Mini-Review Article

WM&R

Waste Management & Research
1–13

DOI: 10.1177/0734242X211029446
journals.sagepub.com/home/wmr
SAGE

Construction and demolition waste management in Australia: A mini-review

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Abstract

Construction and demolition activities generate huge quantities of waste with substantial impacts on environment. This mini-review article covers the literatures relating to construction and demolition waste management practice in Australia. The Scopus search engine was used in literature search and 26 journal articles relating to construction and demolition waste management in Australia were targeted for analysis. Additionally, various government acts, regulations, policies, and strategy documents were collected and analyzed. This review indicated that the inconsistencies in legislation and landfill levies across states and territories contributed to the cross-jurisdiction waste movement. Given the stakeholders' attitude and project life cycle, this review reported that the design phase had the greatest potential to minimize waste and that the role of designers had been highlighted in various empirical studies. This review provides practitioners and academics with an understanding of the current construction and demolition waste management research in Australia and recommends directions for future research.

Keywords

Australia, construction, demolition, waste management, review

Received 28th January 2021, accepted 14th June 2021 by Associate Editor Rodrigo Navia.

Introduction

Construction and demolition (C&D) activities generate huge quantities of waste, which has substantial impacts on environment, such as sedimentation, soil erosion, and increasing greenhouse gas emissions (Begum et al., 2007; Esa et al., 2017b). By definition, demolition waste is the waste arising from razed structures, while construction waste is the waste from construction, renovation, and repairing of individual premises, commercial buildings, and other types of buildings (Tchobanoglous et al., 1977). In Australia, according to the Department of the Environment and Energy (DEE), C&D waste is defined as the waste produced by building and demolition activities, including road and rail construction and maintenance and excavation of land associated with construction activities (Pickin et al., 2018). The most common C&D waste material profiles include masonry, rock, sand, timber, metals, soil, asphalt, asbestos, plastics, plasterboard, and cardboard (Hyder Consulting, 2011).

A considerable amount of C&D waste is generated around the world every year, evidenced by the disclosed C&D waste statistics of various countries or regions. For example, China was estimated to generate approximately 2300 million tonnes (Mt) of C&D waste in 2019 and became the largest C&D waste producer in the world (Forward, 2020); the USA generated around 600 Mt of C&D waste in 2018 (US Environmental Protection Agency, 2019); the European Union (EU) produced 834 Mt of C&D waste, representing 36% of the total waste in 2018 (Eurostat, 2020); Brazil was estimated to produce 100 Mt of C&D waste in 2016 (Rosado et al., 2019); and Australia generated 20.4 Mt of C&D waste in 2016–17, representing approximately 30.5% of the total waste (Pickin et al., 2018) and indicating an increase by 20% in the past decade.

Effective C&D waste management (WM) has been promoted to reduce or minimize C&D waste generation. Through proper treatment, C&D waste could be reused and recycled and bring economic, environmental, and social benefits (Hwang and Yeo, 2011; McDonald and Smithers, 1998; Wu et al., 2017a). El-Haggar (2007) proposed a WM hierarchy consisting of five steps: reduce, reuse, recycle, recover, and disposal. Similarly, Australia's DEE (2018) proposed a WM hierarchy in the National Waste Policy consisting of seven steps: avoid waste, reduce waste, reuse waste, recycle waste, recover, treat waste, and dispose waste. Both WM hierarchies have incorporated the 3R principle (i.e. reduce, reuse, and recycle). In addition, the concept of circular economy, which eliminates C&D waste by preserving the added value in materials as long as recycling the waste for new products (Mahpour, 2018; Singh and Ordoñez, 2016), has

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been integrated into C&D WM policies in Australia (Pickin et al., 2018).

Approximately 90% of C&W waste is believed to be recyclable (Hyvärinen et al., 2020). Australia nationally recycled 67% of the C&D waste in 2017 (Pickin et al., 2018), while some states have performed better. In the financial year of 2018–19, the states of South Australia and Victoria achieved a C&D waste diversion rate of 91.4% (Green Industries SA, 2020) and 87% (Sustainability Victoria, 2020), respectively. The diversion rate includes both waste recycling and energy recovery. These statistics are comparable to those of EU member countries, such as the Netherlands, Germany, and Denmark, whose C&D waste recycling rates were at 80–90% (Menegaki and Damigos, 2018). Additionally, Australia's recycling rate was significantly higher than those in developing countries, such as 5–10% in China (Ding et al., 2016; Zhang and Tan, 2020) and 1% in India (Saju, 2020). Therefore, previous studies have reported the Australian C&D WM practice (Park and Tucker, 2017; Stephan and Athanassiadis, 2018; Wu et al., 2020), which could be helpful for the countries that are trying to enhance their WM performance.

This study aims to undertake a review of the literatures relating to C&D WM practice in Australia. The current C&D waste statistics are reviewed, and the legislative framework, cross-jurisdiction waste movement, stakeholders' attitude, and behavior, and WM in different phases of a project life cycle are discussed in this study. This review can provide an in-depth understanding of C&D WM practice in Australia and benefit WM planning in other countries.

Previous reviews

Literature review is a more or less systematic method to collect and synthesize previous literatures (Baumeister and Leary, 1997; Snyder, 2019). A literature review sets up a solid foundation for driving theory development and advancing knowledge (Webster and Watson, 2002) and helps to gain an in-depth understanding of a specific research field (Jin et al., 2019a; Zhao et al., 2020). In the C&D WM field, there have been either global or regional reviews.

