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Review

Research trend of the application of information technologies in construction and demolition waste management

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A B S T R A C T

Information technologies are increasingly adopted across the world to promote the efficiency of construction and demolition (C&D) waste management and alleviate the environmental and social effects of waste disposal. In addressing management issues of C&D waste by information technologies, several studies have been published by international peer-reviewing journals related to construction management over the past decades. However, a systematic summary on the research development in information technologies used in C&D waste management discipline is lacking. Therefore, this study examines the latest research situation in this discipline by analysing published construction management research in peer-reviewing journals in the period of 2000–2019, and 57 related papers are collected by filtering. The characteristics of the collected papers are classified according to the following criteria: application scenarios in C&D waste management and different technologies. Eight categories of present advanced technologies used in C&D waste management are identified, namely, building information modelling, geographic information system, big data, radio frequency identification, image recognition technology, image analysis, global positioning system and barcode technology. A critical analysis of the identified technologies is conducted in accordance with their characteristics and applications. This study also performs the scientometric analysis of the collected papers by VOSviewer. The limitations of information technologies and the recommendations for potential future research directions are presented on the basis of the analytical review.

Contents

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1. Introduction

Construction and demolition (C&D) waste is commonly generated from construction, renovation and demolition of buildings, roads, bridges and other structures (Peng et al., 1997; Yuan and Shen, 2011). C&D waste may consist of different sources, such as asphalt, concrete and wood (Poulikakos et al., 2017). The impact of C&D waste cannot be ignored. Several studies have illustrated that C&D waste accounts for 30%–40% of the total solid waste (Akinade et al., 2018; Won and Cheng, 2017; Liu et al., 2015; Li et al., 2014). Owing to urbanisation and related C&D activities, especially in developing countries (e.g. the urbanisation rate of China has increased from 19% to 54% in the past three decades (NBSC, 2014)), C&D waste generation is growing rapidly and will cause additional harmful impacts on the environment and the society, such as occupied land resource and polluted water source (Wang et al., 2018). Moreover, disposing C&D waste to landfills without recycling is a common treatment method in the world (Duan and Li, 2016). Therefore, the performance of C&D waste management can still be improved.

With such background, the research on C&D waste management has become a major topic worldwide, and numerous relevant publications have appeared in scholarly journals across the world. Currently, the research topics in C&D waste management can be divided into the following major categories: (1) estimation and quantification of waste generation, (2) C&D waste diversion research in developing economies and (3) design and planning for waste diversion (Jin et al., 2019). The rapid development of the society has facilitated the gradual adoption of information technologies, such as building information model (BIM), geographic information system (GIS), big data (BD) and radio frequency identification (RFID), in C&D waste management (Wang et al., 2018; Wu et al., 2016; Lu, 2019; Zhang and Atkins, 2015).

Information technologies have promoted the efficiency of C&D waste management and will be a key point in solving C&D waste management issues. For example, Wang et al. (2018) developed a conceptual framework to facilitate the assessment of carbon emissions over building's life cycle via BIM. Cheng and Ma (2013) developed a BIM-based system that automatically estimates and plans for demolition and renovation waste. Seror and Portnov (2018) adopted GIS to identify areas under potentially elevated risk of illegal C&D waste dumping in the Haifa District of Israel. Wu et al. (2016) quantified the demolition waste from generation to final disposal using spatial and temporal dimensions in GIS. Chen and Lu (2017) analysed the key affecting factors of demolition waste generation based on BD. Lu et al. (2016) compared the construction waste management performance of 2 million public and private projects in Hong Kong by using BD technologies. Zhang and Atkins (2015) developed a framework that integrates rule-based reasoning technologies with RFID based on a recycling plant. The above-mentioned information technologies have been proposed to effectively manage C&D waste. However, a systematic review that analyses these information technologies and discusses their applied scenarios in this discipline is lacking. Decision makers should understand the characteristics and applicable conditions of information technologies. In addition, effective understanding on the latest development of the research in information technologies adopted in C&D waste management should be provided. Therefore, a systematic review is important to fill the research gap. The objectives of this research are listed as follows:

(1) To summarise the existing information technologies adopted in C&D waste management and determine their application reasons and contributions.

(2) To outline current C&D waste management issues on the background of information technologies and ascertain which technologies can properly handle these issues.
(3) To seek the limitations of present research and provide recommendations for potential future research directions.

This paper is divided into five parts and starts with the background of information technologies adopted in C&D waste management, followed by an explanation of used research methodologies. The collected studies are then classified to help readers gain a comprehensive understanding of information technologies adopted in C&D waste management. Science mapping analysis results, research topics of information technologies in C&D waste management and future research directions are also suggested. Conclusions are given in the final section.

2. Research methodologies

For research purposes, publications under the subject areas need to be selected from renowned databases and international journals. To provide a comprehensive understanding of the current applications of information technologies in C&D waste management, this study conducted a rigorous retrieval process based on the most world-famous indexed databases: Web of Science (http://www.webofknowledge.com/) and ScienceDirect (http://www.sciencedirect.com/). The two databases contain numerous peer reviewed journals worldwide and have high quality (Wu et al., 2014). The process for retrieving related papers is summarised as follows:

(1) Comprehensive search of potentially relevant papers

Jin et al. (2019) provided an effective bibliometric search method, namely, inputting related keyword in database Scopus, to select related papers. Similarly, the first step of the current study was to input the following relevant keywords in WOS: 'C&D waste and building information modelling', 'C&D waste and geographic information system', 'C&D waste and big data', 'C&D waste and radio frequency identification', 'C&D waste and image recognition technology (IRT)', 'C&D waste and image analysis (IA)', 'C&D waste and global positioning system', 'C&D waste and barcode technology (BT)', 'C&D waste and urban remote sensing', 'C&D waste and internet of things' and ect.

To gain a comprehensive retrieval outcome, this study added eight international journals for further retrieval, namely, 'Waste Management', 'Resources, Conservation and Recycling', 'Waste Management and Research', 'Journal of Cleaner Production', 'Construction and Building Materials', 'Sustainability', 'Open Construction and Building Technology Journal', and 'Renewable and Sustainable Energy Reviews', because they published the largest number of papers concerning C&D waste management (Jin et al., 2019). In addition, two popular top journals, namely, 'Computer-aided Civil and Infrastructure Engineering' and 'Integrated Computer-aided Engineering', were selected for additional retrieval. The authors revisited the searching results issues by issues; as a result, more than 80 papers were collected. Conference papers were excluded as journal papers were more representative than conference papers.

(2) Identifying the retrieved papers

After searching related papers, a filtering process was conducted to identify how the collected papers match the research scope by scanning titles and abstracts. Given that this study only reviewed the information technologies adopted in C&D waste management, papers that adopted those in other wastes (e.g. municipal solid waste (Colvero et al., 2018)) were excluded. After this filtering work, 57 papers remained for the analysis. A brief analysis was conducted to reveal the research trends of information technologies for C&D waste management (Fig. 1). This analysis illustrates that this research topic has received high concerns from researchers over the past 4 years.

The 57 selected articles were classified according to different information technologies. Then, the application of these technologies in construction and demolition waste management were summarised and analysed. Moreover, the future research directions were discussed.

(3) Science mapping analysis

In order to explore the main contributors to existing related research and their inter-relationships. This study adopted a text mining tool, namely, VOSviewer, to analyse the bibliometric network relationship of information technologies in C&D waste management, including co-authorship, co-occurrence keywords and countries' activeness analysis. VOSviewer is usually used to assist researchers in conducting literature review analysis in construction engineering and project management fields because it can visualise bibliometric networks (Jin et al., 2019). The influence of main scholars, keywords and countries in this discipline can be visualised, computed and analysed using this tool.

3. Classification of the selected studies and applied scenarios in C&D waste management

Thought a systematic review of the collected 57 papers, eight information technologies were identified as follows: building information modelling (BIM), Geographic information system (GIS), big data (BD), Radio frequency identification (RFID), image recognition technology (IRT), image analysis (IA), global positioning system (GPS) and barcode technology (BT). In light of the limited research scope in C&D waste management, this study analysed the application reasons of these technologies and their operation and limitations in C&D waste management. Table 1 presents the detailed information of the collected papers.

Fig. 2 presents the numbers of publications related to information technologies. As shown in the diagram, BIM, GIS and BD are the most widely used technologies. A total of 28 papers are related to BIM (47%), 16 are related to GIS (27%) and 8 papers are related to BD (14%). If some papers have adopted more than one technology, then all related technologies will be counted once.

3.1. Building information modelling

BIM, which is an emerging technology in the last decades, has received a wide interest and has become an essential solution in C&D waste management (Liu et al., 2015; Li et al., 2017). Porwal and Hewage (2012) applied BIM in C&D waste management. They also used BIM to simulate architectural and structural design requirements for minimising rebar waste by making design changes on the basis of the simulation results. Cheng and Ma (2013) developed a system to estimate demolition and renovation waste. The trend of adopting BIM in C&D waste management has grown rapidly. Table 1 reveals that more than 20 papers have been published in the past 6 years. BIM is a completely emerging technology in this discipline and has achieved considerable attention from researchers.

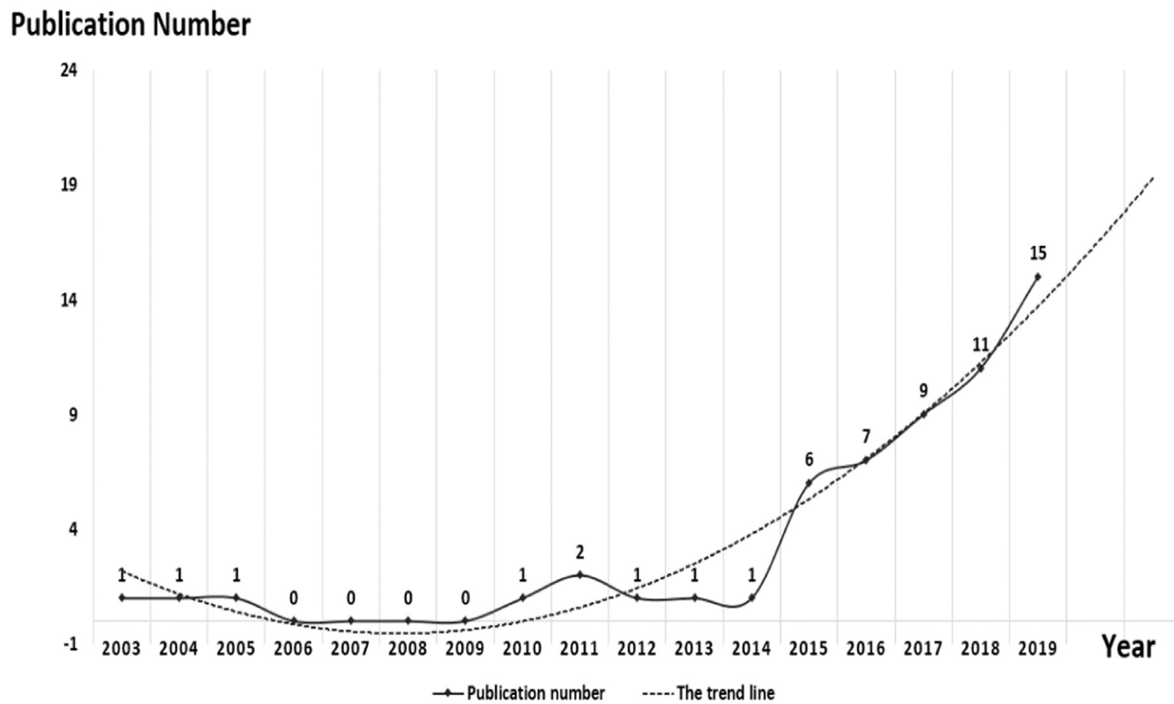

Fig. 1. Diagram of annual publication of the related papers. Note: The deadline for paper collection is September 2019.

