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REVIEW ARTICLE

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Utilizing intelligent technologies in construction and demolition waste management: From a systematic review to an implementation framework

Abstract The rapid increase in global urbanization, along with the growth of the construction industry, highlights the urgent need for effective management of construction and demolition (C&D) waste. Intelligent technologies offer a viable solution to this critical challenge. However, there remains a significant challenge in integrating these technologies into a cohesive framework. This study conducts a quantitative analysis of 214 papers from 2000 to 2023, highlighting the extensive use of artificial intelligence (AI) and building information modeling (BIM), along with geographic information systems (GIS) and big data (BD). A further qualitative analysis of 73 selected papers investigates the use of seven different intelligent technologies in the context of C&D waste management (CDWM). To overcome current limitations in knowledge, future research should concentrate on (1) the comprehensive integration of technology, (2) inclusive studies throughout all lifecycle phases of CDWM, and (3) the continued examination of new technologies, such as blockchain. Based on these insights, this study suggests a strategic framework for the effective implementation of intelligent technologies in CDWM. This framework aims to assist professionals in merging various technologies, undertaking lifecycle-wide research, and narrowing the divide between existing and new technologies. It also lays a solid foundation for future academic work to examine specific intelligent technologies, conduct comparative studies, and refine strategic decisions. Regular updates on technological developments are essential for stakeholders to consistently enhance CDWM standards.

Keywords C&D waste management, construction and demolition waste, intelligent technologies, literature review, implementation framework

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1 Introduction

With escalating concerns about the global environment (Pravalie 2016) and increasing pressure on natural resources (Schandl et al. 2016), the demand for sustainable practices across all industrial sectors has become more urgent (Yang et al. 2022; Wu et al. 2020). The construction industry plays a pivotal role in the global economy (Smol et al. 2015) and significantly contributes to the development of critical infrastructure (Bao et al., 2019; Wu et al., 2014). However, it also consumes a significant amount of energy and resources (Gencel et al. 2012; Bao, Lu, et al. 2023). In light of the growing emphasis on environmental sustainability (Marchese et al. 2018; Kuang et al. 2022; Lei et al. 2023), the construction sector faces substantial pressure to adopt environmentally conscious practices to reduce its ecological footprint (Ravindra et al. 2015;

Kamali and Hewage, 2016; Nasir et al. 2017; Wu et al. 2017). An essential aspect of these efforts involves the efficient management of construction and demolition (C&D) waste, which poses significant environmental challenges due to its large volume and diverse composition (Uyarra and Gee, 2013; Lucena et al. 2014; Bao and Lu 2023; Bao et al., 2020). Acknowledging the limitations of traditional methodologies in handling the complexities and scale of waste generated by construction activities (Duan and Li, 2016; Aslam et al., 2020; Gupta et al., 2022; Bao, 2023), there is an increasing recognition of the transformative potential of intelligent technologies in revolutionizing practices related to C&D waste management (CDWM) (Kor et al., 2023; Jiang et al., 2022b). Intelligent technologies include a range of advanced tools and systems that leverage computational power and data analytics to automate processes, make informed decisions, and optimize resource utilization (Guo et al., 2020; Jiang et al., 2022a; Zhan et al., 2023). These technologies, including building information modeling (BIM) (Hu et al., 2022b; Gupta et al., 2022), geographic information system (GIS) (da Paz et al., 2018; AlZaghrini et al., 2019; Madi and Srour, 2019), artificial intelligence (AI) (Oluleye et al., 2023; Ghoreishi and Happonen, 2019), big data (BD) (Chen and Lu, 2017; Lee and Lu, 2019), and internet of things (IoTs) (Huang et al., 2022; Chandrasekaran et al., 2023), offer innovative approaches to optimize waste sorting, enhance recycling processes, and improve the overall operational efficiency of CDWM.

The adoption of intelligent technologies presents a promising solution to the inherent challenges of CDWM. In recent years, numerous researchers have investigated the application of these technologies in CDWM. For example, BIM has attracted significant interest due to its potential in this field. Studies conducted by Won and Cheng (2017), Han et al. (2021), and Nikmehr et al. (2021) have highlighted the complexities and potential benefits associated with widespread adoption of BIM, emphasizing the need for robust frameworks and methodologies to optimize waste management practices. Li, et al. (2020a) provided an insightful overview of information technology research in CDWM, emphasizing a growing trend and the need for more advanced methodologies. Similarly, research by Jin et al. (2019) and Rodrigo et al. (2023) emphasized the importance of understanding emerging research topics and promoting the principles of circular economy through the integration of digital technologies. Furthermore, studies by Ruiz et al. (2020), Setaki and van Timmeren (2022), and Yu et al. (2022) highlighted the transformative potential of digital technologies, emphasizing their ability to advance environmentally responsible waste management practices in the construction sector. In summary, these studies collectively emphasize the need for comprehensive strategies that integrate intelligent technologies to optimize waste management, minimize environmental impacts, and promote sustainable practices in the C&D sector.

Despite significant progress, there remains a research gap in fully integrating intelligent technologies into a cohesive framework capable of effectively addressing the complex challenges inherent in CDWM. Drawing upon profound insights obtained from a systematic literature review, this study aims to establish a framework that facilitates the efficient implementation of intelligent technologies in CDWM. By identifying and bridging prevailing knowledge gaps, this study seeks to advance sustainable practices in waste management and promote environmentally conscious approaches within the C&D sector.

The subsequent sections of this paper detail the utilization of intelligent technologies for CDWM. Section 2 outlines the research methodology employed in this study, while Section 3 elaborates on the application of various prevalent intelligent technologies in different scenarios. Section 4 critically examines current limitations and outlines potential directions for future research, culminating in the proposal of a prospective implementation framework. Finally, Section 5 summarizes key findings and provides recommendations to advance future sustainable practices in the context of CDWM. The insights presented in this paper are invaluable for establishing a framework that facilitates the seamless integration of intelligent technologies for CDWM. Through a comprehensive literature review, practical guidance is provided for future research implementation, thereby advancing the construction sector toward sustainability.

2 Research methodology

This study employs a systematic four-step research methodology. The initial step involves a thorough retrieval of relevant literature from the Web of Science (WoS) core database. The selection of the WoS core database as the primary source for our literature search is based on its reputable comprehensive coverage in disciplines relevant to our research, such as engineering, environmental science, and construction management (Zhu and Liu, 2020). The primary search strategy consists of a dual-part query string to comprehensively explore the literature related to our research objectives. The first component focuses on terms related to “construction and demolition waste” and its variations, while the second component targets intelligent technologies such as BIM, GIS, and AI. This approach ensures a comprehensive retrieval of literature covering CDWM practices and innovative technological solutions within the scope of this study.

The temporal scope of this literature review spans from 2000 to 2023, with a specific focus on research journal papers and exclusion of conference papers and textbooks. We strictly consider English-language papers to maintain linguistic uniformity. The preliminary search produces a comprehensive pool of 670 papers, which undergo a refined screening process to isolate those specifically addressing the application of intelligent technologies in CDWM. This rigorous selection process results in a final sample set of 214 papers, forming the basis for subsequent literature analysis.

In the second phase of our methodology, a bibliometric analysis is conducted using the widely adopted VOSviewer tool to quantitatively assess the knowledge structure and evolutionary patterns of how intelligent technologies are applied in CDWM. This comprehensive analysis includes publications, co-authorship networks, country contributions, and keyword co-occurrences, providing a thorough understanding of the research landscape. Through this publication analysis, trends in research productivity over time are tracked, revealing shifts in scholarly engagement (Ang et al., 2019). Co-authorship analysis identifies collaborative networks, key contributors, and research clusters (Donthu et al., 2020; Long et al., 2024). Country analysis highlights global research distribution and collaboration patterns (Huang et al., 2019), while keyword co-occurrence analysis reveals thematic focus and facilitates knowledge organization (Ferasso et al., 2020). Finally, a taxonomy of identified technologies is established through rigorous classification using a keyword co-occurrence network, revealing seven distinctive categories.

The third step involves categorizing applications related to the seven identified technologies within the framework of managing C&D waste. To highlight recent advancements, a focused analysis is conducted for literature published from 2013 to 2023. For each technology, a careful selection of 3-5 papers is made based on citation count and publication year, resulting in a refined set of 73 papers for comprehensive scrutiny.

In the fourth step, a thorough reassessment of the identified intelligent technologies, coupled with a thoughtful consideration of existing research limitations, leads to a nuanced classification into five distinct groups. Finally, a conceptual framework outlining potential application scenarios of intelligent technologies across various lifecycle stages within the domain of CDWM is formed accordingly. Figure 1 visually presents the research workflow of this study, encapsulating all four methodological steps.