Global reviews tend to take a holistic view of all the publications in a period and depend on scientometric or bibliometric analysis techniques to summarize research themes and propose future research directions. For example, Wu et al. (2019) used the bibliometric method to review the journal articles relating to C&D WM published in 1994–2017 and detected five research clusters, including recyclability of C&D waste, environmental issues of C&D waste, performance and behavior tests of recycled materials, C&D WM practices, and C&D waste with industrial ecology; and Jin et al. (2019a) undertook a scientometric analysis of the journal articles published in 2009–2018 and discussed the hot research themes, research gaps, and future research directions.

Regional reviews provide insights into one or more aspects of C&D WM in one or more countries or regions. For example, Esa et al. (2017a) undertook a systematic review to investigate how circular economy could be adopted as strategies to minimize C&D waste in Malaysia; Aslam et al. (2020) reviewed C&D WM in the USA and Mainland China and discussed the regulatory environment, marker mode of C&D waste recycling, challenges and contribution made by C&D WM to circular economy in these two countries; Faruqi and Siddiqui (2020) reviewed the existing legislation and challenges of C&D WM in India and proposed a framework for C&D WM, including collecting, storing, transporting, and treating waste; Daoud et al. (2020) performed a literature review to investigate the key challenges faced by C&D WM in Egypt and recommend strategies for improvement; and Shooshtarian et al. (2020b) undertook a review of the documents relating to C&D WM in eight states or territories of Australia, including the definition of waste versus resource, waste recycling and recovery targets, illegal dumping and stockpiling, extended producer responsibility, and use of C&D recycled materials and energy from waste extraction.

Compared with global reviews, regional reviews can provide relatively in-depth discussions in pre-defined aspects and draw implications that are suitable for certain regions. This study is a regional review covering the regulatory environment, stakeholders, and factors influencing C&D WM in Australia.

Methodology

This study undertakes a systematic review of the previous publications relevant to C&D WM. A systematic literature review can be seen as a research method to synthesize all relevant research findings, which fit the pre-defined inclusion criteria to address a particular research question (Snyder, 2019).

The Scopus search engine was applied to search relevant articles. Scopus was selected because Scopus is accurate in performance (Darko et al., 2017) and has a wider coverage of journals and publications than other databases, such as Web of Science (Chadegani et al., 2013). Scopus has been widely used in review articles in the construction management area (Jin et al., 2019a, 2019b). Additionally, only journal articles or reviews were selected for analysis in this study. This is because journal publications are recognized as representative of the most influential and reputable research outputs and most systematic literature reviews used only journal publications (Darko et al., 2019; Zhao et al., 2019). Figure 1 shows the literature review methodology.

The terms "construction," "demolition," "building," "waste," and "C&D" represented C&D waste in the retrieval code. The terms "management," "recycling," "reduction," and "minimizing" denoted WM practice in the retrieval code. The term "Australia," "Australian" and the names of eight states or territories were also included to capture the literatures in the Australian context in the retrieval code. The initial search process started from inputting the following retrieval code in the advanced search engine:

TITLE (construction OR demolition OR building OR C&D AND waste) AND TITLE-ABS-KEY (manag* OR reduc* OR recycl* OR minimi*) AND TITLE-ABS-KEY (Australia OR Australian

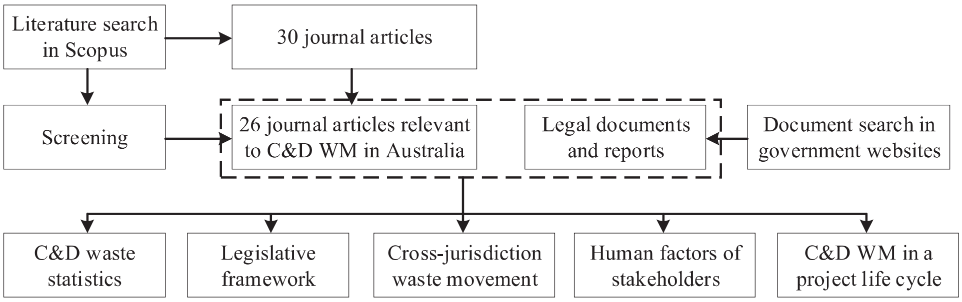

Figure 1. Literature review methodology.

OR Queensland OR "New South Wales" OR "Australian Capital Territory" OR Victoria OR Tasmania OR "South Australia" OR "Western Australia" OR "Northern Territory") AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "re"))

The character "*" enables a fuzzy search to identify variations of a term. The initial search generated a preliminary list of 30 literatures, which were sorted by relevance in Scopus. In the screening, the titles, abstracts, and keywords of them were carefully checked. Finally, 26 journal articles were used for analysis. The earliest one was published in 1998 while the most recent one was published in 2021.

In addition, because C&D WM is closely related to legislation and government policies in Australia, the government reports, acts, regulations, and strategy documents, which were published in government websites, were also reviewed to analyze the legislative framework of C&D WM in Australia.

Findings and discussions

This section covers the discussions on five interrelated topics, including C&D waste statistics, legislative framework, cross-jurisdiction waste movement, human factors related to stakeholders, and C&D WM in a project life cycle. C&D waste statistics show the current state of C&D WM practices, which justify the need for establishing a legislative framework for WM. The legal pressure and financial incentives drive the adoption of WM in the construction industry. However, different states and territories have independent legislative systems in Australia, leading to inconsistencies in policies among different states and territories. This further results in cross-jurisdiction waste movement for reprocessing or recycling in Australia. To meet the compliance requirements set by the state and territory governments, stakeholders (e.g. clients, designers, contractors, subcontractors, and waste recycling companies) need to shift their employees' attitude and awareness and enhance their knowledge relating to WM through training. This will finally bring about effective WM behavior of these stakeholders in different phases across a project life cycle.

