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Effective construction and demolition waste management assessment through waste management hierarchy; a case of Australian large construction companies

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ABSTRACT

The construction industry accounts for an enormous quantity of construction and demolition waste (CDW) where its improper management jeopardizes social, environmental, and economic resources. Although several studies have investigated some aspects of construction and demolition waste management (CDWM), there is a substantial need to empirically analysing effective construction and demolition waste management (ECDWM) considering its contributing factors and the CDWM hierarchy (CDWMH). A framework was proposed to assess the effectiveness of CDWM using CDW stakeholders' attitudes (CDWSA), CDWM within project life cycles (CDWPLC), CDWM with respect to sustainability (SCDWM), and CDWM tools (CDWMT) as factors that effectively affect CDWM, and CDWMH as the most effective strategy to manage CDW, leading to the effective management of CDW. This study analyzed ECDWM in Australia. Thus, 108 large construction companies were approached via an online questionnaire. Data were analyzed through partial least squares based structural equation modelling using SmartPLS. Results (path coefficients) could prove that CDWSA was the most effective factor to CDWM, while CDWPLC was the least effective (ineffective). In addition, recycling strategy received more attention than reusing and reducing strategies, which contrasts with the nature of CDWMH. The study is relevant for CDW professionals as well as academicians involved in CDWM.

1. Introduction

Urbanization and population growth have put a considerable pressure on the construction industry to construct more buildings to fulfill the current and future generations' expectations (Aslam et al., 2020). As a result of increasing construction activities, a tremendous volume of construction and demolition waste (CDW) is produced, which is ranged from engendered debris from demolition, renovation, and construction activities to remnant wastes from calamities such as flood and earthquake (Menegaki and Damigos, 2018; Yeheyis et al., 2013). CDW mainly includes bricks, concrete, plasterboard, asphalt, metals, timber, glass, plastics, cardboards, and others (Wu et al., 2020).

Approximately, over 10 billion tonnes of CDW is produced annually globally (Wang et al., 2019), which occupies 35–65% of global landfills (Chileshe et al., 2018; Nikmehr et al., 2017; Yeheyis et al., 2013). Similarly, over 27 million tonnes of CDW is generated annually in Australia (Pickin et al., 2020), which accounts for 44% of total generated waste (Shooshtarian et al., 2020b), while the recovery rate is less than 60% (Jin et al., 2017). These quantities are alarming as CDW has deleterious impacts on our sustainability needs (Wu et al., 2019a). For instance, each square meter of landfilled CDW is equal to almost 1.5 tonnes of groundwater loss and 53 g of soil deterioration (Ding et al., 2016). In addition, over 30% of construction materials are wasted (Osmani et al., 2011), while the construction materials represent approximately 40% of global material flows (Chileshe et al., 2018; Reza et al., 2011). Therefore, effective management to minimise CDW is important for many reasons (Doan Dat and Chinda, 2016).

Effective construction and demolition waste management (ECDWM) can have both environmental benefits and socioeconomic advantages for associated stakeholders and construction projects (Wang et al., 2019). While the construction and demolition waste management hierarchy (CDWMH), or the 3R principles of reduce, reuse and recycle (Esa et al., 2017a), is considered the most effective strategy for construction and

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Nomenclature

C&D	construction and demolition
CDW	construction and demolition waste
CDWM	construction and demolition waste management
CDWMH	construction and demolition waste management hierarchy
ECDWM	effective construction and demolition waste management
SCDWM	sustainable construction and demolition waste management
CDWPLC	construction and demolition waste within project life cycles
CDWSA	construction and demolition waste stakeholders' attitudes
CDWMT	construction and demolition waste management tools

demolition waste management (CDWM) (Huang et al., 2018), several studies have also addressed factors that effectively affect CDWM. For instance, effective management of CDW has been assessed from the sustainability perspective by evaluating the economic, social, and environmental aspects of CDW (Epstein, 2018; Marzouk and Azab, 2014). Also, stakeholders' attitudes in CDWM, the role of the life cycles of construction and/or demolition projects in CDWM, and technologies and tools for managing CDW have been proven effective in CDWM (Esa et al., 2017b; Udawatta et al., 2015a,b). However, ECDWM can be achieved by incorporating the most effective strategies and factors that contribute to CDWM, which has been ignored.