3 Quantitative analysis

3.1 Publication analysis

Figure 2 illustrates the temporal distribution of the 214 research papers spanning from 2000 to 2023. It is notable that the annual publication output remained relatively modest, with fluctuations between 0 and 3 papers from 2000 to 2014. However, a distinct and substantial increase in research productivity is observed from 2015 to 2023, indicating a period characterized by heightened scholarly engagement and a growing focus on the research theme.

An in-depth exploration of the academic landscape reveals that the 214 papers are disseminated across 74 distinct journals. Table 1 provides insights into the notable contributors, with the top ten journals collectively accounting for 57% of the surveyed literature. “Waste Management” and “Resources Conservation and Recycling” stand out among these influential journals, publishing 23 and 22 papers, respectively, and together comprising over 20% of the total papers included. While other journals also make meaningful contributions, their individual paper count remains below 20.

When it comes to assessing scholarly impact and influence, the citation count emerges as a pivotal metric. The 214 papers included in this study have garnered an impressive total of 5,469 citations, signifying an average of 25.56 citations per paper. This substantial citation record underscores the profound impact of these papers within scholarly discussions on managing C&D waste.

3.2 Co-authorship analysis

Scrutinizing articles to identify authors lays the foundation for constructing a co-authorship network that visually portrays academic collaborations in the field of CDWM through the use of intelligent technologies (Ding and Yang, 2022). Using VOSviewer, a co-authorship network was established, setting a minimum paper threshold of 4, which resulted in 23 authors meeting this criterion out of the 687 identified researchers. Figure 3 provides a graphical representation of the connections between the most active researchers and the top 7 research clusters worldwide.

Authors are categorized into distinct clusters using different colors, with red, green, yellow, and blue representing four independent groups of authors. The size of each circle corresponds to the author’s publication count, with larger circles indicating a higher number of publications. This visual representation offers insights into the collaborative dynamics among researchers in each network cluster. Notably, the red cluster highlights active contributors from the University of Hong Kong, including “Lu, Weisheng,” “Xue, Fan,” “Xu, Jinying,” “Chen, Xi,” “Webster, Chris,” and “Yuan, Liang.” The green cluster predominantly features contributors from Huaqiao University, the yellow cluster signifies collaboration from the Beijing University of Civil Engineering and Architecture (BUCEA), the blue cluster indicates collaboration between two Korean universities, and the purple cluster

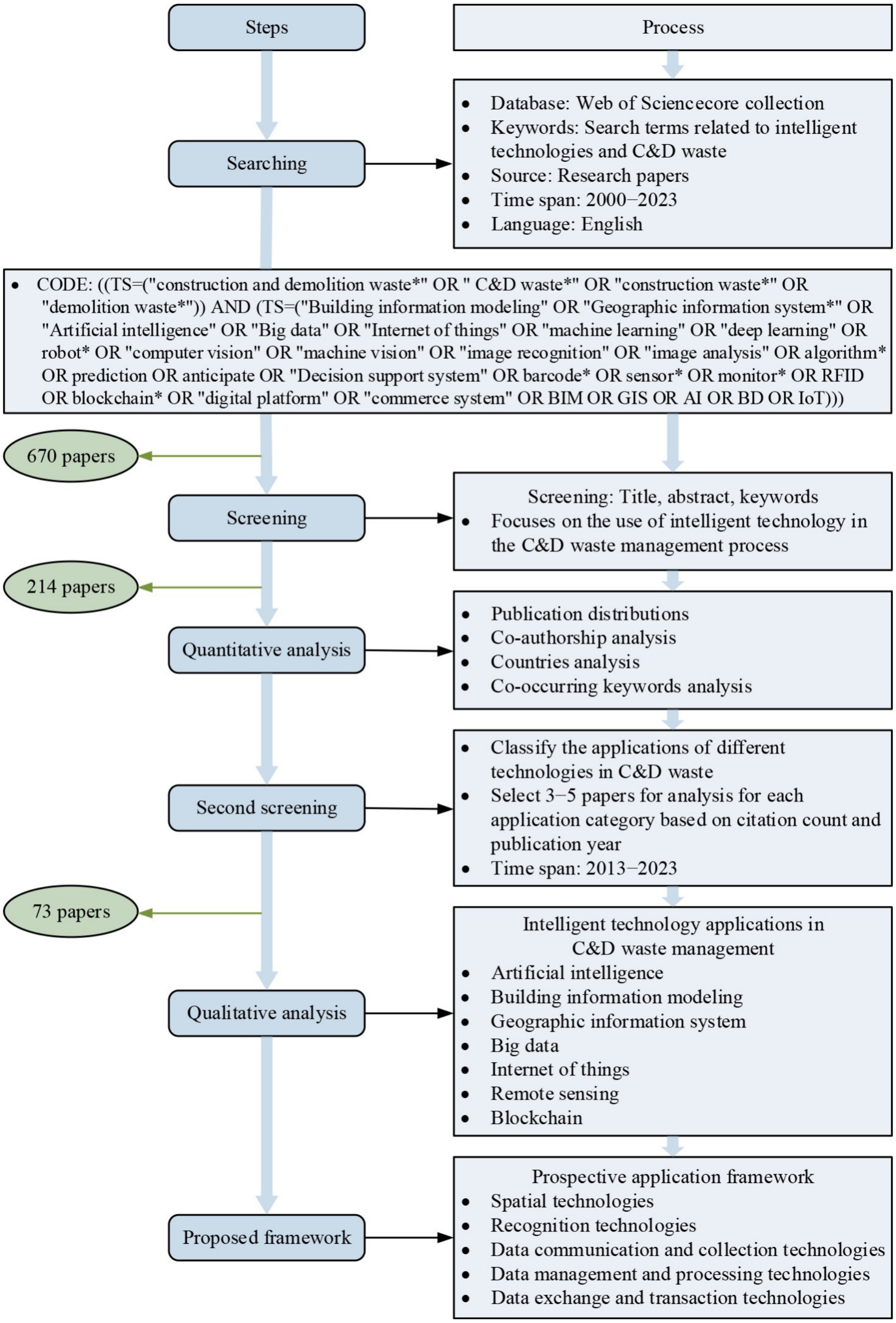

Fig. 1 Overall research workflow.

shows collaboration involving the University of West England. Detailed collaborative information is presented in Table 2.

Table 2 distinctly highlights Lu, Weisheng as the most prolific author, making a substantial contribution to the field with 20 published papers—an exemplar of significant engagement in this research domain. Notably, despite a relatively lower paper count, scholars such as Oyedele, Lukumon O., Akinade, Olugbenga O., Bilal, Muhammad, Chen, Xi, and Duan, Huabo, exhibit an average citation count exceeding 60, emphasizing their considerable impact in this research domain.

3.3 Countries analysis

By visually analyzing the contributions of different nations to the application of intelligent technologies in CDWM, valuable insights can be obtained (Shen et al., 2022). In Fig. 4, we illustrate the inclusion of the nine most influential countries from a pool of 49, setting a

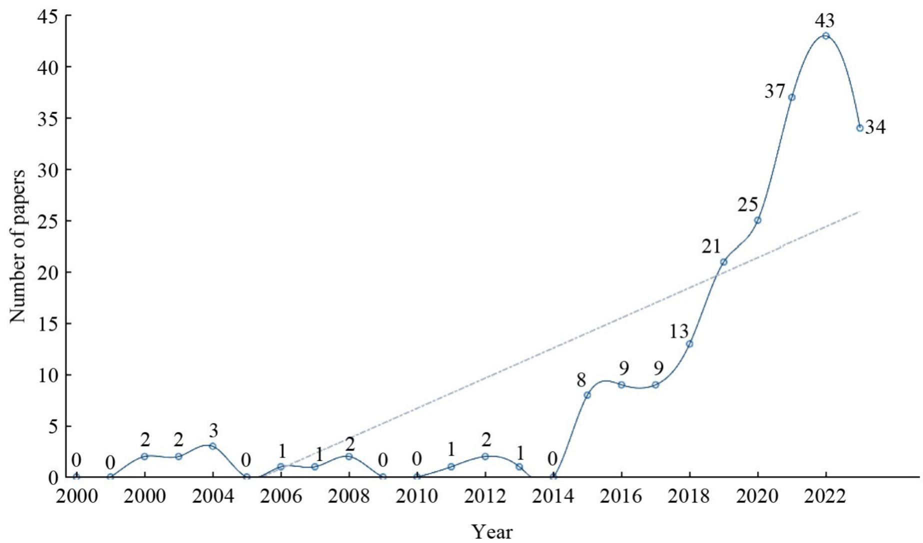

Fig. 2 Trends of research interest in related papers.