C&D waste statistics in Australia

Australia, officially the Commonwealth of Australia, is the largest country in Oceania and the sixth largest country in the world, with a population of 25.7 million. Australia consists of six states: New South Wales (NSW), Victoria, Queensland, Western Australia (WA), South Australia (SA), and Tasmania, and two territories: the Australian Capital Territory (ACT) and the Northern Territory (NT).

According to the National Waste Report 2018 (Pickin et al., 2018), Australia generated 20.4 Mt of C&D waste (0.84 t per capita) in the financial year of 2016–17, representing approximately 30.5% of the total waste generation. This indicated a 20% increase in the total amount of C&D waste generation and a 2% increase in the amount per capita, compared with 2006–07. In addition, Australia has promoted recycling and recovery of C&D waste and recycled 13.6 Mt of C&D waste in 2016–17, representing a recycling rate of 67%. C&D materials represented the largest source (43%) of the recycled materials. In the 11-year period of 2006–17, C&D waste recycling increased by 3.4 Mt or 34%, namely 13% per capita. As for waste disposal, 6.71 Mt C&D waste was landfilled in 2016–17, and 2.32 Mt, 1.97 Mt, and 1.55 Mt were disposed in Queensland, NSW, and Victoria, respectively. These figures also included cross-jurisdiction waste disposal. The amount of C&D waste disposal per capita has declined by 15% in the 11-year period of 2006–17 to 0.27 t, while the total amount has remained stable in 2006–17. The C&D waste used for energy recovery accounted for a small proportion, only 0.046 Mt.

In addition, the Australian Bureau of Statistics (ABS, 2020) publishes annual waste statistics per industry, which covers construction waste generation but excludes demolition waste. In the financial year of 2018–19, Australia generated 12.75 Mt of construction waste, including 8 Mt of masonry materials (e.g. bricks, concrete, and asphalt), 0.95 Mt of metal (e.g. steel and aluminum), 1.23 Mt of organic waste (e.g. garden organics and timber), and 1.7 Mt of hazardous waste, and spent around AUD 2 billion on collection, treatment, and disposal of construction waste, which was the highest in all the industries. The waste intensity of construction waste was 87 t, suggesting that 87 t of construction waste was generated per million Australian dollars of value added to the economy (ABS, 2020). Using the data from ABS, Tam and Lu (2016) found that Australia generated 28.48–44.04 t of C&D waste as construction Gross Domestic Product increased by USD 1 million.

Despite some inconsistencies in waste data among different jurisdictions, these statistics provide an understanding of the Australian C&D waste generation and recycling, encourage public environmental awareness, and support the policy-making of governments. Ratnasabapathy et al. (2020) suggested that C&D waste data reporting should be made mandatory, starting from the project level, to assure the reliability and consistency of the national waste data.

In developing countries, governments may not prioritize publishing sufficient and accurate C&D waste statistics (Kabirifar et al., 2020). Experts or researchers may be engaged to estimate and predict the waste statistics, which may not be freely accessible to the public. Yuan (2017) found that the government of Shenzhen, China did not attempt to collect real-time fundamental C&D waste data but invited researchers to estimate waste generation based on the surveys with limited sample projects, while some studies (Masudi et al., 2012; Mercader-Moyano et al., 2013) attempted to quantify C&D waste generation across project phases and develop databases for low-waste design.

Legislative framework

In Australia, the federal government does not directly legislate C&D WM because this falls within the responsibility of state and territory governments. However, Australia's DEE (2018) published a National Waste Policy, which adopts the concept of circular economy and provides a framework for continuing collaboration between governments, businesses, industry, communities, and individuals until 2030. In states and territories, governments enforce acts and regulations, make policies and specifications, and develop WM strategies that are suitable for their specific conditions. These constitute the legislative framework for C&D WM in Australia (Hyder Consulting, 2011). It is worth noting that the state and territory acts, regulations and policies usually target all categories of waste, including C&D waste.

Acts, regulations, and policies. Table 1 shows the acts, regulations, and policies relevant to C&D WM in each state and territory. For example, in NSW, the Protection of the Environment Operations (POEO) Act 1997 has an objective to promote the reduction in the use of materials and the reuse, recovery or recycling of materials, thus providing a legislative framework for promoting C&D waste recycling infrastructure and business while the Waste Avoidance and Resource Recovery (WARR) Act 2001 includes objectives to encourage the efficient use of resources, minimize the final disposal of waste through avoiding, reusing, and recycling waste and ensure the industry shares with the community the responsibility for reducing and handling waste. The NSW Environment Protection Authority (EPA) has enacted a series of regulations under the POEO Act 1997, including POEP (Waste) Regulation 2014 that covers the detailed calculation of contributions by occupiers of scheduled waste facilities, measurement of waste and monitoring, tracking of waste transported within, out of and into NSW, classification of waste with immobilized contaminants, etc. This regulation is supported by the Waste Levy Guidelines that specify how to calculate waste levy liability, the deductions claimable by waste operators, and the requirements for records, surveys, and reports (EPA NSW, 2020). These levy guidelines also apply to C&D waste. In addition, the NSW Government Sustainability Policy 2008 requires all NSW government agencies and public trading companies to develop and implement formal plans to reduce waste, including C&D waste, and purchase materials with recycled content if they are cost and performance competitive. Then, the NSW EPA (2010) issued Specification for Supply of Recycled Material for Pavements, Earthworks, and Drainage, which provides detailed requirements for recycled materials and encourages the use of quality-assured recycled materials in both private and public engineering projects, while NSW Road & Maritime Services (RMS, 2016) published a technical guide for the management of road construction and maintenance wastes, which encourages the use of recycled materials. Specifically for C&D waste, NSW EPA (2019a) published new standards for C&D WM in NSW, detailing on inspection, waste sorting, storage, and transportation requirements.