3.1.1. *Main application reasons in C&D waste management*

(1) 3D visualisation

A building is designed by various project participants. Thus, some inevitable design errors occur in the architectural, engineering and construction industry. The errors can only be corrected when the building is in the stage of construction, which results in design changes and increased waste (Won et al., 2016). A distinct advantage of BIM is its 3D visualisation capability, which helps designers determine design errors and detect collusion in different construction majors. Won et al. (2016) developed a BIM-based design validation system to verify the effect of construction waste reduction by detecting design errors. Two projects were imported into the system and compared. The results reveal that 4.3%–15.2% construction waste is prevented using this system.

(2) Huge information on construction life cycle

BIM, which is a “rich repository” of information, contains considerably more information than 2D CAD drawings (Li et al., 2017). BIM not only contains geometric information as CAD drawing but also contains non-geometric information and different types of information (Pratt, 2004). BIM can also be imported into building’s life cycle by accumulating all information in BIM (Akinade et al., 2015) and provides important information for life cycle estimation (Wang et al., 2018). The accumulated information can provide basic data resources for future research on C&D waste management or needed information for deconstruction. In the meantime, BIM has superior automation capability and can thus avoid potential errors and reduce cumbersome operations made by manual work (Wang et al., 2018).

(3) Simulation of different types of design

In practice, a construction project is on and off, requires investing massive resources and is irreversible. Therefore, researchers cannot simulate different designs and construction plans in real life. However, BIM can provide a platform that is low cost, virtual and computational; thus, it allows designers to realise different design options and contractors to estimate different construction plans; then, the risk of construction waste amongst different options can be compared in a virtual environment (Li et al., 2017). This way allows researchers to continually optimise the construction design and plan during the design phase for reducing waste generation.

3.1.2. *Role of building information modelling in research*

(1) Application programming interface

The application programming interface of BIM is a function module that allows users and developers to exploit an extra application by writing a programming or script. Although several add-on software applications are available, none of them are proposed for C&D waste management until a study conducted by Cheng and Ma (2013). They developed a BIM-based waste estimation and planning system by application programming interface to a) provide detailed volume information about each element category and material type, b) estimate the total amount of demolition and renovation waste, c) estimate demolition and renovation waste disposal charging fee and d) estimate the total number of pick-up trucks. Akanbi et al. (2018) established a BIM-based whole-life performance estimator integrated with BIM by application programming interface. The whole-life performance estimator can determine reuse and recyclable materials when buildings dismantle at the design stage. Lu et al. (2017)a,b integrated BIM and the database they created, namely, design options-waste generation database by application programming interface. Through this interface, the waste generation of each component of BIM model is automatically matched in design options-waste generation database. The application programming interface function enables

Table 1
Classification of the collected paper.

	Reviewed paper	Region	BD	BIM	GIS	GPS	RFID	IA/IRT	BT
1	Lu et al. (2016)	HK	✓						
2	Lu et al. (2015)	HK	✓						
3	Lu et al. (2018)	HK	✓						
4	Chen and Lu (2017)	HK	✓						
5	Lu (2019)	HK	✓						
6	Bilal et al. (2016a)	UK	✓						
7	Bilal et al. (2016b)	UK	✓						
8	Liu et al. (2015)	UK		✓					
9	Kim et al. (2017)	South Korea		✓					
10	Cheng and Ma (2013)	HK		✓					
11	Jae-Woo et al. (2014)	South Korea		✓					
12	Porwal and Hewage (2012)	Canada		✓					
13	Lu et al. (2017b)	Singapore		✓					
14	Wang et al. (2018)	China		✓					
15	Lu et al. (2017a)	HK		✓					
16	Ge et al. (2017)	Australia		✓					
17	Akinade et al. (2018)	UK		✓					
18	Won and Cheng (2017)	South Korea		✓					
19	Sacks et al. (2010)	Israel		✓					
20	Won et al. (2016)	HK		✓					
21	Akanbi et al. (2018)	UK		✓					
22	Alwan et al. (2017)	UK		✓					
23	Zhang et al. (2017)	USA		✓					
24	Akinade et al. (2015)	UK		✓					
25	Ajayi et al. (2015)	UK		✓					
26	Ooshaksaraie and Mardookhpour (2011)	Iran			✓				
27	Robinson and Kapo (2004)	USA			✓				
28	Miatto et al. (2019)	USA			✓				
29	Wu et al. (2016)	China			✓				
30	Li et al. (2005)	HK			✓	✓			
31	Seror and Portnov (2018)	Israel			✓				
32	Paz et al. (2018)	Brazil			✓				
33	Göswein et al. (2018)	Portugal			✓				
34	Zainun and Othman (2015)	Malaysia			✓				
35	Blengini and Garbarino (2010)	Italy			✓				
36	Kleemann et al. (2017)	Austria			✓				
37	Lu et al. (2011)	HK					✓		
38	Zhang and Atkins (2015)	China					✓		
39	Li et al. (2003)	HK							✓
40	Di Maria et al. (2016)	Italy						✓	
41	Yu et al. (2019)	China			✓			✓	
42	Guerra et al. (2019)	USA		✓					
43	Akinade et al. (2017b)	UK		✓					
44	Akinade et al. (2017a)	UK		✓					
45	Akanbi et al. (2019a)	UK		✓					
46	Jalaei et al. (2019)	Iran		✓					
47	Bakchan et al. (2019)	USA		✓					
48	Wang et al. (2019a)	China			✓				
49	Chen et al. (2018)	China	✓						
50	Ding et al. (2018)	China			✓				
51	Wang et al. (2019b)	China						✓	
52	Madi and Srour (2019)	Lebanon							
53	Liu et al. (2019)	USA		✓					
54	Xu et al. (2019)	China		✓					
55	Heigermoser et al. (2019)	Germany		✓					
56	Akinade and Oyedele (2019)	UK		✓					
57	AlZaghrini et al. (2019)	Lebanon			✓				

Please note the acronyms as follow: Hong Kong - HK; United Kingdom - UK; BIM - Building Information modelling; GIS - Geographic information system; BD - Big data; RFID - Radio frequency identification; GPS - Global positioning system; IA - Image analysis; IRT - Image recognition technology; BT - Barcode technology.

researchers to achieve additional possibilities in C&D waste management.

(2) Automation

BIM can automatically extract object size, volume, location and other information from the models and is more precise than manual work. Many researchers have used BIM to collect such information for further research, such as calculated waste amount and carbon emissions (Akinade et al., 2015; Bakchan et al., 2019; Cheng and Ma, 2013; Ge et al., 2017; Guerra et al., 2019; Kim et al., 2017; Lu et al., 2017a; Wang et al., 2018). In addition, prediction method based on BIM can achieve improved accuracy compared with other methods.

(3) High-quality collaboration

The construction process is a complex system and involves various construction participants, stakeholders, professionals and complicated workflows. A project facing inefficient coordination and collaboration can lead to construction errors, which can generate unnecessary construction waste (Zhang et al., 2017). In the

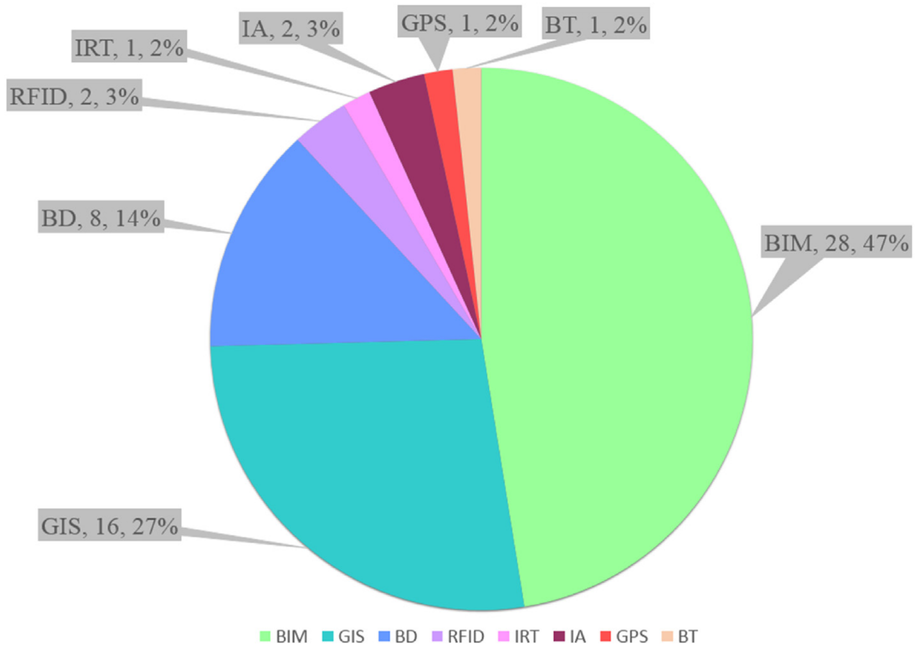

Fig. 2. Diagram of publications related to information technologies.

meantime, the originality of BIM lies in its ability to fully coordinate project information; thus, it strengthens information management and cooperation (Ajayi et al., 2015). In addition, BIM can help stakeholders communicate efficiently to improve coordination and supervise the entire construction process (Akinade et al., 2015). Porwal and Hewage (2012) argued that BIM is an effective communication hub amongst various design teams in a project and serves as a vehicle that allows engineers to optimise and coordinate rapidly. Li and Yang (2014) presented that waste management contractors should participate in projects at the early stages by BIM to improve construction efficiency in waste management.