Table 1 Leading 10 journals by publication count

Journal	Documents	Citations
Waste Management	23	809
Resources Conservation and Recycling	22	1134
Journal of Cleaner Production	18	1017
Automation in Construction	14	601
Sustainability	13	213
Environmental Science and Pollution Research	7	47
Journal of Building Engineering	7	169
Waste Management & Research	7	119
Journal of Environmental Management	6	69
International Journal of Construction Management	5	122

minimum paper threshold of 6. Notably, the node representing China stands out prominently, indicating robust connections with other nations and highlighting the substantial contributions of Chinese scholars in this research domain. Additionally, countries such as Australia, the UK, Republic of Korea, and the USA are actively involved in this field.

Table 3 depicts detailed country network information, highlighting the prominent positions of China, Australia, and the UK in the field of implementing intelligent technologies for CDWM. These three nations excel with a significant number of published papers—104, 22, and 19 respectively—alongside considerable citation counts of 2010, 718, and 1056, underscoring their exceptional research quality. Notably, while Republic of Korea and the USA contribute an equal number of papers, American researchers exhibit higher citation counts and total link strength, indicating a higher level of international collaboration. The analysis of average publication year also reveals emerging nations in this domain, including India, China, Australia, Republic of Korea, and Spain.

3.4 Co-occurring keywords analysis

Within the domain of text mining, frequency analysis is a fundamental methodology that allows for statistical computation and examination of the occurrence rates of crucial terms in a given document (Donthu et al., 2020). In this study, insights derived from the keyword co-occurrence network have been utilized to elucidate the principal themes and focal points within the research domain of applying intelligent technologies to CDWM. A minimum threshold of three occurrences has been established for each keyword in this context. Out of a comprehensive pool of 5,949 identified keywords, 517 meet this predetermined criterion, deliberately excluding generic terms such as "C&D waste," "building," and "waste management." The filtration process results in a network composed of 34 keywords, visually represented in Fig. 5.

The visual representation in Fig. 5 illustrates tightly interconnected clusters, indicative of robust correlations. Node dimensions correspond to the frequency of keyword occurrence, while edge thickness outlines the co-occurrence frequency between keywords. These 34 keywords can be categorized into three groups: technologies, methods, and applications. This study primarily focuses on analyzing the utilization of various intelligent technologies for CDWM. The initial examination involves identifying intelligent technologies and methods present in the keyword co-occurrence network, such as machine learning, genetic algorithms, and artificial neural networks, all falling within the domain of AI technology. The identified intelligent technologies include BIM, GIS, AI, BD, IoT, remote sensing, and blockchain. These

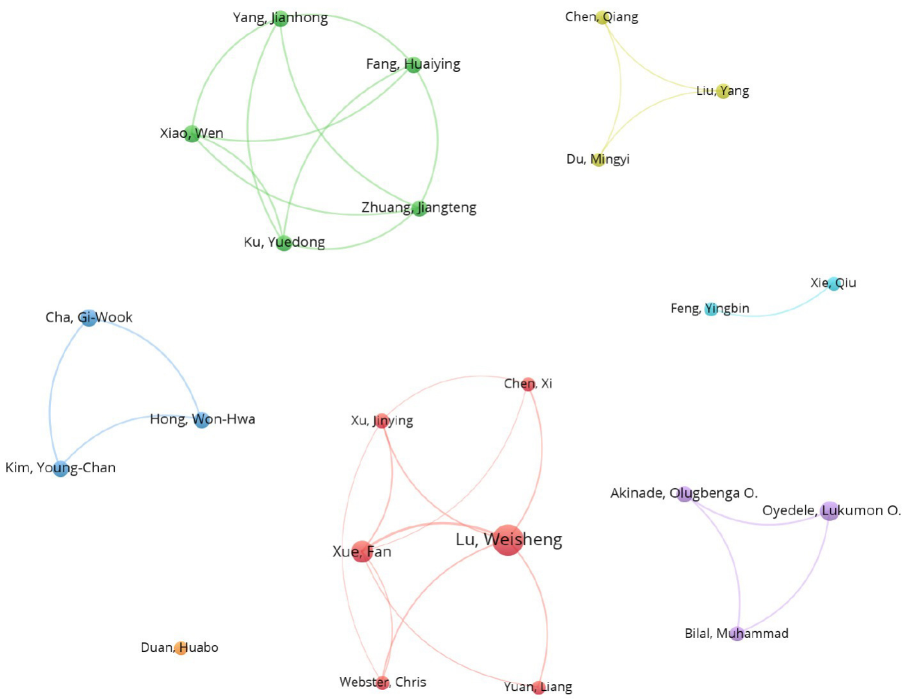

Fig. 3 Co-authorship network visualization.

Table 2 Details of productive scholars

Scholar	Affiliation	Documents	Citations
Lu, Weisheng	University of Hong Kong	20	560
Xue, Fan	University of Hong Kong	10	217
Oyedele, Lukumon O.	University of West England	8	565
Cha, Gi-Wook	Kyungpook National University	7	127
Xiao, Wen	Huaqiao University	7	103
Akinade, Olugbenga O.	University of West England	6	487
Fang, Huaiying	Huaqiao University	6	90
Hong, Won-Hwa	Kyungpook National University	6	105
Kim, Young-Chan	Dongguk WISE University	6	124
Ku, Yuedong	Huaqiao University	6	90
Yang, Jianhong	Huaqiao University	6	90
Zhuang, Jiangteng	Huaqiao University	6	90
Bilal, Muhammad	University of West England	5	413
Liu, Yang	BUCEA	5	27
Xu, Jinying	University of Hong Kong	5	90
Chen, Qiang	BUCEA	4	24
Chen, Xi	University of Hong Kong	4	246
Du, Mingyi	BUCEA	4	23
Duan, Huabo	Huazhong University of Science and Technology	4	240
Feng, Yingbin	Western Sydney University	4	52
Webster, Chris	University of Hong Kong	4	56
Xie, Qiu	Chongqing University	4	52
Yuan, Liang	University of Hong Kong	4	34

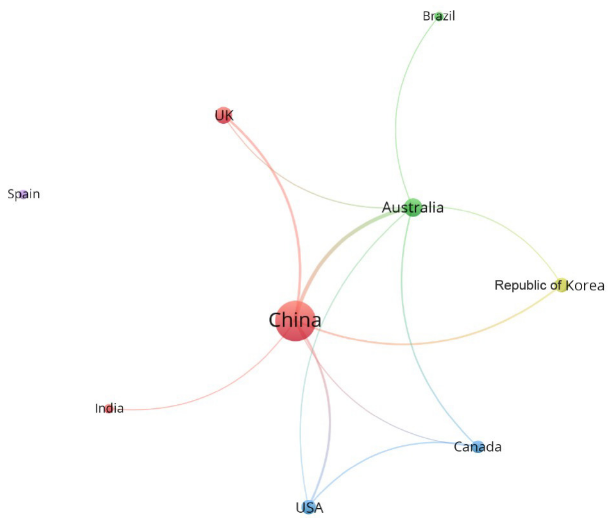

Fig. 4 Map of active countries.

Table 3 Details of active countries

Country	Documents	Citations	Avg. pub. year	Avg. citations	Total link strength
China	104	2010	2020	19	26
Australia	22	718	2020	32	18
UK	19	1056	2017	55	6
Republic of Korea	14	336	2020	24	4
USA	14	529	2016	37	7
Canada	11	298	2019	27	5
Brazil	6	210	2016	35	1
India	6	30	2022	5	1
Spain	6	71	2020	11	0

seven technologies are selected for further analysis, integrating keyword examination of their applications, including prediction, site selection, identification, classification, and others.

The analysis of technologies utilized in each article is visually represented in Fig. 6. The left bar chart illustrates the frequency of applications of different technologies in the existing literature (with papers potentially using multiple technologies), while the right pie chart illustrates the proportional distribution of these technologies. Significantly, AI and BIM technologies have emerged as predominant, followed by GIS and BD.

4 Intelligent technology applications in CDWM

The systematic categorization of applications involving the seven identified intelligent technologies in the context of CDWM is a key focus of this review. To highlight recent advancements in scholarly research, a targeted analysis of literature spanning from 2013 to 2023 was conducted. Through a careful selection process based on citation count and publication year, 3 to 5 papers were thoroughly curated for each technology application. This process, which focused on representative intelligent technologies, resulted in the refined selection of 73 papers, which were subjected to comprehensive scrutiny. When a paper adopts multiple intelligent technologies, a detailed investigation is conducted to determine the primary intelligent technology, with the others classified as assistive. Only the primary intelligent technology is extracted for analysis in these papers. For a visual representation of the detailed analysis, please refer to Fig. 7.