The legislative framework for C&D WM is typically based on the acts and regulations relevant to environment protection and pollution control in Australia. In most states, the regulatory environment for general WM has been mature and specifications or guidelines have been published for using recycled materials in pavement construction. However, the Building Code of Australia (BCA) does not require much consideration into sustainable use of materials and fails to provide specific methods to measure the effectiveness of sustainable building practices (Park and Tucker, 2017). BCA seemed to have limited impact on C&D WM in Australia. Udawatta et al. (2018) found that "insufficient industrial performance standards and regulation on WM" was ranked as the least significant obstacle to C&D WM in Australia but also indicated that the BCA and National Construction Code (NCC) without provisions for WM would hinder WM in building construction. In addition, Udawatta et al. (2015b) indicated that it was necessary to reinforce legislation and regulation and check the compliance of C&D WM practices and that legislation could be a tool to promote the benefits of C&D WM with the involvement of practitioners. Thus, it is recommended that BCA and NCC could be amended to incorporate the 3R principle and circular economy into the design stage and relevant legislation could be further reinforced. However, resistance to change may be incurred due to the increased workloads of professionals. "Resistance to change" was ranked the top barrier to C&D WM in Australia (Udawatta et al., 2018).

Although the specific acts, regulations, and policies relating C&D WM may be inconsistent between states and territories, they share some common themes. For example, except NT, all the other jurisdictions have imposed landfill levies and most jurisdictions have published their WM strategy documents that set up specific targets for waste recovery or recycling.

Landfill levy. Imposing a landfill levy can increase the cost of C&D waste disposal in landfill sites and encourage reusing and recycling C&D waste materials (Udawatta et al., 2015b). The landfill levies are determined by several factors, such as the

Table 1. Legislative framework of WM in Australia.

State and territory	Act, regulation, policy, and specification
NSW	Protection of the Environment Operations Act 1997
	Waste Avoidance and Resource Recovery Act 2001
	Protection of the Environment Operations (Waste) Regulation 2014
	Extended Producer Responsibility
	State Environmental Planning Policy No 48 1995 - Major Putrescible Landfill Sites
	State Environmental Planning Policy (Major Projects) 2005
	NSW Government Sustainability Policy 2008
	Specification for Supply of Recycled Material for Pavements, Earthworks and Drainage 2010
	Road and Maritime Services Technical Guide-Management of road construction and maintenance wastes 2016
	Standards for managing construction waste in NSW
Victoria	The Environment Protection Act 1970
	The Environment Protection (Resource Efficiency) Act 2002
	The Environment Protection (Amendment) Act 2006
	Sustainability Victoria Act 2005
	Environment Protection (Distribution of Landfill Levy) Regulations 2010
	Environment Protection (Industrial Waste Resource) Regulations 2009
	Industrial Waste Management Policy (Waste Acid Sulfate Soils) 1999
	Waste Management Policy (Siting, Design and Management of Landfills) 2004
	Waste Management Policy (Used Packaging Materials) 2010
	VicRoads Standard Specifications for Roadworks and Bridgeworks
	Waste Management Policy (Movement of Controlled Waste Between States and Territories) 2002
Queensland	Environmental Protection Act 1994
	Environmental Protection (Waste Management) Regulation 2000
	Environmental Protection Regulation 2008
	Waste Reduction and Recycling Act 2011
	Waste Reduction and Recycling Regulation 2011
	The Environmental Protection (Waste Management) Policy 2000
	Main Roads Specification MRS35 - Recycled Materials for Pavements
	Transport and Main Roads Specifications MRTS36 Recycled Glass Aggregate
	Transport and Main Roads Specifications MRTS102 Reclaimed Asphalt Pavement Material
	Recycling policy for buildings and civil infrastructure
SA	Environment Protection Act 1993
	Development Act 1993
	Zero Waste SA Act 2004
	Environment Protection (Waste to Resources) Policy 2010
	Standard for the production and use of Waste Derived Fill
	Recycled Fill Materials for Transport Infrastructure - Operational Instruction 21.6 Policy
	Specification: Part 215 Supply of Pavement Materials
WA	Environmental Protection Act 1986
	Waste Avoidance and Resource Recovery Act 2007
	Waste Avoidance and Resource Recovery Levy Act 2007
	Environmental Protection Regulations 1987
	Environmental Protection (Controlled Waste) Regulations 2004
	Waste Avoidance and Resource Recovery Levy Regulations 2008
	Waste Avoidance and Resource Levy Regulation Administration Policy 2009
	Extended Producer Responsibility Policy Statement
	Main Roads Western Australia Specification 501 – Pavements
Tasmania	Environmental Management and Pollution Control Act 1994
	Environmental Management and Pollution Control (Waste Management) Regulations 2020
	Environmental Management and Pollution Control (Controlled Waste Tracking) Regulations 2010.
	Litter Act 2007
ACT	Environment Protection Act 1997
	Environment Protection Regulation 2005
	Waste Minimization Act 2001
	Waste Management and Resource Recovery Regulation 2017
	Waste Management and Resource Recovery Act 2016
NT	Waste Management and Pollution Control Act 1998
	Waste Management and Pollution Control (Administration) Regulations 1998
	Environment Protection Act 2019
	Environment Protection Regulations 2020
	Northern Territory Environment Protection Authority Act 2012

location of landfills (metropolitan, regional, or rural), levy exemption for certain materials, and levy zones. NSW and SA have relatively high landfill levies for C&D waste, while Tasmania adopt the voluntary levy in regional areas. The landfill levies periodically increase every year. State and territory governments tend to allocate the landfill levy revenue to improve the waste and resource recovery industry through financial incentives to companies and research funding. For example, the NSW EPA (2016) started a "Waste Less, Recycle More" initiative, which was funded by the waste levy revenue, to invest AUD337 million to the waste recycle and recovery sector in 2017–21; and the Victoria government enacted Environment Protection (Distribution of Landfill Levy) Regulations 2010 to regulate the allocation of landfill levy revenue among the state agencies.