Thus, the current study aims at filling this gap by designing a thorough assessment framework for ECDWM based on the incorporation of CDWMH and factors that effectively affect CDWM. To empirically investigate and assess the effectiveness of CDWM in the Australian construction context, contributing factors to ECDWM are first identified. These factors are then justified and theorized to form a hypothesized framework with the potential to analyze ECDWM. At last, the effectiveness assessment of CDWM is measured based on empirical data from Australian construction professionals.

2. Literature review

CDWM has gained significant global attention due to its socio-economic and environmental impacts (Kabirifar et al., 2020b). Difficulties of the construction industry in alleviating these impacts due to its low performance has been noted by many scholars (Bai et al., 2016). Despite tremendous attempts that have been made to mitigate CDW (Wu et al., 2019b; Yuan, 2012), the increasing rates of generated and landfilled CDW have prompted scholars to initiate more effective mechanisms to manage CDW. Although this research seeks to address the effectiveness of CDWM in the Australian context, the Global-Local-Context approach has been adopted in reviewing past studies in discussing the issues surrounding ECDWM practices.

The CDWMH, also known as the 3R principles of 'reduce', 'reuse' and 'recycle' strategies, which is also the main principle of circular economy, is considered the widely acceptable and applicable strategy for CDWM (Huang et al., 2018). The order of preference from the most to the least preferable is reduce, reuse then recycle (Kabirifar et al., 2020a). Along with the CDWMH, several factors effectively affect CDWM (e.g., Ghisellini et al., 2018). Some researchers have studied these factors as a case study or in the form of nationally, regionally, or globally developed frameworks.

Based on existing global frameworks for CDWM, Lu and Yuan (2011) established a highly versatile framework for CDWM where factors such as origins, impacts and quantities of CDW as well as performance measurement, regulations, tools and humans in CDWM were revealed effective. Similarly, Yuan and Shen (2011) developed a framework, in which CDW generation, CDWM from a general perspective, the CDWMH, and the role of humans in CDWM were considered effective. Besides, Yuan (2013) elaborated a framework to assess ECDWM based on the key indicators of sustainability criteria including economic, social, and environmental aspects of CDWM.

Considering CDWM regionally, Gálvez-Martos et al. (2018) established a framework for CDWM in Europe considering the circularity of CDWM and with regards to the effective role of the regulatory framework, waste to products, preconstruction, construction, and demolition in CDWM. Similarly, del Río Merino et al. (2009) investigated CDWM in Europe and came up with a waste management plan and reusing construction materials as effective factors in CDWM. Several scholars have also studied the effective factors in CDWM from the national perspective. Table 1 summarizes the most relevant studies addressing factors that effectively affect CDWM.

In line with global practices of CDWM, several studies have addressed factors that effectively affect CDWM in Australia. For instance (Udawatta et al., 2015b), came up with appropriate design and documentation, CDWM within the project life cycles, strategic guidelines in waste management, decisions, and supervision as critical factors that affect CDWM. Similarly, the effective role of stakeholders' attitudes in CDWM (Udawatta et al., 2015a), as well as the role of green building rating tools in CDWM (Zillante et al., 2020), were also addressed. Some other scholars have also considered the role of regulations that affect CDWM in the Australian context (Shooshtarian et al., 2020a).