4.1 Artificial Intelligence

AI represents a groundbreaking technology that aims to replicate specific human thought processes and intelligent behaviors through computer systems. Research in this field spans various areas, including natural language processing, machine learning, robotics, computer vision, and image recognition (Graham et al., 2019; Duan et al., 2019). The broad application of AI has yielded significant results across various research domains (Yu et al., 2018; Debrah et al., 2022; Rajpurkar et al., 2022; Yang et al., 2021; Yang et al., 2023). In the field of CDWM, the prevalence of AI applications has gained widespread recognition.

4.1.1 C&D waste generation prediction

The accurate quantification and forecasting of C&D waste generation are crucial prerequisites for the effective implementation of waste management strategies. In response to this need, numerous researchers have utilized AI technology. For example, Lu, et al. (2016b) used a large data set of waste disposal records and employed artificial neural networks to develop an S-curve model for predicting construction waste generation. Song et al. (2017) integrated gray models and support vector regression to forecast the quantities and analyze the trends of each component of C&D waste. Notably, some scholars have combined AI and BIM technologies, using a neuro-fuzzy system that combines fuzzy logic and artificial neural networks to predict C&D waste generation, and integrating these predictions into a BIM platform (Akinade and Oyedele, 2019). Lu, et al. (2021b) applied four machine learning models to forecast C&D waste generation using a limited data set. They conducted a comprehensive comparative analysis to identify the strengths and limitations of each model. In a similar vein, Hu et al. (2023) presented a predictive framework based on time-series analysis, specifically tailored for forecasting C&D waste generation. They demonstrated its effectiveness, even with a limited data set.

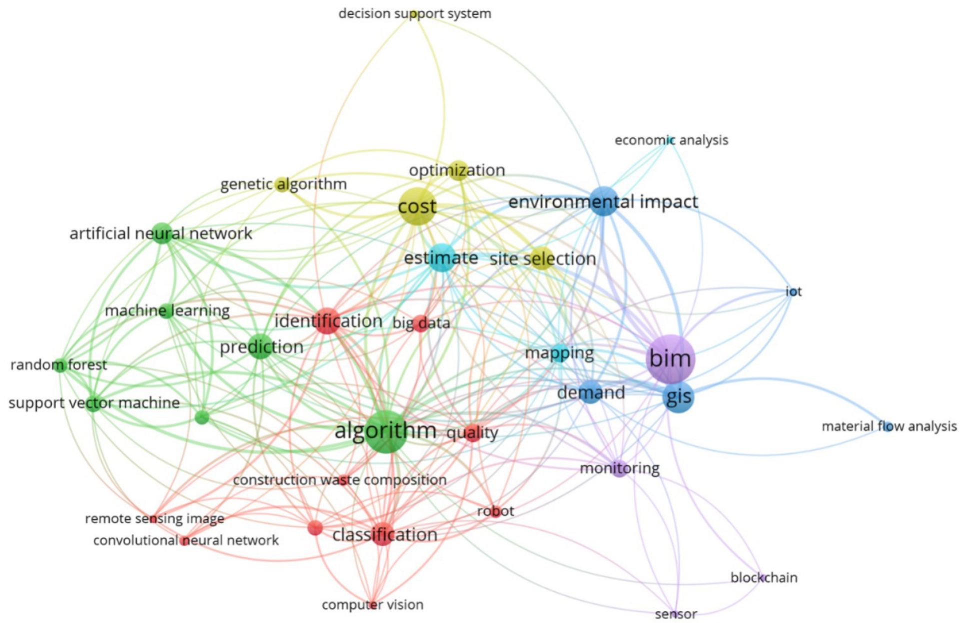

Fig. 5 Map of keywords.

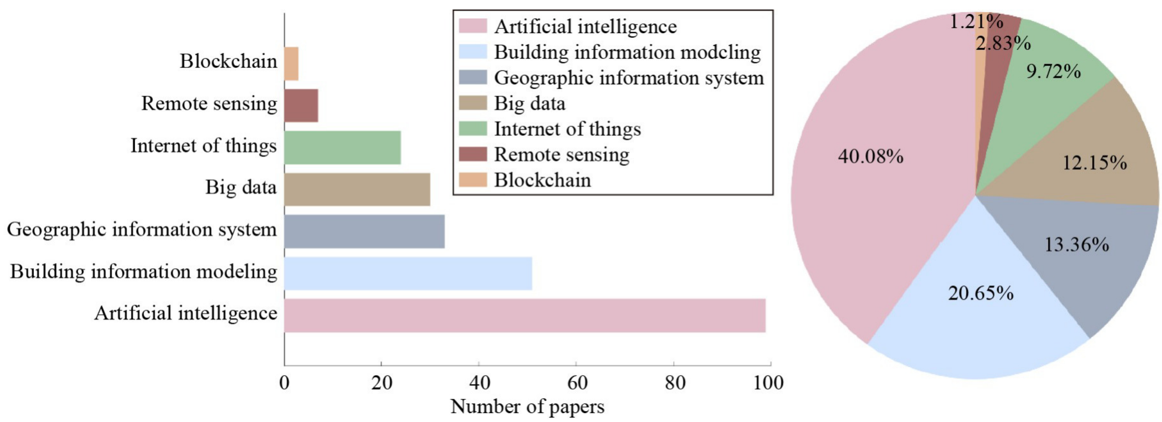

Fig. 6 Overview of major technology applications.

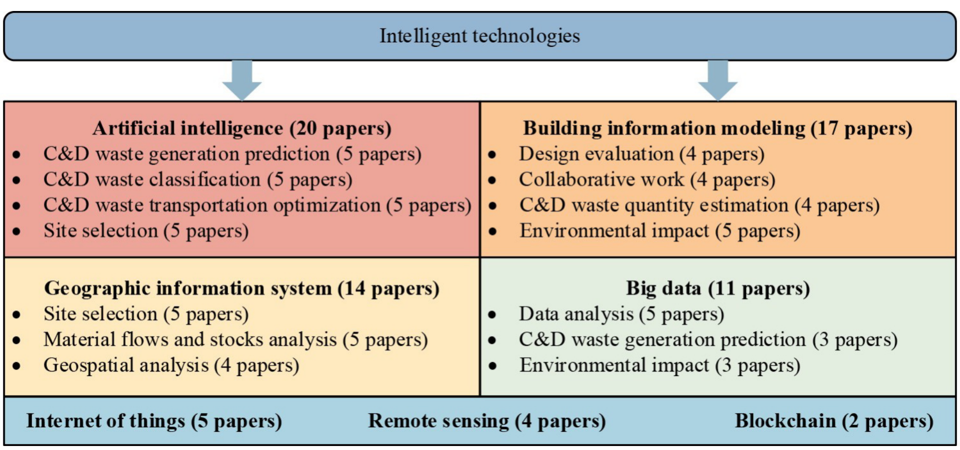

Fig. 7 Application of intelligent technologies in CDWM.

4.1.2 C&D waste classification

The complexity and diversity associated with the generation of C&D waste highlight the importance of accurate classification, which is a crucial step within the broader framework of effective CDWM. In pursuit of this objective, Wang, et al. (2019b) introduced a recycling robot equipped with computer vision technology to collect and classify C&D waste. Xiao et al. (2019) proposed an innovative online identification method using extreme learning machines to recognize feature reflectance. They complemented this approach with a random forest algorithm for verification, thereby enhancing the model's accuracy. To address challenges posed by uneven terrain on construction sites, Wang et al. (2020) incorporated simultaneous localization and mapping technology into their system to achieve precise robot identification and classification. Ku et al. (2021) contributed to CDWM by presenting a robot that integrates deep learning for grab detection, thereby facilitating efficient sorting processes. Addressing real-life complexities, Lu et al. (2022) introduced a method that utilizes advanced image analysis techniques to identify high-fidelity components of deconstructed C&D waste in complex environments.

4.1.3 C&D waste transportation optimization

Choosing the appropriate site for waste management activities is a crucial aspect within the field. To ensure efficient operations and logistics, researchers have examined various strategies and models. For instance, Zhang and Atkins (2015) integrated rule-based reasoning technology with RFID technology in an intelligent framework to enhance management efficiency for recycling companies. This approach facilitates monitoring, dispatching, and automated decision-making for waste transportation, thereby preventing illegal dumping. Rahimi and Ghezavati (2018) proposed a sophisticated strategy that employs multi-period, multi-objective mixed-integer linear programming. The aim is to optimize economic benefits and minimize environmental impact when establishing a logistics network specifically for recycling C&D waste, especially in uncertain conditions. Wang, et al. (2022a) utilized mathematical models and algorithms to design an optimized transportation network for C&D waste, taking into account the objectives of various stakeholders. Pan et al. (2020) presented a comprehensive optimization framework for designing a recycling network dedicated to C&D waste, addressing the needs of diverse stakeholders. Finally, Zhang and Ahmed (2022) utilized queuing theory within a reverse logistics framework to coordinate CDWM. The primary objectives were to minimize adverse impacts resulting from truck delays and optimize the handling of inert waste in reverse logistics.