As for the effectiveness of landfill levies, Shooshtarian et al. (2020a) collected 132 responses from industry practitioners to investigate their perceptions on landfill levies for C&D waste and indicated that 89% of the respondents perceived the effectiveness of landfill levy imposition. Similarly, the WA Department of Water and Environmental Regulation (DWER, 2020) revealed that an increase in landfill levies led to less C&D waste disposal. Rameezdeen et al. (2016) undertook a study on reverse logistics in the SA construction industry and indicated that a higher landfill levy could cause illegal dumping. Thus, government supervision is required, and public participation is encouraged to reduce illegal dumping.

The majority of states and territories have strategies to reduce illegal dumping, and some have set numerical targets. The WA government has decided to achieve zero illegal dumping in community by 2030 (WA Waste Authority, 2019) while the NSW government planned to reduce illegal dumping by 30% by 2020 in comparison with 2011. Several studies have attempted to model the effect of landfill levy on illegal dumping and determine an appropriate landfill levy through the system dynamics technique (Au et al., 2018; Yuan and Wang, 2014). Advanced technologies could also be used to capture illegal dumping (Lu, 2019; Seror and Portnov, 2018).

Strategy documents. Most jurisdictions have published their WM strategy documents that are developed under jurisdictional acts to provide guidance for better WM practices and set up specific targets for waste recovery or recycling in a period of five to ten years. These strategy documents do not have statutory power but are still an important element of the legislative framework. Shooshtarian et al. (2020b) reviewed these strategy documents in terms of improvements in legislative frameworks, definition of waste versus resource, strategies to reduce illegal dumping, and plans for recycled materials and energy recovery.

Some of the states and territories have set up numerical recycling or recovery targets specifically for C&D waste. For example, the NSW government set a target for the C&D waste recycling rate at 80% by 2021–22 (NSW EPA, 2014); the SA government planned to increase landfill diversion rate of C&D waste to 90% in the metropolitan area by 2020 (Green Industries SA, 2015); the WA government set a target to reach a C&D waste recovery rate of 80% by 2030 (WA Waste Authority, 2019); and the Queensland Government (2019) set a target to achieve the C&D waste recycling rate of 75% and 80% by 2025 and 2030, respectively. It is worth attention that various factors influence the achievement of these targets in specific states and territories. For instance, NSW experiences increasing waste generation; Queensland receives huge quantities of cross-border waste generated from other jurisdictions; Tasmania does not have mandatory landfill levy; and NT does not effectively collect waste data (Shooshtarian et al., 2020b).

Cross-jurisdiction waste movement

Australia is large in size but small in population. Although most of the C&D waste is treated or recycled within one jurisdiction or region, some waste generated in one jurisdiction has to be transported to interstates for recycling or landfill or exported to other countries. Wu et al. (2020) performed an exploratory study of waste mobility in Australia and found that cross-border waste mobility was driven by the availability of local C&D waste recycling facilities or landfill sites, inconsistencies in landfill levies between states, and the waste recycling market. Newaz et al. (2020) indicated that recycling opportunities varied with locations and cross-regional waste movement could be attributed to the inconsistent policies in NSW, Queensland, and Victoria.

Wu et al. (2020) indicated that SA was at the center of cross-jurisdiction waste movement for reprocessing or recycling in Australia. In the financial year of 2018–19, SA imported 172,500 t of waste materials for resource recovery, including 27,200 t of metals, 68,000 t of organics, and 58,200 t of glass, but no masonry, paper, and cardboard waste. Victoria transported the most 88,700 t of waste to SA, followed by NSW and NT that sent 27,600 t and 9700 t to SA, respectively, while ACT, WA, and Tasmania did not transport any waste to SA (Green Industries SA, 2020). Queensland sent around 1.41 Mt of waste to interstate or overseas for processing or recovery, which included no masonry waste, and received 1.18 Mt of waste, including 855,000 t of C&D waste, from other states and territories in 2018–19 (Queensland Government, 2020). In addition, Victoria sent 487,000 t (33%) of metals, 484,000 t (38%) of paper and cardboard, 82,000 t (57%) of plastics, and 14,400 t (7%) of glass to interstate or overseas for reprocessing (Sustainability Victoria, 2020). In NSW, the waste received from interstate or overseas and recovered or disposed in NSW is considered to be in non-levied area (NSW EPA, 2019b). Thus, some masonry waste generated in ACT was sent to NSW for landfilling because of shorter transportation distance, lower transportation cost and no landfill levy, while NSW also transported waste to Queensland, ACT and Victoria (Wu et al., 2020). Before landfill levy was imposed in Queensland, NSW transported a huge amount of waste to Queensland (Newaz et al., 2020).

Cross-jurisdiction C&D waste movement and trading is not uncommon around the world as this is seen as a natural solution to the mismatch between supply and demand. Learning from smart grids, Lu et al. (2020) proposed innovative institutional arrangements to boost the cross-jurisdiction C&D waste material trading market in China and recommended generic strategies, including standardizing tradable C&D waste materials, building an information exchange platform, and establishing an administrative body across jurisdictions. This could be a reference to cross-jurisdiction recycled waste material trading in Australia.

Human factors related to stakeholders

C&D WM practice is influenced by various factors. Previous empirical studies have identified the influential factors in Australia (Park and Tucker, 2017; Treloar et al., 2003; Udawatta et al., 2018). The influential factors should be considered in association with relevant stakeholders (Zhao, 2021), including external and internal stakeholders. External stakeholders include governments, the general public, and experts, while internal stakeholders are direct participants of construction projects and waste recycling, including clients, designers, contractors, subcontractors, waste recycling companies (Park and Tucker, 2017). As legislation, policies and government pecuniary imposts have been discussed there before in this study, this part focuses on the factors relating to internal stakeholders.