(4) Design of deconstruction based on BIM

Deconstruction instead of demolition can help improve the recycling efficiency of buildings in their end-of-life stage. Deconstruction can eliminate environmental affect and C&D waste generation and can therefore be more beneficial than demolition (Akinade et al., 2017b). Researchers have applied BIM technologies to enhance the efficiency of building deconstruction from the design stage. Akinade et al. (2017b) conducted focus group interviews with professionals and highlighted functionalities, such as improved collaboration amongst stakeholders and visualisation of deconstruction process, to determine the essential functionalities of BIM for design of deconstruction (DfD) tool. Akinade et al. (2017a) illustrated that the BIM technology plays an important role in design of deconstruction. In addition, Akanbi et al. (2019b) developed a disassembly and deconstruction analytic system to assess buildings' end-of-life performance at the design stage. The performance of design of deconstruction can be significantly improved by BIM technology.

3.1.3. Current limitations

(1) Lack of BIM models in existing buildings

BIM is still an emerging technology in developing countries. Thus, most existing buildings have no BIM model during construction, and their building drawings may have been lost or damaged. Current related studies mainly focus on new buildings under construction. However, BIM models for existing buildings are required because waste generated from demolition during building dismantle phase is larger than that generated from construction.

(2) Lack of adequate data support

The literature review reveals that existing waste estimation methods lack complete and high-precision databases (Akinade et al., 2018). Databases are critical in ensuring data accuracy because BIM-based C&D waste estimation methods are based on index of waste combined with waste volume. In addition, existing regional disparity amongst different regions cannot be neglected. If the estimation methods are intended to be expanded to other regions, then the databases for BIM must be comprehensive and accurate.

3.2. Geographic information system

GIS is a computer-based system to collect, store, integrate, manipulate, analyse and display data in a spatially referenced environment; GIS assists in analysing data visually and finding patterns, trends and relationships that may be invisible in tabular or written form (EPA, 2014).

Li et al. (2005) integrated GPS and GIS to reduce construction waste with construction material and equipment management onsite. A total of 11 journal articles have been published in the past 14 years. Table 1 shows that researchers from many countries, such as the United States, China, Hong Kong, Brazil, Israel, Malaysia, Italy, Portugal and Austria, have adopted this technology to address C&D waste management issues.

3.2.1. Main application reasons in C&D waste management

(1) Successful applications in other waste management fields

The review of the retrieved papers reveals that GIS is a common tool in studying environment issues (Seror and Portnov, 2018) and has been widely used to address waste management issues. Gorsevski et al. (2012) integrated multi-criteria evaluation techniques with GIS to select appropriate landfill sites. Che et al. (2013) integrated a questionnaire survey and GIS to assist decision markers in planning municipal solid landfills. Colvero et al. (2018) used GIS tools to identify municipal solid waste landfills and dumps for pursuing potential landfill sites. The above-mentioned researchers have achieved meaningful results with GIS technologies. Correspondingly, GIS can help researchers and decision makers efficiently address C&D waste management issues, particularly identifying the best waste landfill sites or illegal waste areas.

(2) Convenience and ease of promotion

The required operating environment of GIS software is considerably lower than those of BIM and BD. In the meantime, the model based on GIS with comprehensive data can be easily applied in other areas (Paz et al., 2018; Robinson and Kapo, 2004; Seror and Portnov, 2018). Accordingly, this technology can be easily applied to other case studies. Therefore, it can be easily promoted.

(3) Suitability in analysing spatial relationship

Many researchers have adopted GIS technology because it is a powerful tool for geographical data storage, analysis and building models (EPA, 2014). GIS has advantages in data collection, storage, integration, processing, analysis and presentation and has a spatial form to help researchers in their studies. Ooshaksaraie and Mardookhpour (2011) used GIS to display the best location of waste storage areas and as a supportive tool for analysing spatial relationship in C&D waste management. Wu et al. (2016) illustrated that GIS is a suitable tool that can manage demolition waste flow direction with spatial and time dimensions.

3.2.2. Role of geographic information system in research

(1) Process data

GIS can analyse the relationship amongst diverse elements, and GIS data have been used by researchers to generate results in diverse forms. Wu et al. (2016) established a model based on GIS. They imported all collected information into ArcGIS, namely, GIS software, to help researchers predict and assess demolition waste. The GIS approach can provide various expression forms, such as maps, tables, figures and simulation animations, for producing an overall result for research (Wu et al., 2016).

(2) Position display and identification of sites of recycling facilities and landfills

The literature review indicates that GIS is a powerful tool for analysing spatial relationship. Thus, researchers have used GIS to identify and display illegal waste sites, waste spatial flow directions, waste storage area, cargo position and recycling plant site. For instance, Ooshaksaraie and Mardookhpour (2011) established a system based on GIS. This system displays the best location of waste storage area visually. Li et al. (2005) displayed accuracy position of construction material cargos on a GIS map. Seror and Portnov (2018) mapped every illegal C&D site and elevated risk area in Haifa on a GIS map. Blengini and Garbarino (2010) illustrated that the C&D waste recycle chain positively affects energy and the environment by using GIS integrated with life cycle assessmen. A total of 89 C&D waste recycling factories data with position information were imported into GIS software and displayed on a GIS map. Ding et al. (2018) integrated analytic hierarchy process and GIS technologies to analyse the best location of waste landfills for facilitating the site selection of construction waste landfills. Moreover, Madi and Srour (2019) located suitable recycling plants by GIS to minimise environmental and economic costs against a background of war.

(3) 4D GIS

The concept of 4D GIS was proposed by Tanikawa and Hashimoto (2009) in a study on material stocks in urban areas. The 4D GIS methodology is based on traditional 3D GIS technology with an added time dimension; the former can collect, store, analyse and display spatial variation of entities (Wang et al., 2019a). Miatto et al. (2019) utilised 4D GIS to study construction material storage volume and dynamic waste spatial flow from 1902 to 2007 in Padua, an Italian city. On the basis of their previous work, they presented a forecast of waste potential from demolition activities. In the meantime, a 4D GIS model was developed by Wang et al. (2019a) to analyse the material metabolism process. They applied the model in a case study in Shenzhen, a city that is undergoing rapid urban renewal. Waste flows of C&D waste were analysed. Their proposed 4D GIS model can clearly produce the status quo and future trends of C&D waste collection and transportation. Moreover, the model can help plan C&D waste landfills. 4D GIS is an emerging method based on GIS in C&D waste management. It will be given additional attention in this discipline in the future due to its superiority in analysing dynamic waste flow of C&D waste with an added time dimension, especially in the areas of fast urban renewal.

3.3. Big data

BD has three defining attributes, also known as 3Vs: volume, variety and velocity. Volume means terabytes, petabytes of data and beyond. Variety means heterogeneous formats, such as text, sensor, audio, video, graph and file. Velocity means continuous streams of data (Bilal et al., 2016b; Chen and Lu, 2017). This technology can excavate the depth information behind such enormous amount of information and the connection amongst different matters. Therefore, an extra ‘V’ is proposed for BD, that is, value (Dumbill et al., 2013). BD has been applied in many fields, including science, business, public government, innovation, competition and productivity (Sagiroglu and Sinanc, 2013). In the meantime, this technology has been adopted to analyse massive amount of information generated from C&D waste for settling management issues (Lu et al., 2016). BD was first adopted for construction waste management by Lu et al. (2015). They used BD to benchmark the performance of construction waste management. Since then, 7 related papers have appeared in the past 3 years, which demonstrates the great potential of this technology.

3.3.1. Main application reasons in C&D waste management

(1) Suitability to construction activities

BD is characterised by volume, variety, velocity and value. Therefore, the source inputs into BD need to be enormous, diverse and continuous. Given that the information from construction activities is huge, diverse and dynamic, BD is suitable for promotion in C&D waste management. For example, the waste disposal records from 2 million waste disposal records generated from approximately 5700 projects in Hong Kong can provide suitable data for analysing some problems that cannot be solved by traditional means (Lu et al., 2016).

(2) Improved forecasting and decision making

The unique superiority of BD to traditional technologies lies in large sample size coming from enormous data resource. Compared with small samples from traditional studies, the former can help researchers obtain reliable analysis results. Therefore, BD can help researchers further understand C&D waste management. In the meantime, analysing BD can reveal hidden relationship and valuable information, which offers decision-making bases for precise forecasting to governments (Chen and Lu, 2017; Lu et al., 2018).

(3) Limitation of traditional technologies

The results of statistical analysis based on BD have high reliability because of the massive number of samples. Applications of BD to the analysis of massive samples can alleviate the deviation from the analysis results of small samples. As a result, analysing consequences from BD will be close to real situation (Lu et al., 2016, 2018). Lu et al. (2015) established the benchmarks of different types of construction waste management performance by using reliable waste generation rates (WGRs). The fundamental support of reliable waste generation rates is based on BD, which can utilise the collected BD set to obtain reliable key performance indicator(KPI).

Bilal et al. (2016)a,b presented a summary of construction waste treatment methods, namely, 'Waste intelligence' and 'Waste analytics'. In this previous study, 'Waste intelligence' means the waste treatments are conducted after the construction waste is generated, and it is also called the afterward treatment. Another waste treatment idea, namely, 'Waste analytics', focuses on the early stage of construction projects. It reduces construction waste with higher efficiency than 'Waste intelligence'. However, advanced analytical technologies cannot perform effectively without BD technologies (Bilal et al., 2016a). In the meantime, traditional technologies can barely analyse and store data when their amount is enormous. BD technologies for construction waste management should be proposed to promote the performance of construction waste management.

3.3.2. Role of big data in research

(1) Data analysis

BD is used in C&D waste management research to analyse information from a large amount of construction projects. Lu (2019) built an analytical model by using BD and assessed 9 million waste disposal records to identify illegal waste dumping sites. In this previous study, an illegal dumping filter (IFD) was established by developing a core algorithm. This illegal dumpling filter contains a well-structured data table that consists of all indicators and their computer values from the BD. This model has four databases: Facility database, Project database, Waste Disposal database and Vehicle database. Facility database contains information of entire facilities, facility's code and locations of facilities. Project database contains information of account, contract number, contract sum, site address, department, type of construction work and detail of construction work. Waste disposal database contains information of facility, date of transaction, account, time-in, time-out and vehicle numbers. Vehicle database contains information of vehicle number and permitted gross vehicle weight. However, the connection amongst these indicators is unclear due to lack of previous experience of the most suitable analytical methods for illegal dumping identification. Researchers must keep trying different models and examine their result to obtain an appropriate method for identifying illegal cases. The model should be trained, evaluated and calibrated as well.

Bilal et al. (2016)a,b put forward a BD-based architecture for construction waste analytics for the first time; a total of 200,000 waste disposal records were obtained from 900 complete projects (Bilal et al., 2016a). In this previous study, the researchers selected an appropriate BD platform to develop waste analytical architecture, and BD was adopted to store and analyse 2,000,000 waste disposal records. The proposed BD architecture for waste analytics comprised three layers: Application layer, Analytics layer and Storage layer. The Storage layer had two storage tools: one was Hadoop distributed file system (HDFS) for initial storage of all unstructured data, and the other was Neo4J graph database for efficiently storing massive graph data, predictive models and prescription in predictive model markup language. In the Analytics layer, SparkR, MLLib and GraphX were used for analytical pipelines of waste estimation and minimisation. In the Application layer, the Revit software was used for plugin development. The hadoop distribution file system and Tribe store were utilised to store Industry Foundation Class files of BIM. Spark streaming was also used to launch analytics pipeline for estimating waste and optimising construction design.