4.1.4 Site selection

To address the crucial aspect of site selection in CDWM, researchers have utilized various methodologies to optimize the placement of waste management facilities. Zavadskas et al. (2015) responded to the technical and sustainability requirements by employing a comprehensive decision-making methodology to study the site selection problem for waste incineration plants. Shi et al. (2019) introduced a site selection model that integrates genetic algorithms and probabilistic robust optimization, with the aim of minimizing costs and mitigating adverse environmental impacts associated with CDWM processing facilities. Considering the dual objectives of reducing overall expenses incurred by recycling plants and mitigating adverse effects on residents, Liu et al. (2019) established a dual-objective programming framework. They subsequently utilized genetic algorithms to optimize the placement of C&D waste recycling facilities. Lin et al. (2020) developed a multi-period robust facility placement model to identify optimal transfer station sites, aiming to reduce total expenses associated with C&D waste collection. Addressing uncertainty in both the waste supply and demand for recycled products, Yao et al. (2022) formulated a site selection framework for C&D waste treatment facilities, aimed at minimizing total system costs and facilitating rational facility placement.

AI emerges as a transformative force within the domain of CDWM, enabling precise waste generation prediction, efficient waste classification, optimization of transportation processes, and strategic site selection. However, existing limitations of AI, such as data dependency, uncertainty handling, technological complexity, and practical implementation barriers need to be addressed in order to fully harness its value for CDWM (Abioye et al. 2021; Bang and Olsson, 2022). Despite these challenges, the integration of AI technology streamlines operational processes and enhances decision-making capabilities, propelling the construction industry toward sustainable practices and technological excellence. Further research and innovations are required to overcome these limitations and fully leverage the potential of AI in CDWM.

4.2 Building Information Modeling

BIM is a dynamic concept that includes both the results of architectural models and the process of architectural modeling (Patraucean et al., 2015; Li et al., 2017). Its versatility enables the achievement of various operational goals in design, construction, and facility management, including visualization and simulation assessments, as well as stakeholder collaboration (Zhao, 2017; Zheng et al., 2019). The extensive use of BIM has led to a growing body of scholarly research focused on harnessing its potential to enhance and optimize construction waste management, particularly in the phases of design, construction, and demolition, with a strong emphasis on promoting sustainable development practices.

4.2.1 Design evaluation

In the complex domain of the design evaluation phase, where the salvageability of a building is thoroughly examined, researchers have embraced innovative methodologies to improve decision-making processes. Akanbi et al. (2018) introduced a comprehensive system that utilizes BIM to evaluate the overall life cycle performance of a building. This system enables the assessment of a building's salvage performance by estimating the quantity of materials that can be reused and recycled at the end-of-life stage. Deconstruction, a purposeful procedure involving the systematic dismantling of a building to optimize the retrieval and repurposing of its elements and materials, plays a crucial role in promoting the sustainable use of resources. Akinade et al. (2015) presented a deconstructability evaluation metric that utilizes BIM to assess the feasibility of deconstructing a building during the design phase. Comparative analysis of building models based on this scoring system facilitates the selection of designs with optimal deconstructability. Marzouk and Elmaraghy (2021) developed plugins that capture the connectivity relationships among BIM objects to assess the deconstructability of various elements. By visualizing these relationships, the plugins enable on-demand removal of building components. Porwal et al. (2023) integrated BIM with systems dynamic modeling to reduce C&D waste resulting from alterations through BIM coordination during the design phase.

4.2.2 Collaborative work

Within the domain of collaborative efforts aimed at advancing sustainable practices in the construction industry, researchers strategically utilize BIM as a central platform. Alwan et al. (2017) position BIM as a collaborative tool to facilitate the coordination of various stakeholders within the construction industry. Its purpose is to mitigate the adverse effects associated with the generation of C&D waste and promote sustainable construction practices. Heigermoser et al. (2019) introduce a last planner system integrated with BIM, employing 3D construction models for lean construction management. This approach enhances the efficiency of C&D waste-handling processes, resulting in significant waste reduction. Atta et al. (2021) develop a digital material passport that integrates material passports and BIM. This tool enables the recording and sharing of building material information, promoting proper handling of building materials throughout different phases of a building's lifespan. Wang et al. (2021) create a decision-support framework specifically tailored for stakeholders engaged in CDWM. This BIM-centric system, guided by principles of cost optimization, is designed to synchronize transportation and demolition processes related to C&D waste. By extracting material information from BIM models, the system provides economically efficient strategies for managing the logistics and demolition aspects of C&D waste.

4.2.3 C&D waste quantity estimation

An important aspect of effective CDWM involves accurately estimating the quantity of waste generated during the design and construction stages. Poor design and construction alterations often contribute to significant C&D waste generation. Won et al. (2016) present a novel technique for estimating avoidable C&D waste generation using a BIM-incorporated design verification method. This method is validated through two construction projects in Republic of Korea. Guerra et al. (2019) propose an automated approach for estimating C&D waste generation. By utilizing BIM for automatic quantity estimation and integrating project procurement records, this approach enhances the decision-making efficiency of implementing effective waste management strategies at construction sites. Bakchan et al. (2019) propose a multi-dimensional framework for CDWM that incorporates BIM. This framework provides guidance for various applications, including planning for C&D waste disposal, estimating associated costs, and facilitating the on-site reuse of materials. Quiñones et al. (2021) develop a multi-platform approach grounded in BIM to estimate C&D waste generation during the architectural design stage. This approach enables the automatic and detailed quantification of C&D waste, aiding in the identification and selection of strategies that enhance sustainability during the design phase.

4.2.4 Environmental impact

In the comprehensive assessment of environmental consequences throughout the lifecycle of CDWM, researchers have employed diverse methodologies. Wang et al. (2018) developed a computational model for lifecycle assessment to quantify carbon emissions associated with the handling of C&D waste. This model utilizes BIM technology to streamline data collection and integration, optimizing the data processing workflow. Xu, et al. (2019a) developed a BIM-enabled system for managing information related to C&D waste, facilitating a comprehensive estimation process for C&D waste generation and enabling precise calculations of greenhouse gas emissions. They also proposed targeted recommendations for carbon emission reduction. Jalaei et al. (2021) utilized an integrated BIM-life cycle assessment (BIM-LCA) system to quantify C&D waste generation throughout its lifecycle and conducted a comprehensive assessment of its consequential environmental impacts. Su et al. (2020) developed a model that utilizes dynamic LCA in conjunction with BIM to assess the changing environmental effects of buildings. This model utilizes BIM to extract material and progress information and employs analytical software to evaluate the time-related aspects of the building lifecycle. Wang, et al. (2022b) introduced a process-based LCA method to assess the ecological implications of various C&D waste disposal methods, including landfilling, reuse, and recycling. Additionally, they developed a BIM-based plugin to automate environmental impact assessments during the building scraping phase from software applications.

BIM stands out as a central force in transforming CDWM, offering benefits such as evaluating building design, fostering collaboration, estimating C&D waste generation, and assessing environmental impacts. However, it is important to note that BIM's effectiveness relies heavily on data quality and availability, which can be challenging, especially in complex construction projects (Xing and Tao, 2016; Gan et al., 2021). Moreover, the complexity of BIM and the specialized skill set required for its implementation may pose barriers for small and medium-sized enterprises with limited resources (Lv et al., 2022; Ding 2020). Additionally, existing uncertainties introduced by BIM in decision-making processes and potential resistance to change among related stakeholders may hinder its full potential for CDWM. Therefore, while acknowledging the value of integrating BIM into CDWM, future research efforts are urgently needed to address the aforementioned challenges in order to fully realize its transformative potential in the construction industry.

4.3 Geographic Information System

GIS, or Geographic Information System, is a technical system that revolves around spatial databases and is supported by computer software and hardware. It is thoroughly designed for the handling and examination of spatial data (Sánchez-Lozano et al., 2013; Zhu, Wang, et al., 2019). In addition to its ability to identify, correlate, and analyze spatial relationships, GIS excels in visually presenting developmental trends and project results using various sources of information (Xiao et al., 2020; Almendros-Jimenez et al., 2021).