Although many studies have addressed various factors that affect CDWM effectively, a broad classification of these factors has received less attention from scholars. By considering the main factors that effectively affect CDWM in previous studies, these factors can be classified into four main groups of i) stakeholders' attitudes in CDWM (CDWSA), ii) CDWM during the project life cycles (CDWPLC), iii) sustainability aspects of CDWM (SCDWM), and iv) tools in CDWM (CDWMT). Considering CDWSA, the three main stakeholders with significant impact on CDWM are generally considered clients or head-contractors, consultants and contractors where the head-contractors specify the project goals, consultants plan, design and supervise the job, and the contractors review and implement the CDWM plan (Ismam and Ismail, 2014; Kim Soo et al., 2020). Regarding CDWPLC, a range of factors affect CDWM during the project life cycles (e.g., changes in planning and design stage, material ordering and handling in procurement stage, and waste management plans and technologies during construction and demolition stage, etc) (Esa et al., 2017a). With respect to the SCDWM, a widely applicable approach of sustainability, including economic, social and environmental aspects of CDWM has been utilized by scholars (e.g., Negash et al., 2021). These factors could substantially be reflected in the forms of regulations addressing landfill levies, incentive policies, and heavy penalties on illegal dumping for better management of CDW, costs associated with reducing, reusing, and recycling of CDW including supervision, collection, transportation, recycling and disposal of CDW, and health and safety issues associated with CDW, etc. (Husgafvel et al., 2015; Marrero et al., 2017; Murtagh et al., 2016). Finally, CDWMT could be classified into digital tools including Building Information Modelling (BIM), Radio Frequency Identification (RFID), Global Positioning System (GPS), Big Data (BD), and Geographic Information System (GIS); approaches including zero waste approach, circular economy, lean construction, site waste management plan, and green rating system; and technologies such as modularization and industrialised building system based on a systematic review of CDWMT (Kabirifar et al., 2020b). The following section explains the development of the conceptual framework and hypotheses.

3. Conceptual framework and hypotheses

In this step, a conceptual framework to analyze ECDWM is

Table 1
Factors that effectively affect construction and demolition waste management in a regional scale.

Factors	Key concepts	Region	Reference
The role of tools, technologies, and principles in ECDWM	Tools	Portugal	(Karaz et al., 2021)
The role of stakeholders' attitudes towards CDWM	Stakeholders' attitudes	Vietnam	(Kim Soo et al., 2020)
The waste diversion rate (WDR) as a critical indicator of ECDWM	Tools	Australia	(Ratnasabapathy et al., 2020)
The Assessment Index for Construction Waste Management (ICWM) as an effective tool for CDWM	Tools	Brazil	(Moraes et al., 2020)
The role of government and regulations in CDW recycling	Sustainability	China	(Bao and Lu, 2020)
The capacity of architects to minimise CDW at the design phase	Stakeholders' attitudes and CDWM in project life cycles	Nigeria	(Olanrewaju and Ogunmakinde, 2020)
Three major factors, economic, regulatory and technical, as effective parameters contribute to ECDWM	Tools and Sustainability	Saudi Arabia	(Blaisi, 2019)
A waste management fee (waste charging system) as an efficient method to reduce waste generation and maximise the landfill diversion rate	Tools	China	(Wang et al., 2019)
CDWM practices including the stages of CDWM in projects, strategies of CDWM, and stakeholders in ECDWM	CDWM in project life cycles and Stakeholders' attitudes	Malaysia	(Esa et al., 2017a)
Four stages of CDWM in projects including procurement, design and planning, demolition, and construction	CDWM in project life cycles	Iran	(Nikmehr et al., 2017)
Legislation and tax measures, construction/deconstruction adaptability, plan for site waste management, waste tools, waste efficient procurement, off-site construction, and sorting, reusing and recycling of materials were considered effective	Sustainability, Tools, and CDWM in project life cycles	The United Kingdom	(Ajayi et al., 2015)
The effective role of tax penalties and incentives in altering the behaviour of CDWM stakeholders	Sustainability and CDWM in project life cycles	Spain	(Calvo et al., 2014)
On-site management of CDW was considered effective in CDWM	CDWM in project life cycles	Spain	(Gangolells et al., 2014)
The role of the life cycles of a CDW project and the CDWMH in which construction practice, material management, policies, design specifications and demolition methods were revealed effective	Sustainability and CDWM in project life cycles	Canada	(Yeheyis et al., 2013)
Recycling target as an effective factor for CDWM should be defined for each construction project	Tools	United Kingdom	(Oyedele Lukumon et al., 2013)
The role of stakeholders as success factors in CDWM	Stakeholders' attitudes	China	(Lu and Yuan, 2010)
The impacts of the phases of CDW projects and involved stakeholders in the performance of CDWM	CDWM in project life cycles and Stakeholders' attitudes	Portugal	(Couto and Couto, 2010)
Stakeholders' attitudes as an effective factor in CDWM	Stakeholders' attitudes	Malaysia	(Begum et al., 2009)

