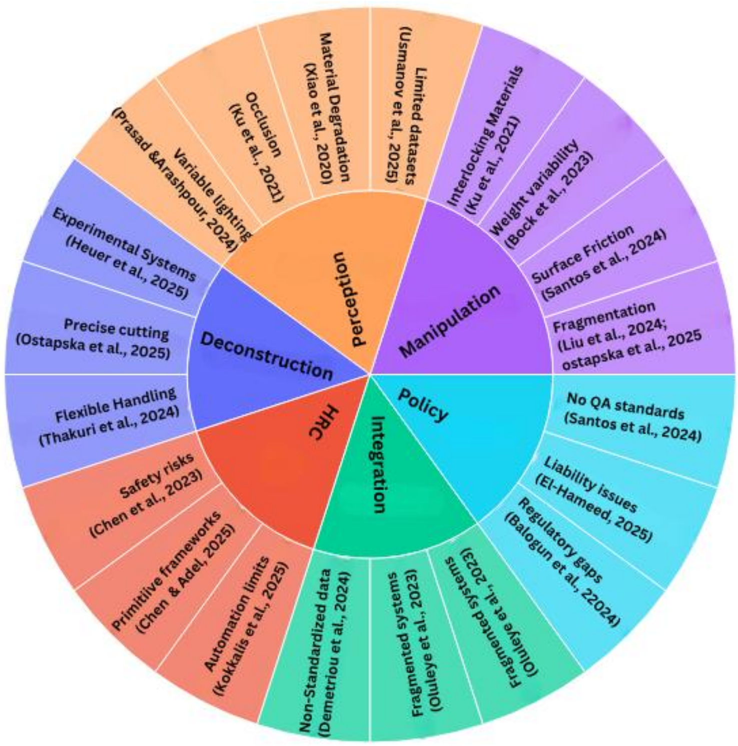

Figure 8: Gaps in the existing literature

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