4.3.1 Site selection

To tackle the significant challenge of selecting sites and optimize the management of C&D waste, several methodologies have been employed to improve the strategic positioning of waste facilities. AlZaghrini et al. (2019) proposed a solution that incorporates GIS and optimization methods to address the multi-level facility location problem. This sophisticated tool aids in the selection and optimization of C&D waste facilities, with the goal of achieving cost-effectiveness and environmental benefits in waste management. Madi and Srour (2019) presented an automated site selection framework that utilizes GIS, specifically focusing on post-war or post-natural disaster demolition waste. This framework identifies suitable land for constructing C&D waste recycling facilities by optimizing the facility selection process and thoroughly addressing both environmental and economic objectives. Ağaçsapan and Çabuk (2020) introduced a GIS-based method for selecting sites for C&D waste transfer stations, aiming to address the challenges of uneven C&D waste generation and high transportation costs. This approach involves a comprehensive examination of spatial factors and the overlay of weighted data layers to advance sustainable waste management practices in areas with uneven and dispersed population distribution. Taking into account the uncertainties in C&D waste generation and transportation costs, Li, et al. (2022a) developed a robust optimization approach for site selection of C&D waste facilities. The objective was to identify optimal locations while considering overall cost considerations. Recognizing the diverse technical, economic, and social criteria involved in selecting sites for C&D waste facilities, Soto-Paz et al. (2023) proposed a hybrid decision-making tool that combines GIS and Monte Carlo simulation methods for site selection in developing countries. This tool incorporates multi-criteria analysis supplemented with economic assessments to ensure a comprehensive and well-informed decision-making process.

4.3.2 Material flows and stocks analysis

In the assessment of the ecological implications of CDWM, a critical aspect involves accurately estimating the quantity and composition of materials within existing building stocks. Material flow analysis is a crucial method for precisely measuring resource extraction and waste flow. Mastrucci et al. (2017) developed an approach that integrates GIS, spatiotemporal databases, and LCA to comprehensively characterize building material stocks. This comprehensive methodology enables the evaluation of potential environmental impacts associated with demolishing large-scale urban buildings, providing valuable insights to guide decision-making in CDWM strategies. In Italy's city of Padua, an intermediate-sized urban center, Miatto et al. (2019) utilized a sophisticated methodology that integrates a compiled 4D-GIS map and a database of building material intensities to quantify the overall material stock at various time points. By incorporating data on building lifespan, researchers estimated the flow of demolition waste, contributing to a nuanced understanding of material dynamics. Mesta et al. (2019) conducted an extensive examination of material stocks within structures and their spatial dispersion throughout the urban area. This investigation involved leveraging various data sources, including GIS, census data, and Google Maps. Wang, et al. (2019a) developed a forward-looking "4D-GIS" framework for Longwu Village in the city of Shenzhen. This innovative model seamlessly integrated stock analysis and material flow with GIS, enabling the anticipation of material requirements and the projection of C&D waste generation within the specific setting of the village. The application of this modeling framework proves essential in directing initiatives to reduce material usage and improve C&D waste recovery rates. Guo et al. (2019) computed building stock meticulously for 14 major cities in the East China region using building GIS data sets. By conducting a spatial analysis focused on identifying concentrations of material stocks, the researchers successfully identified regions with a higher probability of generating significant volumes of C&D waste. This outcome provides valuable insights for relevant stakeholders, facilitating the development of targeted waste management strategies.

4.3.3 Geospatial analysis

Recognizing the formidable challenge of optimizing CDWM through geospatial analysis, researchers have employed a diverse range of methodologies to refine the strategic allocation of waste facilities. Wu et al. (2016) systematically quantified the flow of C&D waste resulting from building demolition using GIS and conducted comprehensive visual analyses. By leveraging the spatial and temporal dimensions of GIS, they developed tailored CDWM strategies for different demolition scenarios. Göswein et al. (2018) investigated the significance of traditional and alternative concrete mix transportation, employing a combined approach of LCA and geospatial analysis. Their study involved assessing the environmental impacts of various concrete mixes at specific locations of concrete production plants. Meanwhile, Seror and Portnov (2018) utilized GIS and geostatistical models to evaluate and delineate regions with a high probability of illegal dumping of C&D waste. This approach facilitated subsequent monitoring through environmental law enforcement at specific locations, resulting in the reduction of C&D waste illegal dumping. In the context of CDWM in Brazil, da Paz et al. (2018) strategically planned the municipal management network using GIS. They meticulously mapped illegal disposal sites of C&D waste in Recife City, classified them, and proposed transportation and final destination plans for C&D waste to improve its material recovery rate.

GIS is emerging as a cornerstone in revolutionizing CDWM, providing essential functions such as strategic site selection, waste flow quantification, and geospatial optimization. However, challenges persist within GIS itself, particularly in accessing accurate spatial data, where inconsistencies or outdated sources can impede reliable analyses (Akindele et al. 2023; Glinka 2022). Additionally, there is a risk of potential biases in analyzing outputs derived from GIS, stemming from its interpretation of spatial data or simplification of complex relationships (Irizarry et al. 2013; Selvam et al. 2019). Consequently, the effectiveness of CDWM strategies derived from GIS analyses may be affected. Recognizing the continuing importance of GIS in CDWM, future research efforts should be directed toward overcoming these challenges to enhance sustainability and CDWM practices.

4.4 Big Data

BD represents a compilation of data sets collected within a specific timeframe that traditional computing tools struggle to acquire, organize, and process effectively (Wamba et al., 2015). These data sets include various types, such as video, text, and audio, often originating from interactions between humans and computers, such as online applications, online communities, and sensors (Deepa et al., 2022). By gathering and analyzing such data, researchers can uncover latent knowledge or actionable information, helping to mitigate biased results caused by limited data (Hu et al., 2014; Zhong et al., 2016). The crucial role of data in the big data era is essential for advancing C&D waste management, minimizing environmental consequences, and facilitating the recycling of C&D waste.

4.4.1 Data analysis

In the field of data analysis applied to CDWM, scholars have effectively utilized BD methodologies to extract insightful findings. Lu et al. (2015) leveraged extensive data sets to perform performance benchmarking for different types of construction projects, effectively utilizing more accurate C&D waste generation rates. Subsequently, Lu, et al. (2016a) conducted an empirical study using comprehensive data sets derived from CDWM documentation, revealing notable performance disparities in both the public and private sectors. Additionally, Xu et al. (2020) identified efficiency differences in CDWM across various sectors and established correlations between project progress and cumulative C&D waste generation. These findings provide valuable insights for waste management planning and waste transportation optimization. Moreover, Lu (2019) analyzed behavioral indicators and big data extracted from waste disposal records, uncovering the factors contributing to illegal dumping of C&D waste. This research offers a significant human-factor analysis, which is essential for the strategic development of C&D waste handling protocols. In a complementary approach, Bi et al. (2022) conducted a systematic examination of a substantial data set containing C&D waste transport truck trips, identifying potential factors that influence waste collection efficiency and proposing optimization strategies.

4.4.2 C&D waste generation prediction

Within the expansive domain of CDWM, harnessing the capabilities of BD technology has emerged as a key focal point in advancing our ability to predict waste generation. As researchers have grappled with the crucial of forecasting C&D waste generation, considerable progress has been made through the refinement and advancement of methodologies. Bernardo et al. (2016) outlined an approach detailing the assessment of C&D waste resulting from demolition activities within specific regions. In a similar vein, Umar et al. (2018) articulated a predictive model tailored for residential C&D waste generation. Significantly, predictive modeling has witnessed noteworthy advancements through the integration of sophisticated technologies, namely BD and AI, for forecasting C&D waste generation. In a related pursuit, Akanbi et al. (2020) developed a deep-learning framework based on an extensive data set containing 2,280 demolition records. This framework demonstrates a capacity for accurately predicting the recycling of C&D waste materials from dismantled structures, yielding results of elevated precision.

4.4.3 Environmental impact

Environmental impact assessment holds a pivotal position in the discourse surrounding CDWM. Lu, et al. (2021a) investigated how prefabrication practices influence the reduction of C&D waste, utilizing an extensive data set involving 114 large-scale projects of high-rise buildings. This investigation provides an intricate analysis of the nuanced relationship between prefabrication practices and strategic measures for reducing C&D waste. Similarly, Hu, et al. (2022a) evaluated the ecological implications of prefabrication in reducing C&D waste, using data from 412 construction projects. Their conclusion, affirming that prefabrication is proficient in substantially reducing various waste types, and establishes its credibility as a sustainable approach within the construction sector. In a parallel vein, Wei et al. (2022) examined the freight characteristics of C&D waste transport trucks and the associated carbon emissions, using a comprehensive data set from waste transport trips in Hong Kong, China. This study provides valuable insights into broader environmental considerations for CDWM.