developed. The four factors of CDWSA, CDWPLC, SCDWM, and CDWMT have been introduced as contributing factors to ECDWM. The CDWMH as the most effective way to manage CDW has also been located between contributing factors to ECDWM and ECDWM. This juxtaposition has formed the conceptual framework of this study. The framework reflects the impacts of factors that contribute to ECDWM, which is then measured in the forms of reduce, reuse, or recycle strategies. This framework can also specify the most effective strategy of the CDWMH for each set of contributing factors to ECDWM. For instance, considering the impact of GPS on ECDWM, this impact is reflected and measured in the form of reduce, reuse, or recycle strategies (to assess its effectiveness) and by considering the effect of the CDWMH on ECDWM, the most effective strategy for this specific factor can also be measured (Kabirifar et al., 2020a).

In addition to the literature supporting the proposed framework, two categories of contributing factors to ECDWM, CDWSA and SCDWM, are supported by the theory of planned behaviour and the sustainability concept, respectively. The theory of planned behaviour is the most widely applied theory in waste management that supports the effectiveness of stakeholders' attitudes and behaviour on CDWM (Jain et al., 2020; Kabirifar et al., 2020a) while the sustainability concept supports the effectiveness of economic, social, and environmental aspects of CDWM (Kabirifar et al., 2020a; Yuan, 2013). The proposed framework includes five hypotheses that explain the effects of factors and are used to test the validity of the framework (Hair et al., 2017) as hypotheses play a transitional role from theory formation to empirical analysis (Sekaran and Bougie, 2016). Fig. 1 illustrates the conceptual framework of the study.

3.1. *H_1: The effect of CDWSA on the CDWMH*

Different stakeholders have affected CDWM by their attitudes and behaviour (Kim Soo et al., 2020). For instance, architects/designers play a pivotal role in CDWM by on-time delivery of drawings (Olanrewaju and Ogunmakinde, 2020). Contractors can also affect CDW generation, reuse, and recycling by their attitudes (e.g., by setting up priorities in CDWM) (Chen et al., 2019; Saunders and Wynn, 2004). Also, the role of clients in motivating contractors for better management of CDW has been highlighted by some authors (Udawatta et al., 2015a). Therefore, it is hypothesized that CDWSA affects CDWMH (H_1).

3.2. *H_2: The effect of the CDWPLC on the CDWMH*

Dealing with CDW during the project life cycles have been investigated by several scholars. For example, Olanrewaju and Ogunmakinde (2020) found that the design phase plays a significant role in CDWM. Additionally, Esa et al. (2017b) emphasized the prominent role of procurement, and construction and demolition phases in managing CDW. Therefore, it is hypothesized that CDWPLC affects CDWMH (H_2).

3.3. *H_3: The effect of SCDWM on the CDWMH*

Several studies have addressed the impacts of sustainability criteria, including environmental issues, economic matters, and social aspects on CDWM (Li and Du, 2015; Santos et al., 2019). For instance, Gálvez-Martos et al. (2018) emphasized the pivotal role of environmental aspects of CDWM. Besides, Negash et al. (2021) analyzed the SCDWM and found that regulations have a great impact on balancing the triple pillars of sustainability. Similarly, Ghisellini et al. (2018) asserted that the roles of economic and environmental aspects of CDWM are deniable. Meanwhile, Yeheyis et al. (2013) pointed out the role of social sustainability in CDWM. Therefore, it is hypothesized that SCDWM affects CDWMH (H_3).