Human factors, such as awareness, attitude, and behavior of individuals, have been recognized as influential factors to C&D WM around the world (Ajayi and Oyedele, 2018; Li et al., 2015; Osmani et al., 2008; Udawatta et al., 2015a; Wu et al., 2017b). Theory of planned behavior (Ajzen, 1991) presents a broad framework using attitude, subjective norms, and perceived behavioral control to predict behavioral intentions and observed behavior of stakeholder while extended theory of planned behavior include more variables (e.g. moral norms, consumer identity, technological advancements) for better prediction accuracy. Institutional theory explains the influence of institutions on organizations (DiMaggio and Powell, 1983) and can be used to explain the effects of external pressures (e.g. social and political pressures) on the organizations involved in C&D WM. Jain et al. (2020) used a hybrid model of extended theory of planned behavior and institutional theory to explain stakeholders' behavior in C&D waste recycling. Norm activation model explains the conditions under which altruistic behavior occurs and consists of three core variables: awareness of consequences, ascription of responsibility, and personal norms (Schwartz, 1968), which were found to predict waste reduction behavior (Ebreo et al., 2003).

Awareness and attitude of clients or developers significantly influence designers, contractors, and subcontractors in terms of C&D WM (Kabirifar et al., 2020). Clients are usually profit-driven and sensitive to cost (Park and Tucker, 2017), and tend to be passive to C&D WM without perceivable profitability (Hao et al., 2008). In an empirical study, Udawatta et al. (2015a) interviewed several practitioners in SA and indicated that government clients were more favorable toward WM practice than private clients and had prequalification processes to select contractors with consideration into their WM capabilities and experiences. Park and Tucker (2017) revealed that market demand, regulatory requirements, and government financial incentives could motivate clients to increase reuse of C&D waste materials, while Udawatta et al. (2015b) argued that demonstrating the benefits produced by effective C&D WM could positively shift clients' attitude toward C&D WM. An early case study in Victoria by McDonald and Smithers (1998) reported that WM on site reduced waste generation by 15%, reduced waste for landfill by 43%, and saved 50% of waste handling charges. Clients can also influence design, and their decisions may lead to waste generation. Li and Yang (2014) investigated WM in Australian office building retrofit projects and found that the last-minute change in clients' requirements was among the most significant factors resulting in construction waste.

Designers play a key role in minimizing C&D WM. Previous studies indicated that designers may not be aware of the potential of materials for waste minimization (Poon et al., 2004; Yuan, 2017) and misunderstand that waste is generated from site operations rather than the design phase (Osmani et al., 2008). In Australia, early studies by Faniran and Caban (1998) reported that design changes, design, and detailing errors were among the top construction waste sources while Jaques (2000) suggested that designers should create buildable designs to enable a logical sequence in construction and less design change and waste. More recently, Li and Yang (2014) indicated that design change was one of the most critical sources of waste in office building retrofit projects; Udawatta et al. (2015a) found that designers were not likely to consider waste minimization if they did not have to satisfy the requirements of green building rating tools, such as Green Star; Udawatta et al. (2018) revealed that the design and documentation influenced contractors' ability to reduce waste; Forsythe and Fini (2018) suggested that recycling and reuse should be taken into consideration in fit-out design to reduce demolition waste; and Doust et al. (2021) reported that 48% of the respondents adopted innovative design and that 56% used the designs with prefabrication or modularization in Australia. Designers' attitude and behavior could be influenced by clients; and in turn, designers with relevant knowledge and experience can inform clients of the benefits of C&D WM. At the early stage of a project, designers can undertake environmental impact assessment, adopt WM plans and consider the life cycle of materials or components, including their eventual reuse, recycling, recovery, or disposal (Lu and Yuan, 2010).

Contractors are directly involved in C&D WM and need to follow their WM plans. Although contractors may view C&D WM a cost burden due to the competitiveness in the construction industry, contractors are motivated to adopt C&D WM if clients consider their WM capabilities in prequalification or tendering processes (Udawatta et al., 2015a). Construction workers' attitude and behavior should also be taken into considerations. Teo and Loosemore (2001) applied extended theory of planned behavior to investigate the attitudes of on-site workers toward waste in Australia and found that they perceived waste as inevitable by-products, but this perception was influenced by senior management support and availability of supporting facilities, resources, and incentives. Lingard et al. (2000) undertook interviews with staff in a large Australian contractor and indicated that management staff perceived environmental issues as less important than time, cost and quality while workers viewed environmental issues as more important. This study also found that availability of local recycling facilities and top management support were perceived to drive C&D WM by both workers and managers. Udawatta et al. (2018) revealed that attitude and behavior of construction practitioners was still one of the top barriers to C&D WM in Australia.

Training and education enable stakeholders to enhance their employees' knowledge, attitude, and awareness relating to WM. Previous empirical studies in Australia have revealed the importance of training and education for C&D WM. For instance, Lingard et al. (2000) suggested that training should be provided for site managers in order to motivate them to prioritize WM; Udawatta et al. (2015b) indicated that most interviewees highlighted the importance of training and education for all stakeholders to enhance C&D WM performance; and Newaz et al. (2020) interviewed 19 practitioners in NSW and found that knowledge, experience, and training of site operatives were one of the key factors influencing C&D WM. Park and Tucker (2017) argued that higher education of architects and continuous professional development programs could help designers to adopt low-waste design and that training should be provided for staff at all levels of contractors and subcontractors, regardless of company size. The importance of training and education was also highlighted by the studies undertaken in other countries, such as the USA (Warren et al., 2007), China (Lu and Yuan, 2010; Yuan et al., 2011), Vietnam (Ling and Nguyen, 2013), Malaysia (Begum et al., 2009), and the United Arab Emirates (Al-Hajj and Hamani, 2011).