Undoubtedly, BD is widely recognized as a pivotal factor in revolutionizing contemporary CDWM practices. It enables various advancements such as C&D waste prediction, optimization of CDWM strategies, and thorough environmental impact assessments. However, it is essential to acknowledge certain limitations. First, the effectiveness of BD relies on the availability of extensive and high-quality data sets, which may not always be easily accessible (Mathur and Gupta, 2020; Pant and Tanwar, 2016; Volk et al., 2019). Moreover, there is a risk of bias in the obtained outputs, and uncertainties persist regarding the accuracy and reliability of BD-driven predictive models for C&D waste generation (Trang, 2020; Sabarmathi and Chinnaiyan, 2017). Although BD holds great promise in improving construction sustainability and CDWM efficiency, it is crucial to invest more research efforts in addressing these existing limitations in order to fully realize its potential in CDWM.

4.5 Internet of Things

IoT embodies an efficient paradigm of information interaction facilitated by information-sensing devices. This concept enables the exchange of information between physical entities or between humans and physical entities (Banerjee et al., 2018; Ray, 2018). With this transformative concept, intelligent functions such as identification, localization, tracking, and supervision are empowered (Chen et al., 2014; Malik et al., 2021).

To advance effective strategies in CDWM, experts have pioneered innovative monitoring and tracking systems to address challenges posed by illegal disposal, building restoration, and the environmental impact of waste dumping. You et al. (2020) introduced an integrated supervision system that utilizes sensor technology, computerized video image recognition, GPS, mobile communication, GIS, and BD, enabling continuous surveillance of illicit activities during C&D waste disposal. Recognizing the significance of monitoring in diverse contexts, researchers have also developed specialized systems that utilize power line communication for dilapidated buildings (Huh, Park, 2020). To address the intricacies of processes related to CDWM, Kang et al. (2022) advocated for a framework that integrates smart BIM and IoT technologies to track the building demolition processes, facilitating the prompt identification and resolution of issues. Huang et al. (2022) further contributed to this academic discourse by developing a BIM-GIS-IoT framework that utilizes RFID technology to streamline the routing of various soil types to recycling plants or landfills, thereby enhancing efficiency. Additionally, Chandrasekaran et al. (2023) utilized sensor technologies and GIS models for monitoring and analyzing the environmental consequences of C&D waste dumping sites, contributing to a comprehensive understanding of waste disposal implications.

In summary, the IoT is revolutionizing conventional CDWM by enabling real-time monitoring and tracking through technologies like GPS, GIS, and BD. This approach enhances efficiency, sustainability, and issue resolution in the disposal of construction and demolition waste. However, there are some critiques that need to be considered. The reliance on sensor technology and GPS inevitably brings complexities in system integration and data management, which can potentially result in interoperability issues and data overload (Shvets and Hanák, 2023; Alzubi et al., 2022). Environmental factors such as signal interference and device malfunction may also limit the effective operation of IoT-driven systems (Sarrab and Alnaeli, 2018; Kant et al., 2024). Therefore, while IoT shows promise in CDWM, targeted future research should be undertaken to address these issues and maximize its benefits.

4.6 Remote sensing

Remote sensing, a transformative technology traditionally associated with satellite and airborne platforms that use optical and radar sensors (Zhang, et al., 2022; Colomina and Molina, 2014), has evolved to include various image and spatial data collection methods, incorporating airborne measurements and photogrammetry (Fraser et al., 2005; Alshawabkeh et al., 2021). The definition of remote sensing now goes beyond the traditional applications of terrain mapping and land cover classification, reflecting its broader range of uses (Zhao et al., 2022; Zhang, et al., 2022).

In the pursuit of intelligent monitoring of C&D waste, Zhou et al. (2021) conducted an investigation into the actual conditions of waste landfill sites in selected areas of Beijing using remote sensing imagery. They explored optimized machine learning-based methods for remote sensing and automatic identification of C&D waste. Recognizing the widespread, irregular, and easily confused distribution of urban waste, Chen et al. (2021) employed advanced remote sensing technology coupled with a comprehensive analysis of various features and a hierarchical segmentation approach to efficiently extract and identify waste information. Acknowledging the concealed nature of illegal dumpsites, which results in high detection costs and low efficiency, Karimi et al. (2022) utilized advanced satellite imaging during nighttime and various remote sensing parameters. They applied sophisticated decision-making methodologies and classification algorithms to produce probability maps that pinpoint potential illegal dumping sites. To identify urban C&D waste and evaluate the effectiveness of dust-proof nets, Li, et al. (2022b) suggested a comprehensive classification approach utilizing multiple layers and remote sensing technology.

In summary, remote sensing plays a significant role in revolutionizing intelligent monitoring of CDWM. However, it is important to recognize the inevitable limitations associated with remote sensing. These limitations include accurately identifying and categorizing C&D waste, addressing potential obstacles in detecting illegal dumpsites, and eliminating or minimizing biases introduced by machine learning algorithms. These limitations highlight the need for further research in these areas (Arabshahi et al., 2021; Vincke et al., 2019; Konikov and Garyaev, 2021; Guan et al., 2022). Despite these limitations, remote sensing remains a valuable tool in advancing the technological advancements of CDWM practices.

4.7 Blockchain

Blockchain is a paradigm-shifting technology that revolutionizes the storage and handling of information (Zheng et al., 2018; Yang et al., 2020). Acting as a decentralized system for transactional data management, blockchain operates independently of trusted third parties, performing tasks such as storage, manipulation, and transaction control (Yang, 2019; Li, et al., 2020b). Through blockchain, participants can engage in direct interactions via a decentralized network, facilitating seamless data exchange and financial transactions without the need for intermediaries (Perboli et al., 2018; Xu, Chen, et al., 2019b).

In the context of advancing cross-border trade in C&D waste materials, Wu et al. (2023) have introduced an innovative blockchain framework. This framework utilizes non-fungible tokens and integrates the waste material passport (WMP) concept, aiming to mitigate potential information asymmetry between buyers and suppliers. Furthermore, to enhance the holistic implementation of modularization in Hong Kong, China, Loo and Wong (2023) have presented a pioneering framework supported by technologies such as BIM, RFID, and blockchain. This approach enables transparent and traceable storage of substantial data.

In essence, blockchain represents a revolutionary technology that decentralizes data management and enables direct peer-to-peer interactions. Its transformative potential is evident in its specific applications related to cross-border trading in C&D waste, facilitating transparent and traceable waste data handling. However, it is crucial to acknowledge potential limitations. Currently, blockchain-enabled frameworks are primarily explored through sporadic case studies and require further validation in real-world settings (Nandakumar et al., 2020; Bruschi et al., 2022). Additionally, the limited representation of organizations in prototype blockchain systems may not fully capture the complexity of real-world C&D waste trading markets (Zhu and Wang, 2019). Addressing these challenges through ongoing research and practical testing is crucial to maximize the efficacy of blockchain technology in CDWM practices.

5 Discussion

5.1 Current limitations

The present research landscape regarding the integration of intelligent technologies into CDWM reveals noteworthy limitations that warrant careful academic consideration.

5.1.1 Insufficient integration of technologies

A fundamental limitation lies in the inadequate integration of diverse technologies. Despite a substantial body of research, there is a prevailing tendency to focus on the isolated application of specific technologies, neglecting the exploration of potential synergies. The limited inclusion of multiple technologies in existing studies, only 35 out of 214, underscores the challenges in seamlessly integrating these technological tools into established construction practices. Addressing issues related to interoperability, specialized expertise, and resistance to technological change is crucial for harnessing the transformative capabilities of intelligent technologies in practical C&D waste scenarios.

5.1.2 Limited exploration across lifecycle phases

A more significant limitation is the insufficient exploration throughout all lifecycle stages of construction projects. While the design and construction phases have received considerable attention, there is a noticeable research gap concerning the later stages, such as demolition, transportation, disposal, and recycling. This bias may result from the inherent complexities of these stages, potentially leading researchers to focus on the more manageable phases, namely design and construction. However, considering the increasing significance of C&D waste recycling, a more balanced approach is necessary, including all stages of the construction lifecycle and requiring the development of a comprehensive waste management strategy.

5.1.3 Underutilization of emerging innovations

A significant limitation lies in the underutilization of emerging innovations in the field of CDWM. This is likely due to researchers' bias toward established technologies rather than embracing novel advancements. Particularly, there is limited exploration of avant-garde intelligent technologies, such as blockchain, within the domain of CDWM. Despite a few academic recommendations, the practical implementation of blockchain applications to facilitate international trade in C&D waste remains limited. This indicates a clear disparity between theoretical proposals and practical applications.