3.4. *H_4: The effect of CDWMT on the CDWMH*

The application of digital tools, approaches, and technologies (e.g., BIM, green rating systems, circular economy, etc) in managing CDW has

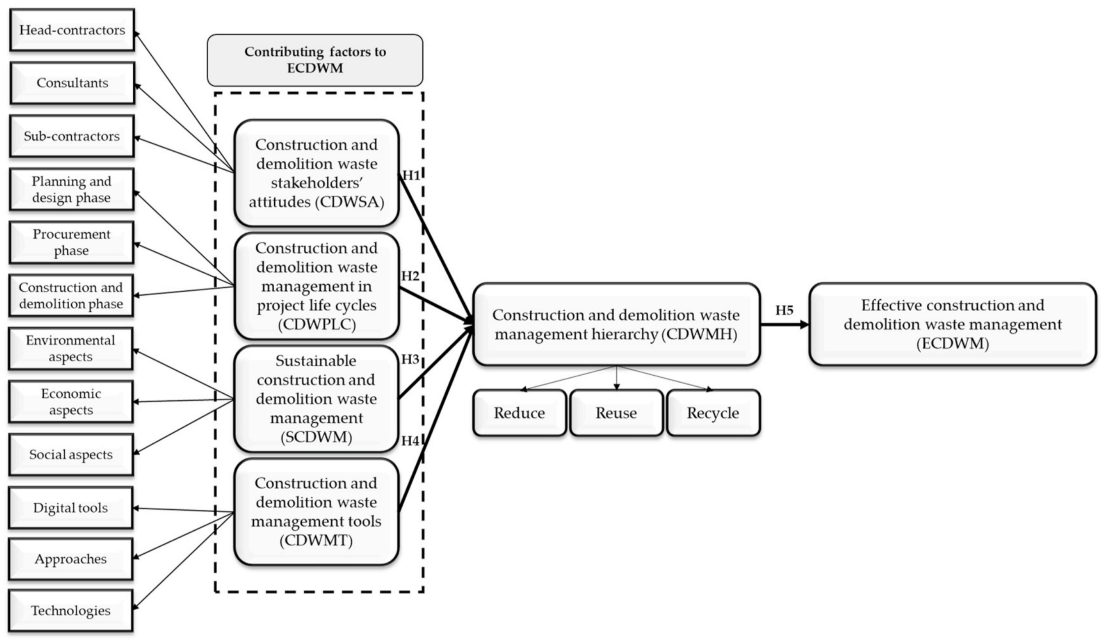

Fig. 1. The conceptual framework for ECDWM.

widely been addressed and investigated by several authors (e.g., Bao and Lu, 2020; Li et al., 2020). For instance, Tam and Hao (2014) highlighted the prominent role of prefabrication in reducing CDW. Meanwhile, Xu et al. (2019) asserted that BIM has a great impact on reducing environmental concerns associated with CDWM. Therefore, it is hypothesized that CDWMT affects CDWMH (H_4).

3.5. H_5: The effect of the CDWMH on ECDWM

The CDWMH encompassing the 3R strategies of reduce, reuse and recycle has been acknowledged as the most effective way to manage CDW (Kabirifar et al., 2020b). Therefore, it is hypothesized that CDWMH affects ECDWM (H_5).

4. Materials and methods

4.1. Questionnaire preparation and distribution

The effects of contributing factors on the CDWMH and the effect of the hierarchy on ECDWM are verified to delineate the key factors and strategies to effectively manage CDW in Australia. A survey research design was utilized in this study as it is an appropriate method of data collection from target population in a timely manner (Creswell and Creswell, 2017). Thus, questionnaire survey (Appendix 1) as an effective way to gain data for analysis and supply less biased outcomes in comparison to other methods was provided (Babbie, 2015; Phillips and Stawarski, 2008). To avoid systematic bias in data collection, the questionnaire was prepared carefully with concise and classified questions (Podsakoff et al., 2003). Researchers benefit from questionnaire surveys in collecting the industry experts' responses as well as generalising the results to the population of interest (Babbie, 2015; Sekaran and Bougie, 2016).