(2) Data mining

Data mining can conduct automatic or semi-automatic exploration and analysis with massive data for mining hidden relationships. BD is beneficial in analysing non-trivial relationship, but the scope of data mining is broader than those of other data analysis methods (Bilal et al., 2016b). BD technology has superior performance in mining the hidden relationship amongst data. Thus, it can be used by researchers to analyse potential patterns and rules in complicated C&D waste management. With this technology, researchers can remove the outliers of data and then draw waste generation rate distribution figures. Accordingly, indicators (e.g. mean and standard deviation) of different study cases in public and private sectors can be compared (Lu et al., 2016).

3.3.3. Current limitation

(1) Privacy invasion and data security

The literature review reveals that BD analytics can lead to ethical consequences and privacy invasion. To date, no appropriate means are available to handle the resulting consequences. In the meantime, data security, data ownership and management issues are important problems in BD technology.

(2) Lack of data source

Only a few countries or regions have their own official agencies that collect basic data related to C&D waste management. This situation results in a lack of basic research data. However, most researchers demand basic data to continue digging into their research. Given that unavoidable expensive costs and implantation pressure result from collecting basic data, an entire system is needed to realise this target. Urging authorities to consciously collect data related to waste management is important. In the meantime, data quality of C&D waste is another issue that should be addressed.

(3) Costs of investment

The costs of importing this technology in C&D waste management are non-negligible. Companies or governments need to establish a BD centre and obtain software licenses, which can be a large investment. Skilled engineers are also required to handle the entire system (Bilal et al., 2016b).

3.4. Radio frequency identification

RFID can identify objects by using different wave frequencies. This technology consists of three components: RFID tag, antenna and reader. The RFID tag is often made by a microchip that stores data and an integrated antenna that serves as a transmitter. RFID can be divided into two types, namely, passive RFID and active RFID, according to their power source. Passive RFID has no power source and needs readers to supply power by wireless communication. Active RFID has its own power source installed inside (Lu et al., 2011).

RFID has been applied in various areas (e.g. car assembling, express service and Internet of things) and is not a completely new technology in the construction industry. Tzeng et al. (2008) explored the influence of RFID and interior decorating materials on the RFID system by identifying two factors, namely, suitable combination manners and tag space layout. Lin et al. (2014) developed a system that integrates mobile 2D barcode and RFID to improve maintenance management in the construction lab (Lin et al., 2014). Li and Becerik-Gerber (2011) suggested to use RFID in the construction industry, especially integrating RFID technology to assess building's life cycle. The results of the current filtering procedure show only two papers on this topic. Therefore, the RFID technology has been overlooked for a long period in the discipline of C&D waste management.

3.4.1. Main application reasons in C&D waste management

(1) Reliable identification function

RFID can record on time and provide real-time information and is a suitable data resource. RFID readers or writers can be installed at exits and entrances of construction sites. RFID tags can be installed on transport vehicles or other subjects. Information, such as waste disposal time, waste type, waste volume of transportation vehicle and location can be recorded in the RFID tags (Lu et al., 2011). The process of reading or writing is automatic and has no delay. Thus, man-made errors are decreased and the efficiency is high.

(2) Low cost and feasibility

The rapid development of technologies has made the use costs of RFID tags and devices acceptable for studying and real-life construction practices. Li et al. (2017) launched a study that developed an RFID-enabled BIM platform to enhance schedule performance of prefabricated house construction. They implanted RFID tags into each of the prefabricated components in a practical prefabricated construction project. Successful applications of RFID in other industries also show that the cost of RFID is acceptable.

3.4.2. Role of radio frequency identification in research

Zhang and Atkins (2015) developed a system that uses RFID to capture research data records, including position, volume, weight, movement of cargo containers and tracking inventory. The obtained information can be input into a management system, which can assist decision makers in analysing, planning and tracking. The application of this system in a case study shows that RFID technology is an efficient way to gain real-time and reliable information, which is the basis of this system.

3.4.3. Current limitations

The literature review indicates that the identification performance of RFID is easily affected by mental interference. Keeping an appropriate distance solves this problem. In addition, the transport vehicles are large in size, and active RFID is more suitable than passive RFID because the reading range of the former (5−25 m) is larger than that of the latter (less than 16 cm) (Lu et al., 2011). However, using active RFID is costly. RFID can automatically record positions or other intimate information but has ethical issues in some cases.

3.5. Other information technologies

Four other technologies, namely, image recognition technology (IRT), image analysis (IA), global positioning system (GPS) and barcode technology (BT), have also been introduced. These technologies have been discussed in only one or two papers in C&D waste management. Thus, the related information is limited.

3.5.1. Image recognition technology (IRT)

Yu et al. (2019) introduced a hybrid method for predicting demolition waste generation during large-scale urban renewal. Given that IRT can recognise and extract building outline, they combined image recognition with Google Earth to quickly and precisely acquire an area of each building for calculating gross floor area of renewal project. The highlights of their study relied on large-scale demolition waste estimation. The demolition waste estimation is beyond a single building instead of an area of buildings. Thus, measuring the whole area of renewal project by manual work is tedious and inaccurate. Therefore, image recognition can handle this issue.

3.5.2. Image analysis (IA)

Di Maria et al. (2016) suggested to use IA for assessing the recycling aggregate distribution size of C&D waste. The IA method based on the 'look-up catalogue' approach consists of three steps. Firstly, an image catalogue of materials representing known particle size distributions is defined. The next step is to create the corresponding catalogue. Thereafter, the unknown sample of C&D recycling aggregate distribution size is accessed using a best-fit procedure by interpolating in the elements of the catalogue. This method based on IA is proven to be effective and accurate by a case study on a C&D waste treatment factory. Wang et al. (2019b) used satellite-based IA to identify and estimate landslide susceptibility of landfills in Guangming, Shenzhen.

3.5.3. Global positioning system (GPS)

GPS technology can provide accurate positioning, but only one paper is related to GPS. Li et al. (2005) integrated GIS and GPS technology with M&E management system for construction waste reduction. GPS was installed on cargos to provide position data and transmit them to the central station, which is a monitoring station that allows position information display on a GIS map. At present, information on the applications of GPS in C&D waste management is limited, but the position system plays an important role in the practice of C&D waste management. For instance, GPS can be embedded in the transportation vehicles for real-time monitoring of C&D waste transportation.

3.5.4. Barcode technology (BT)

BT can automatically identify and collect information. Since 1960s, this technology has been adopted in various fields, such as stock taking, assembly checking and library automation. Later in 1980s, barcode has begun to be introduced into the construction industry (Li et al., 2003). Li et al. (2003) proposed an approach to reduce construction waste onsite by integrating barcode technologies and incentive reward programme. They developed a barcode-based system to provide the following functions in implementing incentive reward programme: (1) tracking real-time data of new construction and unused materials onsite, (2) tracking real-time data of packing of materials and equipment, (3) tracking real-time waste debris of materials onsite, (4) recording historical data of construction materials consumed in the project, (5) monitoring material consumption of working groups, (6) transferring real-time data of materials to project management system and (7) transferring real-time data of materials to the head office via the Internet.

The development of RFID technology has enabled its application in identifying not only items but also barcode systems. Lu et al. (2011) concluded the advantages of RFID by comparing RFID technology, BT and magnetic strip. The comparative outcomes show that RFID technology can read faster, has larger storage capacity and is more reliable and writable than BT. Therefore, RFID technology is more suitable to meet the requirements of research and practice in C&D waste management than other tools. The applications of BT in C&D waste management have not been paid additional attention.

4. Results and discussion

4.1. Science mapping analysis of information technologies in C&D waste management

4.1.1. Analysis of co-authorship

The collaborations amongst researchers can promote communication and productivity in research communities. In this co-authorship of information technologies in C&D waste management research, the minimum number of publications of an author was set at 2 in VOSviewer. Then, 26 out of 147 authors were selected from literature samples. Fig. 4 and Table 2 present the detailed information of the selected authors. Fig. 3 shows that the authors can be divided into six clusters, which represent six categories, such as the research groups of Olugbenga O. Akinade (Akinade et al., 2018), Jiayuan Wang (Wang et al., 2018) and Weisheng Lu (Lu et al., 2015). Fig. 3 also indicates that collaboration and communication in this domain are not well developed given that the six clusters are isolated. However, the research group of Olugbenga O. Akinade, which contains most scholars in this domain, has closely related members as highlighted by the link lines amongst scholars, as visualised in Fig. 3.

Table 2 illustrates the five major quantitative measurements of selected scholars who published more than three articles, including number of articles, total citations in WOS, average publication year, average citations in WOS and average normalised citations. The former three measurements present the research output and influence of the given authors to the research fields. Table 2 shows that Olugbenga O. Akinade and Lukumon O. Oyedele are the most productive scholar amongst selected scholars, with 9 articles and 225 total citations, respectively. Therefore, they are the most influential scholars. The link line indicates a strong connection between two scholars. Other scholars, including Muhammad Bilal, Weisheng Lu, Hakeem A. Owolabi, Xi Chen and Saheed O. Aiayi, have also made significant contributions in this domain. The average publication year of scholars illustrate that most scholars are emerged over the past 4 years. The normalised citation analysis suggests the average publication yearly influence of an author (Jin et al., 2019). Although Sururah A. Bello, Hafiz A. Alaka, Saheed O. Aiayi and Jiayuan Wang have published fewer articles than others, their average normalised citations rank first, second, third and fifth, respectively. Therefore, their yearly influence is higher than those of other scholars.

4.1.2. Analysis of co-occurrence of keywords

Keywords represent the research focus and direction in the current research domain. The minimum keyword frequency was set to 3. From 297 keywords, 54 keywords were selected to meet the requirement. Then, a few general items were removed, such as ‘construction’, ‘construction waste’ and ‘management’. In addition, a few keywords were combined because of their same meaning, such as ‘BIM’ and ‘building information modelling’ and ‘GIS’ and ‘Geographic information system’. After the filtering process, 26 keywords were left, as shown in Fig. 4 and Table 3.

A large node size indicates high occurrence of the items, and a thick connection line indicates a close relationship between two items. Different colours divide nodes into different clusters. Fig. 4 indicates that the most frequent keywords are BIM, generation, reduction, prefabrication, design and China. BIM, generation, reduction and prefabrication are strongly connected to different clusters.