C&D WM in a project life cycle

C&D WM should be taken into consideration in different phases across a project life cycle, including project planning and design, tendering, construction, and demolition phases. It is important to consider these phases when managing C&D waste. The project operation phase is not covered in this study.

In the project planning and design phase, designers should consider the potential to minimize waste and reuse materials through communicating with clients (Park and Tucker, 2017). Forsythe and Fini (2018) indicated that proactive WM should be initiated from design and advocated the concepts of design for disassembly, design for deconstruction, and design for reuse or recycle to increase diversion from landfill. Udawatta et al. (2015b) suggested that WM plans should be incorporated into design and that design for adaptability and standard design could be adopted to enhance C&D WM performance. In addition, prefabrication and modularization could be used to standardize plans and designs and reduce waste during construction (Kabirifar et al., 2020; Tam et al., 2007), and building information modeling could be applied to compare environmental impact and waste generation between design options (Guerra et al., 2019, 2020). Furthermore, WM is required in a number of green building rating tools, including Australia's Green Star initiative. Using case studies in SA, Udawatta et al. (2020) found that WM targets in the current Green Star system were not sufficiently challenging and recommended a shift of the WM focus toward regenerative environments.

In the tendering stage, clients' demand for waste minimization should be clearly communicated to potential contractors. WM needs to be part of the tendering documents for each of the trade packages and previous WM experiences and performance and WM plans could be included in the criteria for prequalification and tendering (Udawatta et al., 2015a, 2015b). In addition, contractual clauses have great potentials for waste reduction (Ajayi et al., 2017). The disclaimer or exculpatory clauses in the Australian standard contractual documents and the clauses regarding quality, workmanship, and site inspection tended to cause rework and waste (Mendis et al., 2013). Therefore, contractual clauses may be amended to clarify roles and responsibilities of contractors and subcontractors for C&D WM and minimize design changes and rework (Ajayi et al., 2017; Gangolells et al., 2014; Poon et al., 2004).

In construction, formal C&D WM plans that typically cover waste sorting, waste streams, waste clearance schedule, waste collection and transportation, waste reuse, recycling and disposal, possible issues and solutions, and required resources, are seen as a key prerequisite for effective C&D WM and should be adopted (Udawatta et al., 2015b). Communication and coordination between project participants should be assured (Kabirifar et al., 2020). On-site waste sorting and treatment could be performed to increase reuse and recycling and reduce transportation costs but require sufficient site spaces (Li and Yang, 2014). In NSW, Newaz et al. (2020) found that contractors preferred to outsource WM responsibilities and focused on their core business. In addition, effective site management contributes to C&D waste reduction (Kabirifar et al., 2020), including material management, regular site inspection, rework minimization, and site space planning. Site space planning makes sure that WM processes do not interfere with other construction activities in a constrained site space and enables on-site materials to avoid contamination or mixture (Newaz et al., 2020). Also, Udawatta et al. (2015b) found that construction technologies to minimize waste was the top solution for C&D WM. Examples of such technologies include lean construction that adopts lean principles in construction to create value and eliminate non-value-adding activities (Nahmens and Ikuma, 2012), off-site construction or prefabrication that produces building components in off-site factories (Tam and Hao, 2014), and Geographic Information System that facilitates evaluation of site material layout for waste minimization (Su et al., 2012). These technologies are also applicable to C&D WM in Australia. Furthermore, if on-site recycling is not possible due to site constraints, it is necessary to transport C&D waste to recycling facilities. C&D waste collection and transportation are associated with costs, pollution, and traffic congestion in urban areas. Thus, previous studies have attempted to plan waste collection services and optimize the routing between construction sites and recycling facilities. A recent study by Yazdani et al. (2021) proposed a hybrid algorithm to optimize route planning for C&D waste collection and transportation between construction sites and recycling factories and validated it in a real case in Sydney.

In the demolition phase, traditionally reactive WM strategies need to be replaced by proactive WM, which requires the efforts in the design phase. Forsythe (2011) investigated timber waste recovery in Australian housing demolition and found that the deconstruction approach provided relatively high timber recovery when there was high-value timber waste. Deconstruction is the disassembly of a building piece by piece, which enables the recovery of building materials and elements after the end of life of buildings and reduces waste through reuse (Akinade et al., 2017). Thus, design for deconstruction can be a strategy for the demolition phase. In addition, Forsythe and Fini (2018) revealed that the majority of the demolition waste was sent to landfill could be attributed to the mixture of waste in a fast-track demolition process and recommended using relatively homogenous kit of parts in redesign, which would enable fast and simple deconstruction.

Conclusions and recommendations

C&D waste has been recognized as a key issue by Australia's government. States and territory governments are promoting C&D WM with emphasis on the 3R principle and circular economy. This study aims to undertake a systematic review of the literatures relating to C&D WM practice in Australia. A series of government reports, acts, regulations, policies, and strategy documents were reviewed, and 26 journal articles collected from the Scopus database were analyzed.

This review reported the recent statistics of C&D waste generation, recycling, and composition in Australia, indicating that masonry materials (e.g. bricks, concrete, and asphalt) represented the biggest proportion of the C&D waste and that SA and Victoria have achieve high C&D waste diversion rates. It was also found that the construction industry spent more money on WM than any other industries in Australia.