The questionnaire collected information on the effectiveness of each factor (Appendix 2). The questionnaire had two main sections: Section A had five questions on respondents' characteristics; and Section B had 70 close-ended questions in six parts to seek respondents' opinions on the effectiveness of factors on ECDWM. There was also an open-ended question at the end of the survey to reflect the general opinions of the respondents. A five-point Likert Scale was used for close-ended questions from 1 = not effective at all, to 5 = extremely effective. A five-point Likert scale was used because it is a common and convenient scale, and helps respondents answer (Joshi et al., 2015).

Upon the completion of questionnaire design, two academics with industry background in CDWM scrutinised the questionnaire in two rounds to improve its structure, content, language, and its capability to empirically test the conceptual framework within an appropriate time (Babbie, 2015). Once the questionnaire was approved by the UNSW Human Research Ethics Advisory Panel, the snowballing sampling method (Streeton et al., 2004) was implemented to ease the pilot testing in which participants were asked to forward the questionnaire to other relevant participants. First, 12 experts were chosen and initially approached by email, then face-to-face meetings were held where applicable. The target group was chosen based on their expertise in CDWM with over 20 years of experience in private and public companies. Seven of the 12 experts (three face-to-face as well as four on-line meetings were held) responded by providing feedback on the content, clarity, and ease of applicability.

The questionnaire was then revised and prepared for the main distribution. Convenience sampling approach was performed in this study because it allows target population members with specific practical criteria, such as availability at a given time, ease of accessibility, geographical adjacency, and participation willingness to be included for the purpose of the study (Etikan et al., 2016). Two main criteria were selected to formulate convenience sampling framework in this study; i) large construction companies in Australia reviewed by Housing Industry Association (HIA) based on their total contract sum and revenue (HIA–CORELOGIC, 2016–2017), and ii) construction companies based on tier classification (tier 1, 2, and 3), in which the largest infrastructure projects across Australia are executed. The convenience sampling approach helped ensure that pertinent companies, valuable data, and a same focus to research objective are met. A total number of 108 construction companies were targeted and approached. The highest managerial level in these companies pertinent to CDWM was initially targeted to assist with filling in the questionnaire or to hand the questionnaire to the most relevant person in the company. Homogenous population, which is the main objective of the convenience sampling in data collection, was precisely applied in this study. As a result, 108 industry professionals were selected and then approached by official invitation letters with the link to the online questionnaire. The data collection process started in November 2019 and finished in July 2020. From the 108 distributed questionnaires, 52 responses were received; however, only 41 responses were valid and useable for data analysis as 11 responses were incomplete. The target sample population was small due to the particular focus on large construction companies; however, a larger sample could have yielded more accurate results. The 38% response rate was considered satisfactory with regards to the construction management research (Fellows and Liu, 2008; Teck Heng Lim et al., 2010).

4.2. Post data collection analysis

Collected data were controlled against four criteria, namely: i) missing data, ii) suspicious response pattern, iii) outliers (Hair et al., 2017), and iv) common method bias (Jordan and Troth, 2019). Missing data occurs when a respondent either inadvertently or purposely fails to answer one or more questions (Hair et al., 2017). The online questionnaire had a forced-answer approach to prevent respondents from moving to the next question without completing the current question. This approach ensured no missing values. No suspicious response patterns, including straight or diagonal lining were observed (Hair et al., 2017). Outliers, defined as an extreme response or score to a question totally different from the rest of responses, were investigated by performing descriptive statistics in IBM SPSS 25 software and stem-and-leaf and box plots; however, no significant outliers were identified (Hair et al., 2017; Sarstedt and Mooi, 2019). Common method bias is a cause of concern in empirical studies that deal with measuring behavioral sciences (Podsakoff et al., 2011). As a remedy, full collinearity assessment by using Variance Inflation Factors (VIF) (Latan et al., 2017; Ned, 2015), which is one of the most powerful statistical analysis for reporting the responses bias for Likert Scale type questions in PLS-SEM (Kock et al., 2017), was performed. Results indicated no collinearity associated with data.