Table 3 summarises the quantitative measurement of identified keywords. For the average citation, BIM, design, reduction and generation have received high attention in this domain. The average year published illustrates that the most related research topics of this discipline were raised in 2016, 2017 and 2018. The average normalised citation indicates that information, BD analytics, prefabrication, BIM, life cycle assessment and landfill have attracted considerable attention in the research on information technologies in C&D waste management.

4.1.3. Analysis of countries’ activeness

In this part, countries’ contribution to the global research

Table 2
Quantitative measurement of scholars.

Scholar	Affiliation	Number of articles	Total citations	Average publication year	Average citation	Ave. norm. citation
Lukumon O. Oyedele	University of the West of England	9	225	2017	25	1.29
Olugbenga O. Akinade	University of the West of England	9	225	2017	25	1.29
Muhammad Bilal	University of the West of England	8	225	2016	25	1.46
Weisheng Lu	The University of Hong Kong	8	186	2016	23	1.05
Hakeem A. Owolabi	University of Northampton	7	208	2016	30	1.23
Xi Chen	The University of Hong Kong	6	112	2016	19	0.78
Saheed O. Ajayi	Leeds Beckett University	6	208	2016	35	1.43
Hafiz A. Alaka	Coventry University	5	169	2016	34	1.46
Sururah A. Bello	Obafemi Awolowo University	4	119	2016	30	1.69
Jiayuan Wang	Shenzhen University	3	40	2017	13	1.36
Jack C.P. Cheng	The Hong Kong University of Science and Technology	3	121	2015	40	0.79
Huabo Duan	Shenzhen University	3	39	2017	13	0.91

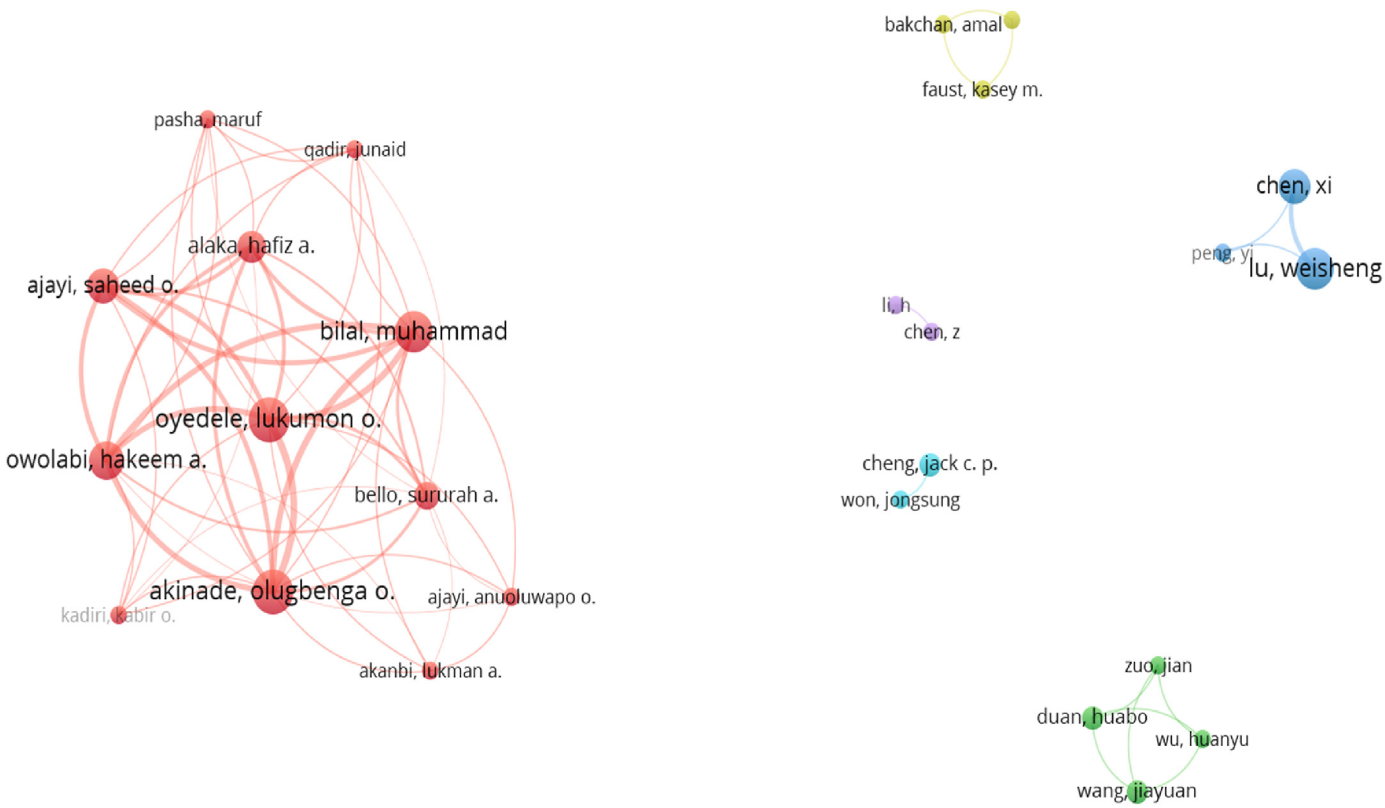

Fig. 3. Diagram of co-authorship analysis of information technology in C&D waste management.

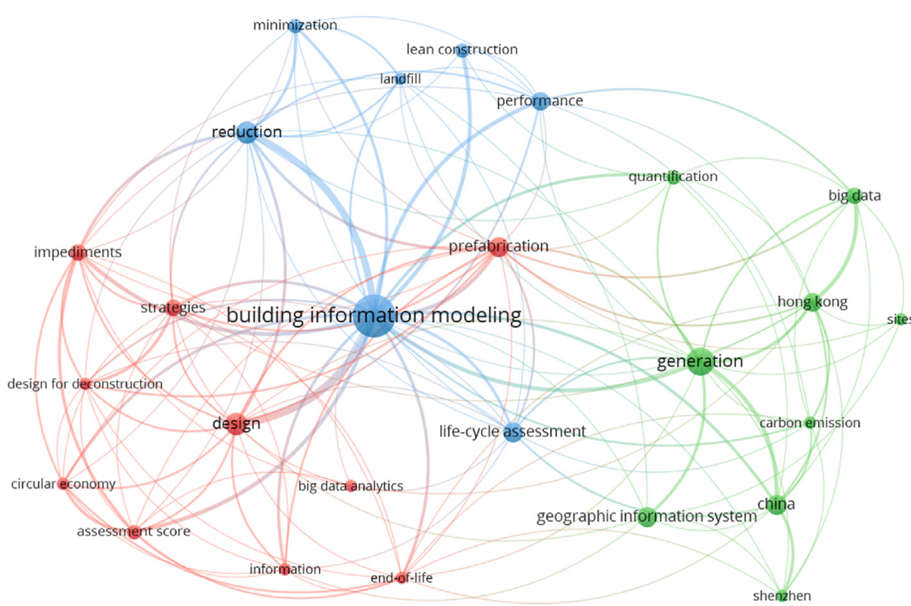

Fig. 4. Diagram of co-occurrence of keyword analysis of information technology in C&D waste management.

community was analysed by VOSviewer. With the minimum publications of a country set at 2, 12 out of 22 countries were listed. Fig. 5 and Table 4 present the detailed information of countries that have been active in the research on information technologies in C&D waste management. Fig. 5 shows that China and England have made significant contributions in this domain compared with other countries. Therefore, information technologies have received great attention in C&D waste management in these countries. The connection line illustrates a strong connection between China and England. Developed and developing countries have paid attention in this domain. Table 4 presents additional information, including number of publications, total citations, average citations and average published year.

Table 4 shows that scholars from China and England rank first in

Table 3
Details of main keywords of information technologies in C&D waste management.

Keywords	Occurrence	Average year Published	Average citation	Ave. norm. citation
Building information modelling (BIM)	24	2017	22	0.96
Generation	12	2017	9	1.01
Design	8	2016	20	0.94
Reduction	8	2017	19	0.91
Prefabrication	7	2016	29	1.42
Life cycle assessment	7	2016	37	1.76
China	7	2018	4	0.72
Geographic information system (GIS)	7	2017	11	0.80
Hong Kong	6	2017	12	1.22
Performance	6	2016	27	1.15
Impediments	5	2018	12	0.74
Strategies	5	2018	16	1.10
Big data (BD)	5	2016	19	0.81
Lean construction	4	2015	31	0.62
Assessment score	4	2018	11	0.96
Minimisation	4	2017	12	0.78
Quantification	4	2017	15	0.58
Circular economy	3	2018	6	1.01
Design for deconstruction	3	2017	26	0.94
Big data analytics	3	2017	28	1.79
End of life	3	2018	9	1.61
Information	3	2016	32	1.90
Carbon emission	3	2018	4	0.71
Shenzhen	3	2018	4	1.10
Sites	3	2014	34	0.76
Landfill	3	2016	26	1.35

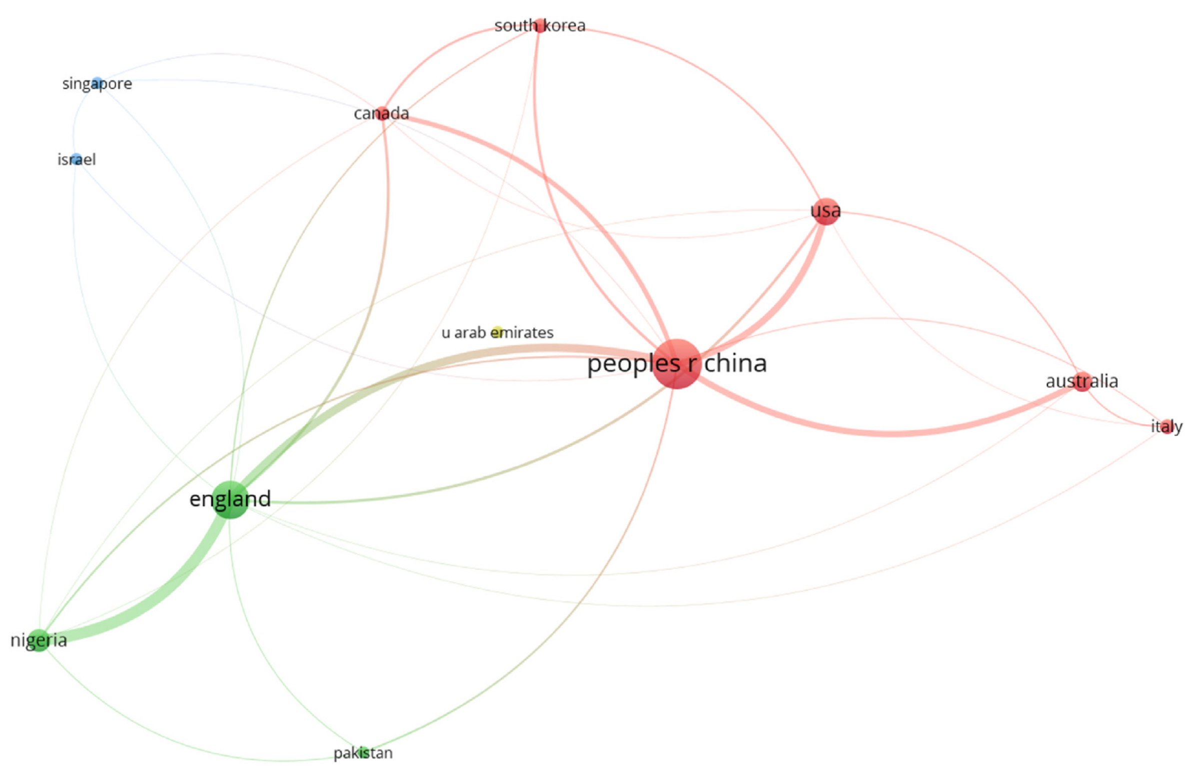

Fig. 5. Diagram of co-occurrence of keywords analysis of information technology in C&D waste management.

terms of the number of publications and total citations, followed by those from the United States, Nigeria and Australia. The rapid urbanisation of China has caused numerous environmental and social problems, particularly a large amount of C&D waste. Researchers are searching for new technologies and methods to solve the problems in C&D waste more effectively and better than before. Developing countries, such as Nigeria, Pakistan and Israel, have been discussed in only two or three articles. However, the average citations of these countries rank first. Developing countries are gradually exerting their influence in this domain. The average normalised citation illustrates that developed countries, such as Australia, Italy and England, have made considerable yearly impact in the research field.