5.2 Future research directions

The current landscape of intelligent technology applications for CDWM reveals inherent limitations, necessitating a critical examination and identification of future research directions. These directions, based on rigorous methodologies and theoretical frameworks, are outlined as follows:

5.2.1 Comprehensive technology integration

Future investigations should address the crucial of enhancing the integration of technology. Moving beyond isolated applications, there is a compelling need for a more holistic strategy. Subsequent research should focus on the development of synergistic models that seamlessly integrate various intelligent technologies to address overarching challenges such as interoperability and resistance to change. For example, BIM technology can be utilized for creating high-precision building models, while the combination of BD and GIS technology can establish a robust big data cloud platform for effective CDWM. This platform aims to forecast and monitor diverse types of waste data throughout all phases of construction projects, including design, construction, and demolition. Implementing this approach enables the assessment of the level of informatization in the CDWM process, facilitating timely improvements in waste handling effectiveness.

5.2.2 Lifecycle-wide exploration

The prevailing research bias toward the design and construction stages necessitates a paradigm shift toward a more comprehensive approach. Subsequent studies should include the entire construction lifecycle, including design, construction, demolition, transportation, and disposal/recycling stages. For example, BIM can simulate the complete demolition process, enabling the prediction of construction waste generation, budgeting for demolition costs, and minimizing C&D waste generation. Simultaneously, actual on-site demolition scenarios should be compared and analyzed against simulation schemes to enhance practitioners' demolition technology, reduce the generation of C&D waste, and address associated ecological impacts. Moreover, a comprehensive integration of IoT, AI, GIS, BD, and AI applications in C&D waste transportation logistics management, C&D waste tracking, regulation of road transportation behavior, and C&D waste identification and classification should be explored. This exploration aims to facilitate recycling and disposal processes while preventing environmental pollution. Expanding the research scope across multiple phases from a holistic lifecycle perspective is essential for generating more comprehensive and impactful research results.

5.2.3 Bridging established and emerging technologies

Emerging technologies, with a particular focus on blockchain, represent an untapped resource in CDWM. Subsequent academic endeavors should actively explore practical applications to overcome adoption barriers and integration challenges. Blockchain holds significant potential in improving supply chain traceability and incentive mechanisms. By leveraging blockchain's information tracing capabilities, building components can serve as the smallest structural units, enabling the comprehensive recording of transparent data throughout the entire building lifecycle. Building upon this foundation, a structured coding and classification system can be established, in conjunction with BIM technology, to thoroughly track C&D waste generation at each stage throughout its entire process.

In advancing future research on intelligent technology applications for CDWM, prioritizing three key aspects is crucial: (1) the comprehensive integration of diverse technologies, (2) adopting a lifecycle-wide perspective, and (3) bridging established and emerging technologies. Approaching these directions with methodological rigor has the potential to propel CDWM toward innovative solutions and more sustainable practices.

5.3 Prospective application framework

After a comprehensive review of the identified intelligent technologies and considering the limitations of existing research, Fig. 8 presents a framework delineating how intelligent technologies can be effectively employed in CDWM. These intelligent technologies are systematically categorized into five groups: (1) spatial technologies, (2) recognition technologies, (3) data communication and collection technologies, (4) data management and processing technologies, and (5) data exchange and transaction technologies. Figure 8 further illustrates the potential application scenarios of these five groups of intelligent technologies in CDWM across its diverse lifecycle stages, including design, construction, demolition, transportation, and disposal/recycling.

This prospective framework serves as a valuable reference for future research and implementation efforts, providing a comprehensive overview of the potential applications of intelligent technologies in CDWM. By addressing the specific challenges at each stage systematically, each group of intelligent technologies can contribute to the development of innovative and sustainable solutions for CDWM.

6 Conclusions

C&D waste is widely acknowledged as a significant impediment to achieving sustainable construction. The rapid progress of urban development and ongoing urban renewal initiatives in the modern era have resulted in a substantial increase in C&D waste, posing additional challenges to traditional waste management approaches. The question of how to adapt CDWM to this rapidly evolving era has long troubled various stakeholders in the

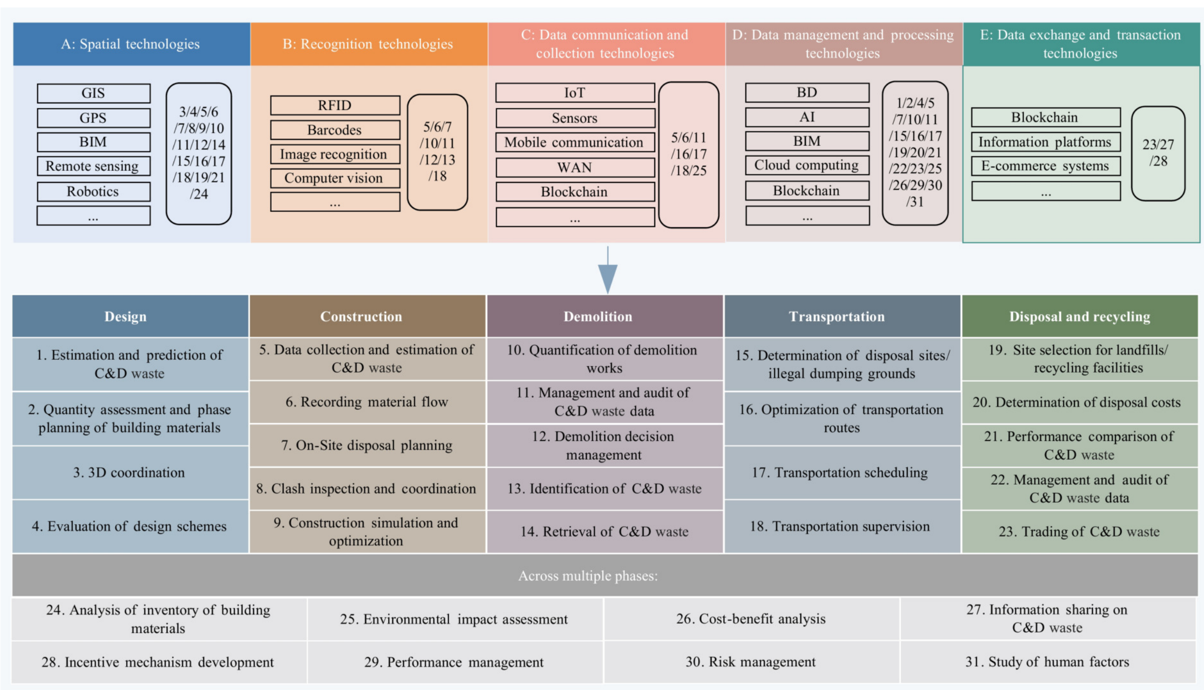

Fig. 8 A prospective application framework of intelligent technologies for CDWM.

construction industry. In alignment with the global drive toward Industry 4.0, there has been a surge in endeavors to apply various intelligent technologies such as BIM, GIS, AI, BD, and IoT to CDWM. However, these pioneering research efforts often lack a cohesive framework, rendering them fragmented. Given that CDWM is a complex undertaking with numerous associated challenges, the need for a well-organized, comprehensive framework is urgent.

This paper aims to conduct a comprehensive literature review to analyze the current state and future prospects of intelligent technology applications in CDWM. After a rigorous review of 214 papers using a rigorous methodology, the findings indicate that AI and BIM are the most frequently explored intelligent technologies for CDWM, followed by GIS, BD, and IoT. To address the current limitations of the existing research, this study also proposes future research directions, including (1) enhancing the comprehensive integration of different technologies, (2) adopting a lifecycle perspective in CDWM, and (3) exploring emerging technologies such as blockchain. Based on these findings, an application framework has been developed outlining how these intelligent technologies can potentially be applied to different lifecycle stages of CDWM. Future investigations could focus on more in-depth analyses within specific technology categories, comparing differences among them, and proposing optimal strategic choices. Additionally, timely reviews on the dynamic advancement of technology applications are essential to assist stakeholders in continually improving CDWM performance. This review paper offers valuable guidance for future research and implementation efforts for key stakeholders in the construction sector, paving the way for innovative and sustainable approaches for CDWM.

However, it is important to acknowledge a few limitations in this paper. First, while this literature review exhibited thoroughness, its sole focus on journal articles indexed by WoS may have inadvertently excluded relevant studies from other sources such as conference papers or industry reports. To enhance further comprehensiveness, future studies are recommended to embrace more databases for literature search, such as Scopus and Google Scholar, to include a broader array of relevant studies for scrutiny and provide a more holistic understanding of CDWM and its technological applications. Second, although the proposed future research directions offer valuable insights for stakeholders, their practical implementation requires addressing challenges such as resource constraints and technological complexities, which were not covered in detail in this paper. Future studies should provide practical guidelines on how to overcome these barriers and effectively apply intelligent technologies for CDWM.

Competing Interests The authors declare that they have no competing interests.

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