Governments play a pivotal role in promoting WM. State or territory governments have enacted several relevant acts, regulations, and policies relating to management of all types of waste with consideration into their specific conditions. However, few have policies focused on C&D WM. Landfill levies have been imposed in all the states and territories except NT. Most previous studies supported the effectiveness of landfill levies, but some concerned regarding the illegal dumping possibly resulting from the levy imposition. In addition, most states and territories published their strategy documents for WM. Although these strategy documents do not have statutory power, they are still an important element of the legislative framework. In the documents, NSW, Queensland, WA, and SA have set their specific targets for C&D waste recycling or diversion rates for the next 5–10 years.

The inconsistencies in legislation and landfill levies between jurisdictions, availability of local recycling facilities and recycling market contribute to cross-jurisdiction waste movement for reprocessing or recycling. The most recent statistical data showed that all the states and territories except Tasmania were involved in cross-jurisdiction waste movement. Most states and territories preferred to handle masonry waste within their jurisdictions. By weight, metals accounted for the biggest proportion of C&D waste that was transported across jurisdictions.

C&D WM practice is influenced by various factors associated with relevant stakeholders. The awareness, attitude, and behavior of internal stakeholders (e.g. clients, designers, and contractors) are usually viewed as human factors. Human factors of clients can influence those of designers and contractors. In turn, designers can promote reusable and recyclable materials to clients while contractors can demonstrate practical benefits of C&D WM to clients, which strengthens clients' positive attitude. The role of designers has been highlighted by many Australian empirical studies, as designers have the greatest potential to minimize C&D waste at an early stage of a project. Contractors may view C&D WM a cost burden but can be motivated to adopt C&D WM if their WM capabilities are taken into consideration in prequalification or tendering. Education and training can significantly enhance the knowledge, attitude and awareness relating to WM.

This study also identified the factors that are directly related to different phases across a project life cycle. Designers need to adopt a low-waste method in the design and planning phase. Clients need to incorporate the C&D WM capability of contractors into prequalification and tendering criteria. Contractual documents may be amended to include specific WM targets and responsibilities for contractors and methods to minimize rework and waste. During construction, contractors need to follow their WM plans and adopt lean construction or prefabrication methods to minimize on-site C&D waste. Contractors also need to perform on-site waste recycling, or transporting waste to off-site recycling facilities, or send the non-recyclable waste to landfill sites. Waste minimization in the demolition phase is usually attributed to the design phase. Design for deconstruction has been found to be effective in Australia.

There are some limitations in this study. First, most discussions are based on the context of Australia. Thus, the findings are subject to a geographical limitation. Second, the five topics, namely WM statistics, related legislations, cross-jurisdiction waste movement, human factors, and C&D WM in a project life cycle, are selected by subjective judgments. Third, this review depends on the qualitative discussion only as it does not qualify for a scientometric analysis, due to a small number of articles. Fourth, this review adopts Scopus database only, which inevitably excludes some potential publications outside this database.

Some implications can be drawn for other countries that aims to improve their C&D WM performance. First, governments need to regularly collect and publish waste statistics to show the current state of WM, justify the need for legislation and help increase the public awareness. Second, a comprehensive legislative framework should be established for WM. The legislation may target all types of waste, including C&D waste. The government should set up short-, mid-, and long-term targets of waste recycling or diversion rate. Financial incentives, such as fine, levy, and subsidy, could be used to motivate internal stakeholders (e.g. clients, designers, contractors, subcontractors, waste recycling companies) to adopt effective C&D WM. In addition, various theories have been adopted to explain the behavior of internal stakeholders in C&D WM in different locations. Previous findings indicated that training and education are crucial for employees' knowledge, attitude, and awareness relating to WM. However, these human factors may be moderated by trait-related factors, such as emotional intelligence, situational awareness, and learning capacity. Furthermore, WM should be considered with a life-cycle perspective and detailed WM plans should be developed for each phase of a project life cycle. The role of designers in C&D waste minimization should also be highlighted in other countries.

Although there have been extensive studies focused on C&D WM in Australia, there still exist some research gaps. First, none have attempted to explore the impact of the legislation on the behaviors of internal stakeholders in Australia. As an external factor, the effects of legislation on C&D WM performance are worth more attention. Second, the interactions among internal stakeholders can be analyzed with a network perspective; however, none have explored the effects of network characteristics and their dynamic evolution across a project life cycle on C&D WM behavior of internal stakeholders. Additionally, while studies have been done to explore the environmental benefits of C&D WM, none have attempted to measure the social benefits of C&D WM in Australia. It has been widely recognized that C&D waste has significant social impacts, and thus effective C&D WM should also have social benefits, which are worth future research. Furthermore, few studies have explored the emerging technologies for C&D WM in Australia, including the information and communications technologies (ICTs) and data analytical techniques that help enhance WM performance (Li et al., 2020; Liao et al., 2021) and the biotechnologies that can produce biofuels using biomass waste from construction sites (Hong and Wu, 2020; Peres et al., 2020; Zhang et al., 2021).

Therefore, future research would bridge these gaps and explore the impact of legislation on the behavior of internal stakeholders in different phases after legislation, which can demonstrate the role of legislation in promoting C&D WM. In addition, future research would also explore the dynamic evolution of C&D WM collaborative networks of internal stakeholders in different phases using longitudinal data and the effects of stakeholder interactions on C&D WM performance. Moreover, future research would develop indicators and models to measure or predict the social impacts of C&D WM practices for different types of projects. Furthermore, future research would explore the potential of adopting the new ICTs, data analytical techniques, and biotechnologies to enhance C&D WM performance.

The contribution of this study includes providing the current state of C&D WM in Australia by identification of the five interrelated topics, presenting researchers and practitioners with an understanding of the existing C&D WM research in Australia, and summarizing implications for researchers in other countries. This study also detects research gaps and recommends directions for future C&D WM research. Global researchers would carry out research to bridges the gaps in future.

Declaration of conflicting interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

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