Table 4
Details of countries or regions of information technologies in C&D waste management.

Countries	Number of publications	Number of total citations	Average year Published	Average citation	Ave. Norm. citation
People's Republic of China	22	463	2016	21	0.87
England	14	444	2015	32	1.17
The United States	8	24	2017	3	0.88
Nigeria	6	158	2016	26	1.33
Australia	5	48	2018	10	2.02
Canada	3	26	2017	9	1.00
Italy	3	117	2015	39	2.25
South Korea	3	45	2016	15	0.50
Pakistan	2	82	2016	41	1.34
Israel	2	99	2014	49	0.67
Singapore	2	47	2018	23	0.98
United Arab Emirates	2	4	2018	2	0.36

4.2. Research topics of information technologies in C&D waste management

The review of collected papers shown in Table 1 indicates that issues exist in C&D waste management in terms of the background of information technologies. On the basis of these issues, research topics can be sorted and future research directions with information technologies can be determined. Therefore, six research topics, namely, C&D waste generation, C&D waste reduction, C&D waste transportation, C&D waste recycling, C&D waste disposal and C&D waste management performance and impact, are identified in this study. Fig. 6 shows a framework that illustrates the status quo of research and future research directions.

Estimating C&D waste generation is the primary research topic in this discipline. The significance of waste estimation lies in offering a pre-requisite for managing C&D waste decision plan, including transportation, treatment and disposal plans, which help the government develop C&D waste management strategies.

The second research topic is 'C&D waste reduction'. The literature review reveals four C&D waste management methods, namely, reduction, reuse, recycle and disposal. Amongst these methods, waste reduction has the lowest impacts on the environment and is the most effective method for minimising waste generation. C&D waste reduction positively affects the three other methods (Yuan and Shen, 2011).

'C&D waste transportation' refers to the transportation process of generation sites to recycling or reuse plants and landfills, which is an indispensable link in the C&D waste management. After C&D waste is generated by C&D activities, a large amount of waste must be transported to recycling plants for reuse or transportation to legal landfills.

C&D waste generation is inevitable. The fourth research topic is 'C&D waste recycling'. Recycling and reuse strategies of C&D waste can effectively reduce the impact of C&D waste when waste is generated. From a sustainable perspective, C&D waste can be utilised as construction material after a series of treatment procedures.

The fifth research topic is 'C&D waste disposal'. In general, C&D waste treatment methods are still not enough in current stage, and most of the C&D waste is directly filled in landfills or casually

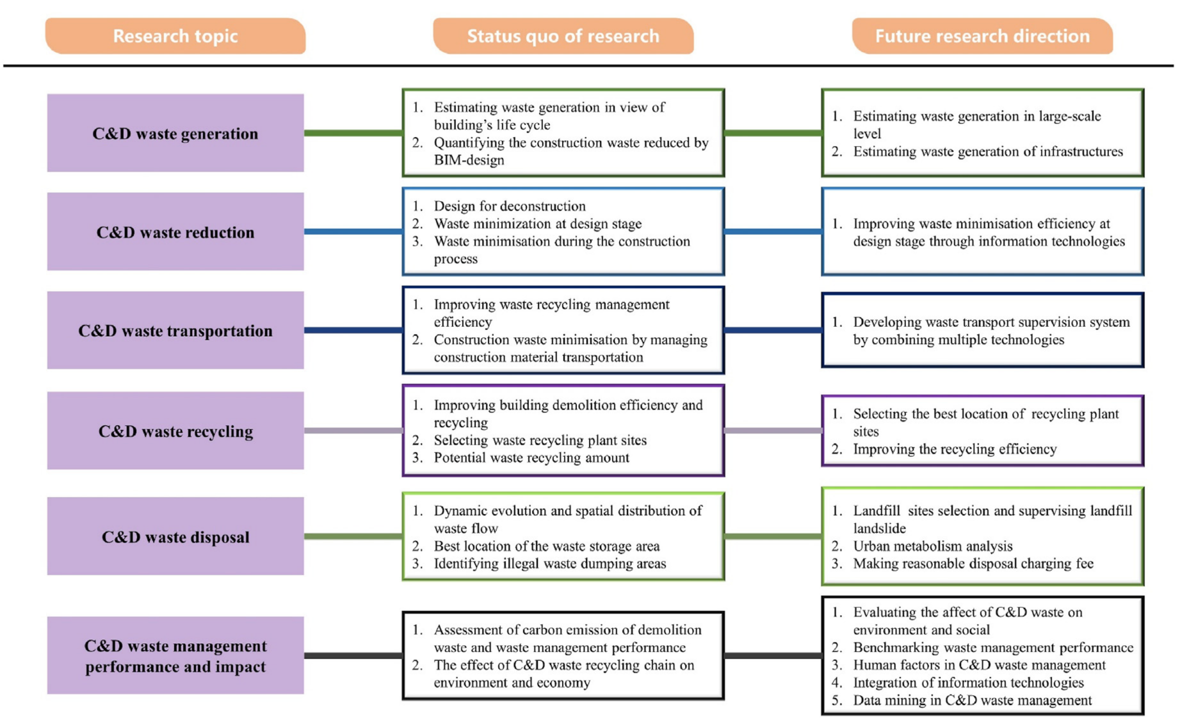

Fig. 6. Framework of status quo of research and future research directions.

placed near construction sites. Therefore, managing C&D waste disposal must be paid sufficient attention.

The last research topic is 'C&D waste management performance and impact', which mainly refers to research for improving waste management performance and assessing environment impacts of C&D waste management using information technologies. In the following part, future research directions are introduced under these research topics.

4.3. Future research directions

After the status quo of research information technologies in C&D waste management is summarised, several future research directions can be further explored through analysing what remains to be conducted and should be paid additional attention. Fig. 6 presents the suggested future research directions.

4.3.1. C&D generation

For the topic of 'C&D waste generation', two major themes should be further explored:

- Estimating C&D waste generation in large-scale levels. BIM-based C&D waste estimation method mainly concerns a single building in a project level instead of areal buildings in a large-scale level. However, in urban renewal projects, demolition waste is generated in a regional level. In such condition, using a BIM model for estimation is impractical. However, a new approach for forecasting waste amount in a large-scale level was introduced by Yu et al. (2019) on the basis of image recognition and GIS technology. In the meantime, analysing large samples enables BD technology to offer precise waste estimation indicators, including waste generation rates. Additional studies should be focused on estimating C&D waste generation in large-scale level in the future.
- Estimating waste generation of infrastructures. Existing studies have often focused on residential and commercial projects because these projects are easier, cheaper to study and has considerably shorter lifespan than public civil projects. However, the environmental effects caused by public civil projects are greater than those by residential and commercial projects (Wu et al., 2014). Information technologies, such as BIM, can significantly improve the efficiency of estimating C&D waste generated from infrastructure because of its automatic computation capability. Therefore, public civil projects should receive additional attention in future studies.

4.3.2. C&D reduction

For the topic of 'C&D waste reduction', subtopics that should be further studied are as follows:

- Improving waste minimisation efficiency at the design stage by using information technologies. Waste minimisation at the design stage can efficiently reduce construction waste and has received considerable attention in this discipline (Wang et al., 2015). However, research on this topic is limited. BIM technology can help designers detect potential design errors, such as building pipeline conflicts. Diverse design plans can be simulated with BIM technology, and optimal design can then be selected. BD technology can provide a data-driven decision-making method for minimising waste by mining potential waste-causing factors, such as construction material and supply chain construction plan, to develop an improved strategy in the early stage. Thus, related articles are further required in the future for promoting the efficiency of waste minimisation at the design stage by using information technologies.

4.3.3. C&D transportation

For the topic of 'C&D waste transportation', the following issues should be addressed in the future:

- Developing waste transport supervision systems by combining multiple technologies. If no effective management method is available for the transportation of waste, then pressure to the traffic condition of the local city will increase, and dust from waste transportation will affect the urban environment. In the meantime, illegal dumping of waste will easily occur when supervision is lacking. However, existing studies have rarely focused on transportation. Therefore, the government can establish a C&D waste transport supervision system by combining RFID, GPS and GIS technology, tracking transport vehicles, and effectively managing C&D waste in real time. Waste treatment contractors can use supervising systems to improve the efficiency of recycling management, such as reducing scheduling plan time and accident processing.

4.3.4. C&D recycling

Two research directions should be noted for the topic of 'C&D waste recycling':

- Selecting the best location of recycling plant sites. The selection of recycling plants sites can play a key role in improving waste recycling efficiency. Locations of the most appropriate C&D waste recycling plants or landfills can be selected through information technology, and material stock of C&D waste in a region can be estimated within a certain period of time. Thus, determining recycling sites with effective and convenient methods is essential.
- Improving recycling efficiency. The literature review indicates that most of the existing BIM related works have focused on construction waste management, and limited studies have focused on demolition waste management. BIM can be used to improve demolition efficiency and identify and measure recyclable materials (Ge et al., 2017). Researchers can use BIM to evaluate the recycling potential of a building after demolition at the design stage. Therefore, information technologies for enhancing recycling efficiency in C&D waste management must be explored.

4.3.5. C&D disposal

In the future, three subtopics should be studied for the topic of 'C&D waste disposal':

- Selecting landfill sites and supervising landfill landslide. GIS and BD technology can help the authority identify illegal waste areas. The best location of landfills can be identified to minimise the negative effects on the environment and the society. Many landfills are under high landslide risk because of the large amount of C&D waste accumulated in the landfill sites and the lack proper management and monitor methods (Wang et al., 2019b). Therefore, information technologies that can handle these aspects should be further explored.

- Urban metabolism analysis. In some developing countries, dynamical C&D waste flow direction due to the development and expansion of the urban area should be addressed. GIS can help decision makers dynamically analyse flow directions of construction waste and provide a decision basis for decision makers in taking certain measures in advance to reduce the adverse impact of C&D waste.
- Proposing reasonable disposal charging fee. BD technology is good at uncovering hidden correlations amongst data and can be used to evaluate suitable disposal charging fee for encouraging different project stakeholders to recycle and reuse C&D waste instead of landfills and promote performance of C&D waste management. Therefore, this direction should be concerned by researchers with advanced technologies and methods in the future.

4.3.6. C&D waste management performance and impact

Five research directions are related to the topic of 'C&D waste management performance and impact':

- Evaluating the effect of C&D waste on the environment and the society. Information technologies can be used to assess the impact of C&D waste on the society, the environment and the economy. In particular, social and environmental impacts are two intangible benefits that cannot be used for quantitative analysis. For example, BIM technology can help measure social, environmental and economic impacts of C&D waste due to its automatic calculation and application programming interface, which is an interface function that allows researchers to implement the functions they want (Jalaei et al., 2019). Notably, information technologies can be applied in C&D waste management in this subtopic.
- Benchmarking waste management performance. Benchmark waste management performance is a major issue but has not been well addressed. This subtopic is also regarded by other researchers as a future research direction (Jin et al., 2019; Wu et al., 2019). However, limited studies have used information technologies as a tool to improve the efficiency of evaluating the effectiveness of C&D waste management (Lu et al., 2015). Therefore, advanced performance assessment method and technologies are worthy of further investigation for benchmarking the performance of waste management.
- Human factors in C&D waste management. Researchers are aware of the importance of human factors to C&D waste management (Yuan and Shen, 2011). The behaviour and attitudes of the participants in C&D waste management greatly impact the performance of C&D waste management. For example, if the treatment contractors can earn revenue through recycling, then the contractors will actively recycle the waste. In addition, the manner by which the government guides contractors to recycle is the key point. For example, BD can analyse behaviours, attitudes, expectations and predictions of stakeholders and participants in construction waste management. It can also explore the impacts of stakeholders on C&D waste management. Therefore, further studies should be conducted in this direction in consideration of information technologies.
- Integration of information technologies. At present, information technologies applied in C&D waste management are in the early stage. A single technology applied in C&D waste management has certain limitation. However, the integration and complementary amongst technologies can overcome these limitations. Combinations of multiple technologies, such as BIM + GIS, BIM + RFID, RFID + GIS and BIM + VR, can enhance the performance of C&D waste management.
- Data mining in C&D waste management. Massive related data are generated during the life cycle of construction, from design to demolition stages. The literature reveals that the in-depth study of these data is still in its infancy, but data mining has been gradually receiving attention from researchers. Therefore, data from construction project practice should be analysed and mined to enhance the efficiency of C&D waste management. Moreover, a comprehensive BD system for data-driven decision making should be developed (Chen and Lu, 2017).

5. Conclusions

Information technologies applied in C&D waste management are still at the early stage. However, trends of information technologies applied in C&D waste management is growing rapidly. These technologies can greatly promote C&D waste management because they are more convenient, precise and efficient than the traditional tools. Mature application of advanced technologies to C&D waste management and practices in the construction industry requires a long time. Existing information technologies are classified and discussed through comprehensive literature review of 57 collected papers. On the basis of the collected papers, co-authors, co-occurrence keywords and countries' activeness are analysed using texting mining tool VOSviewer. Moreover, the status quo of research is identified and future research directions are further suggested.

The information obtained in this study is valuable to researchers and practitioners. It can help researchers understand the current application situation of information technologies in C&D waste management. Practitioners can benefit from understanding the characteristics of technologies. The scope of the search is limited due to physical conditions. Some related papers may have been overlooked. However, the collected papers can still reflect the application of information technologies in C&D waste management.

Declaration of competing interest

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

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References

Ajayi, S.O., Oyedele, L.O., Bilal, M., Akinade, O.O., Alaka, H.A., Owolabi, H.A., Kadiri, K.O., 2015. Waste effectiveness of the construction industry: understanding the impediments and requisites for improvements. Resour. Conserv. Recycl. 102, 101–112.

Akanbi, L.A., Oyedele, L.O., Akinade, O.O., Ajayi, A.O., Davila Delgado, M., Bilal, M., Bello, S.A., 2018. Salvaging building materials in a circular economy: a BIM-based whole-life performance estimator. Resour. Conserv. Recycl 129, 175–186.

Akanbi, L.A., Oyedele, L.O., Omoteso, K., Bilal, M., Akinade, O.O., Ajayi, A.O., Davila Delgado, J.M., Owolabi, H.A., 2019a. Disassembly and deconstruction analytics

system (D-DAS) for construction in a circular economy. J. Clean. Prod. 223, 386–396.
Akanbi, L.A., Oyedele, L.O., Omoteso, K., Bilal, M., Akinade, O.O., Ajayi, A.O., Delgado, J.M.D., Owolabi, H.A., 2019b. Disassembly and deconstruction analytics system (D-DAS) for construction in a circular economy. J. Clean. Prod. 223, 386–396.
Akinade, O.O., Oyedele, L.O., 2019. Integrating construction supply chains within a circular economy: an ANFIS-based waste analytics system (A-WAS). J. Clean. Prod. 229, 863–873.
Akinade, O.O., Oyedele, L.O., Bilal, M., Ajayi, S.O., Owolabi, H.A., Alaka, H.A., Bello, S.A., 2015. Waste minimisation through deconstruction: a BIM based deconstructability assessment score (BIM-DAS). Resour. Conserv. Recycl 105, 167–176.
Akinade, O.O., Oyedele, L.O., Ajayi, S.O., Bilal, M., Alaka, H.A., Owolabi, H.A., Bello, S.A., Jaiyeoba, B.E., Kadiri, K.O., 2017a. Design for Deconstruction (DfD): critical success factors for diverting end-of-life waste from landfills. Waste Manag. 60, 3–13.
Akinade, O.O., Oyedele, L.O., Omoteso, K., Ajayi, S.O., Bilal, M., Owolabi, H.A., Alaka, H.A., Ayris, L., Henry Looney, J., 2017b. BIM-based deconstruction tool: towards essential functionalities. Int. J. Sustain. Built Environ 6, 260–271.
Akinade, O.O., Oyedele, L.O., Ajayi, S.O., Bilal, M., Alaka, H.A., Owolabi, H.A., Arawomo, O.O., 2018. Designing out construction waste using BIM technology: stakeholders' expectations for industry deployment. J. Clean. Prod. 180, 375–385.
Alwan, Z., Jones, P., Holgate, P., 2017. Strategic sustainable development in the UK construction industry, through the framework for strategic sustainable development, using Building Information Modelling. J. Clean. Prod. 140, 349–358.
AlZaghrini, N., Srour, F.J., Srour, I., 2019. Using GIS and optimization to manage construction and demolition waste: the case of abandoned quarries in Lebanon. Waste manage 95, 139–149.
Bakchan, A., Faust, K.M., Leite, F., 2019. Seven-dimensional automated construction waste quantification and management framework: integration with project and site planning. Resour. Conserv. Recycl. 146, 462–474.
Bilal, M., Oyedele, L.O., Akinade, O.O., Ajayi, S.O., Alaka, H.A., Owolabi, H.A., Qadir, J., Pasha, M., Bello, S.A., 2016a. Big data architecture for construction waste analytics (CWA): a conceptual framework. J. Build. Eng 6, 144–156.
Bilal, M., Oyedele, L.O., Qadir, J., Munir, K., Ajayi, S.O., Akinade, O.O., Owolabi, H.A., Alaka, H.A., Pasha, M., 2016b. Big Data in the construction industry: a review of present status, opportunities, and future trends. Adv. Eng. Inform 30, 500–521.
Blengini, G.A., Garbarino, E., 2010. Resources and waste management in Turin (Italy): the role of recycled aggregates in the sustainable supply mix. J. Clean. Prod. 18, 1021–1030.
Che, Y., Yang, K., Jin, Y., Zhang, W., Shang, Z., Tai, J., 2013. Residents' concerns and attitudes toward a municipal solid waste landfill: integrating a questionnaire survey and GIS techniques. Environ. Monit. Assess. 185, 10001–10013.
Chen, X., Lu, W., 2017. Identifying factors influencing demolition waste generation in Hong Kong. J. Clean. Prod. 141, 799–811.
Chen, X., Lu, W., Xue, F., Xu, J., 2018. A cost-benefit analysis of green buildings with respect to construction waste minimization using big data in Hong Kong. J. Green build, 13, 61–76.
Cheng, J.C., Ma, L.Y., 2013. A BIM-based system for demolition and renovation waste estimation and planning. Waste Manag. 33, 1539–1551.
Colvero, D.A., Gomes, A.P.D., Tarelho, L., Matos, M.A.A., Santos, K.A.D., 2018. Use of a geographic information system to find areas for locating of municipal solid waste management facilities. Waste Manag. 77, 500–515.
Di Maria, F., Bianconi, F., Micale, C., Baglioni, S., Marionni, M., 2016. Quality assessment for recycling aggregates from construction and demolition waste: an image-based approach for particle size estimation. Waste Manag. 48, 344–352.
Ding, Z., Zhu, M., Wu, Z., Fu, Y., Liu, X., 2018. Combining AHP-entropy approach with GIS for construction waste landfill selection-A case study of shenzhen. Int. J. Environ. Res. Publ. Health 15, 1–21.
Duan, H., Li, J., 2016. Construction and demolition waste management: China's lessons. Waste Manag. Res. 34 (5), 397–398. https://doi.org/10.1177/0734242X16647603.
Dumbill, E., Mayer-Schonberger, V., Cukier, K., 2013. A revolution that will transform how we live, work, and think: interview an interview with the authors of big data. Big Data 1, 73–77. https://doi.org/10.1089/big.2013.0016.
EPA, 2014. What is GIS (geography information systems)? Available at. http://www.epa.gov/region5fields/htm/methods/gis.
Ge, X.J., Livesey, P., Wang, J., Huang, S., He, X., Zhang, C., 2017. Deconstruction waste management through 3d reconstruction and bim: a case study. Vis. Eng 5, 1–13.
Gorsevski, P.V., Donevska, K.R., Mitrovski, C.D., Frizado, J.P., 2012. Integrating multi-criteria evaluation techniques with geographic information systems for landfill site selection: a case study using ordered weighted average. Waste Manag. 32, 287–296.
Göswein, V., Gonçalves, A.B., Silvestre, J.D., Freire, F., Habert, G., Kurda, R., 2018. Transportation matters – does it? GIS-based comparative environmental assessment of concrete mixes with cement, fly ash, natural and recycled aggregates. Resour. Conserv. Recycl. 137, 1–10.
Guerra, B.C., Bakchan, A., Leite, F., Faust, K.M., 2019. BIM-based automated construction waste estimation algorithms: the case of concrete and drywall waste streams. Waste Manag. 87, 825–832.
Heigermoser, D., de Soto, B.G., Abbott, E.L.S., Chua, D.K.H., 2019. BIM-based Last Planner System tool for improving construction project management. Autom. ConStruct. 104, 246–254.
Jae-Woo, P., Gi-Wook, C., Won-Hwa, H., Hyun-Cheol, S., 2014. A study on the establishment of demolition waste DBSystem by BIM-based building materials. Appl. Mech. Mater. 522–524, 806–810.
Jalaei, F., Zoghi, M., Khoshand, A., 2019. Life cycle environmental impact assessment to manage and optimize construction waste using Building Information Modelling (BIM). Int. J. Constr. Manag. Published online. https://doi.org/10.1080/15623599.2019.1583850.
Jin, R., Yuan, H., Chen, Q., 2019. Science mapping approach to assisting the review of construction and demolition waste management research published between 2009 and 2018. Resour. Conserv. Recycl. 140, 175–188.
Kim, Y.C., Hong, W.H., Park, J.W., Cha, G.W., 2017. An estimation framework for building information modelling (BIM)-based demolition waste by type. Waste Manag. Res. 35, 1285–1295.
Kleemann, F., Lehner, H., Szczypińska, A., Lederer, J., Fellner, J., 2017. Using change detection data to assess amount and composition of demolition waste from buildings in Vienna. Resour. Conserv. Recycl. 123, 37–46.
Li, N., Becerik-Gerber, B., 2011. Life-cycle approach for implementing RFID technology in construction: learning from academic and industry use cases. J. Construct. Eng. Manag. 137, 1089–1098.
Li, H., Chen, Z., Wong, C.T.C., 2003. Barcode technology for an incentive reward program to reduce construction wastes. Comput-aided civ. Inf 18, 313–324.
Li, H., Chen, Z., Yong, L., Kong, S.C.W., 2005. Application of integrated GPS and GIS technology for reducing construction waste and improving construction efficiency. Autom. ConStruct. 14, 323–331.
Li, Z., Shen, G.Q., Alshawi, M., 2014. Measuring the impact of prefabrication on construction waste reduction: an empirical study in China. Resour. Conserv. Recycl. 91, 27–39.
Li, C.Z., Zhong, R.Y., Xue, F., Xu, G., Chen, K., Huang, G.G., Shen, G.Q., 2017. Integrating RFID and BIM technologies for mitigating risks and improving schedule performance of prefabricated house construction. J. Clean. Prod. 165, 1048–1062.
Lin, Y.C., Cheung, W.F., Siao, F.C., 2014. Developing mobile 2D barcode/RFID-based maintenance management system. Autom. Constr.37 110–121.
Liu, Z., Osmani, M., Demian, P., Baldwin, A., 2015. A BIM-aided construction waste minimisation framework. Autom. Constr 59, 1–23.
Liu, H., Sydora, C., Altaf, M.S., Han, S., Al-Hussein, M., 2019. Towards sustainable construction: BIM-enabled design and planning of roof sheathing installation for prefabricated buildings. J. Clean. Prod. 235, 1189–1201.
Lu, W., 2019. Big data analytics to identify illegal construction waste dumping: a Hong Kong study. Resour. Conserv. Recycl 141, 264–272.
Lu, W., Huang, G.Q., Li, H., 2011. Scenarios for applying RFID technology in construction project management. Autom. Constr.20 101–106.
Lu, W., Chen, X., Peng, Y., Shen, L., 2015. Benchmarking construction waste management performance using big data. Resour. Conserv. Recycl. 105, 49–58.
Lu, W., Chen, X., Ho, D.C.W., Wang, H., 2016. Analysis of the construction waste management performance in Hong Kong: the public and private sectors compared using big data. J. Clean. Prod. 112, 521–531.
Lu, W., Webster, C., Chen, K., Zhang, X., Chen, X., 2017a. Computational Building Information Modelling for construction waste management: moving from rhetoric to reality. Renew. Sustain. Energy Rev. 68, 587–595.
Lu, Y., Wu, Z., Chang, R., Li, Y., 2017b. Building Information Modelling (BIM) for green buildings: a critical review and future directions. Autom. Constr.83 134–148.
Lu, W., Chen, X., Peng, Y., Liu, X., 2018. The effects of green building on construction waste minimization: triangulating 'big data' with 'thick data'. Waste Manag. 79, 142–152.
Madi, N., Srour, I., 2019. Managing emergency construction and demolition waste in Syria using GIS. Resour. Conserv. Recycl. 141, 163–175.
Miatto, A., Schandl, H., Forlin, L., Ronzani, F., Borin, P., Giordano, A., Tanikawa, H., 2019. A spatial analysis of material stock accumulation and demolition waste potential of buildings: a case study of Padua. Resour. Conserv. Recycl 142, 245–256.
NBSC, 2014. Available at: http://data.stats.gov.cn/workspace/index Jsessionid=72F31C505EE5881D26929410F8BB362F?m=hgnd.
Ooshaksaraie, L., Mardookhpour, A., 2011. A rule-based expert system for construction and demolition waste management. Am. J. Environ. Sci. 7, 492–498.
Paz, D., Lafayette, K.P.V., Sobral, M.D.C., 2018. GIS-based planning system for managing the flow of construction and demolition waste in Brazil. Waste Manag. Res. 36, 541–549.
Peng, C.-L., Scorpio, D.E., Kibert, C.J., 1997. Strategies for successful construction and demolition waste recycling operations. Construct. Manag. Econ. 15 (1), 49–58.
Porwal, A., Hewage, K.N., 2012. Building information modelling–based analysis to minimize waste rate of structural reinforcement. J. Construct. Eng. Manag. 138, 943–954.
Poulikakos, L.D., Papadaskalopoulou, C., Hofko, B., Gschösser, F., Falchetto, A.C., Bueno, M., Arraigada, M., Sousa, J., Ruiz, R., Petit, C., Loizidou, M., Partl, M.N., 2017. Harvesting the unexplored potential of European waste materials for road construction. Resour. Conserv. Recycl. 116, 32–44.
Pratt, M.J., 2004. Extension of ISO 10303, the STEP standard, for the exchange of procedural shape models, Shape Modelling International. https://doi.org/10.1109/SMI.2004.1314519.
Robinson, G.R., Kapo, K.E., 2004. A GIS analysis of suitability for construction aggregate recycling sites using regional transportation network and population density features. Resour. Conserv. Recycl 42, 351–365.
Sacks, R., Radosavljevic, M., Barak, R., 2010. Requirements for building information modelling based lean production management systems for construction.

Autom. Constr.19 641–655.
Sagiroglu, S., Sinanc, D., 2013. Big data: a review. 2013 international conference on collaboration technologies and systems. https://doi.org/10.1109/CTS.2013.6567202.
Seror, N., Portnov, B.A., 2018. Identifying areas under potential risk of illegal construction and demolition waste dumping using GIS tools. Waste Manag. 75, 22–29.
Tanikawa, H., Hashimoto, S., 2009. Urban stock over time: spatial material stock analysis using 4d-GIS. Build. Res. Inf. 37, 483–502.
Tzeng, C.T., Chiang, Y.C., Chiang, C.M., Lai, C.M., 2008. Combination of radio frequency identification (RFID) and field verification tests of interior decorating materials. Autom. Constr.18 16–23.
Wang, J., Li, Z., Tam, V.W.Y., 2015. Identifying best design strategies for construction waste minimization. J. Clean. Prod. 92, 237–247.
Wang, J., Wu, H., Duan, H., Zillante, G., Zuo, J., Yuan, H., 2018. Combining life cycle assessment and Building Information Modelling to account for carbon emission of building demolition waste: a case study. J. Clean. Prod. 172, 3154–3166.
Wang, H., Chen, D., Duan, H., Yin, F., Niu, Y., 2019a. Characterizing urban building metabolism with a 4D-GIS model: a case study in China. J. Clean. Prod. 228, 1446–1454.
Wang, H., Zhang, J., Lin, H., 2019b. Satellite-based analysis of landfill landslide: the case of the 2015 Shenzhen landslide. Int. J. Geotech. Earthq. Eng. Published online. https://doi.org/10.1080/19386362.2019.1610605.
Won, J., Cheng, J.C.P., 2017. Identifying potential opportunities of building information modelling for construction and demolition waste management and minimization. Autom. Constr.79 3–18.
Won, J., Cheng, J.C.P., Lee, G., 2016. Quantification of construction waste prevented by BIM-based design validation: case studies in South Korea. Waste Manag. 49, 170–180.
Wu, Z., Yu, A.T., Shen, L., Liu, G., 2014. Quantifying construction and demolition waste: an analytical review. Waste Manag. 34, 1683–1692.
Wu, H., Wang, J., Duan, H., Ouyang, L., Huang, W., Zuo, J., 2016. An innovative approach to managing demolition waste via GIS (geographic information system): a case study in Shenzhen city, China. J. Clean. Prod. 112, 494–503.
Wu, H., Zuo, J., Zillante, G., Wang, J., Yuan, H., 2019. Status quo and future directions of construction and demolition waste research: a critical review. J. Clean. Prod. 240, 1–13. https://doi.org/10.1016/j.jclepro.2019.118163.
Xu, J., Shi, Y., Xie, Y., Zhao, S., 2019. A BIM-Based construction and demolition waste information management system for greenhouse gas quantification and reduction. J. Clean. Prod. 229, 308–324.
Yu, B., Wang, J., Li, J., Zhang, J., Lai, Y., Xu, X., 2019. Prediction of large-scale demolition waste generation during urban renewal: a hybrid trilogy method. Waste Manag. 89, 1–9.
Yuan, H., Shen, L., 2011. Trend of the research on construction and demolition waste management. Waste Manag. 31, 670–679.
Zainun, N.Y., Othman, W., 2015. Quantification and mapping of construction waste generation in parit Raja. Appl. Mech. Mater. 773–774, 1032–1036.
Zhang, L., Atkins, A.S., 2015. A decision support application in tracking construction waste using rule-based reasoning and RFID technology. Int. J. Comput. Intell. Syst 8, 128–137.
Zhang, X., Azhar, S., Nadeem, A., Khalfan, M., 2017. Using Building Information Modelling to achieve Lean principles by improving efficiency of work teams. Int. J. Constr. Manag 18, 293–300.