4.3. Statistical tool

Structural equation modelling (SEM) was used in this study, which is a multivariate data analysis tool and has a significant preference over other methods of data analysis, such as multiple regression analysis, because it constructs unobservable latent variables, provides ample information about any modelling errors, provides models among the multiple predictors and variables, and tests a priori theoretical assumptions against the empirical data (Hair et al., 2013; Hair Joseph et al., 2019; Hair et al., 2017). SEM has two main classifications: Partial Least Square (PLS-SEM) and covariance-based-SEM (CB-SEM). This research used PLS-SEM, since it works effectively with complex models and small sample sizes, has great statistical power, and deals well with missing data (Hair et al., 2017; Jörg et al., 2012). Additionally, when theory is less developed, or there is a concern with testing a conceptual framework from a prediction perspective, the use of PLS-SEM is more acceptable (Hair Joseph et al., 2019). Therefore, SmartPLS v.3 software was used for the analysis. It is worth mentioning that PLS-SEM works well with non-normally distributed data as it utilizes bootstrapping, which is a nonparametric procedure that allows testing the statistical significance of various PLS-SEM results (Hair Joseph et al., 2019).

4.4. Model description

Fig. 2 represents the research model in SmartPLS software. The path model includes six constructs (values not directly measured and in blue circles): ECDWM, CDWPLC, SCDWM, CDWMT, CDWSA, and CDWMH. The items in yellow rectangles are indicators and classified into six sets with each construct related to a set of indicators as CA, CB, CC, CD, CE, and CF for each set of constructs (naming and coding are only for ease of interpretation). In total, 70 indicators are available in the research model reflecting the questions in the questionnaire. The path model includes the two major elements: the structural model that illustrates the constructs' relationships, and the measurement model in which the relationships between constructs and their assigned indicators are shown.

4.5. Research model assessment

The research model, including the measurement model and structural model, should be evaluated (Hair Joseph et al., 2019). The measurement model was evaluated in order to assess the reliability and validity of the measures. This step was undertaken prior to the structural model analysis because, in the case of invalid or unreliable measurement of constructs, the findings of the nature of relationships among constructs derived from the structural model evaluation might be invalid (Hair et al., 2017). The following four criteria were evaluated and fulfilled (Hair Joseph et al., 2019; Hair et al., 2017; Henseler et al., 2016): indicator reliability, internal consistency (measured through Cronbach's alpha and composite reliability), convergent validity (average variance extracted or AVE), and discriminant validity. In addition, five criteria were used to assess the structural model: collinearity assessment, coefficient of determination (R^2), effect size (f^2), structural model path coefficient including p-value and t-value, and blindfolding and predictive relevance (Q^2) (Hair Joseph et al., 2019; Hair et al., 2017).

5. Results

5.1. Background of respondents

Almost half of the 41 respondents were 35–44 years old (48.78%). Role in the company included project manager (29.27%) followed by project consultant (21.95%) and site engineer (14.63%). More than half of the respondents (51%) had graduate degrees, while most others had a bachelor's degree (39.02%). By experience, 58.54% of respondents had more than 5 years of experience in CDWM. Company field included civil engineering (27.85%), commercial (17.72%), multi-unit housing (16.46%) and industrial projects (16.46%). The profile of respondents is summarized in Table 2.

5.2. Full collinearity assessment

As discussed in section 4.2, a full collinearity assessment (VIF values) was performed as a statistical remedy for concerns associated with common method bias. Table 3 represents results for the full collinearity assessment. Since, VIF values were all close to 3 and below 5 (Hair et al., 2017), no collinearity was observed.

5.3. Measurement model assessment

After running PLS-SEM algorithm in consecutive rounds to reach the accepted threshold of indicator reliability ($x > 0.5$) in the first step, and internal consistency reliability, convergent validity and discriminant validity in the second step, 28 indicators including CA01 and CA02 (from CDWSA), CB07 to CB09 (from CDWPLC), and CD01 to CD18, CD25 to CD28 and CD 34 (from CDWMT) (Appendix 2) were removed from further analysis because their values (outer loadings) were between 0.4 and 0.708 and their removal increased other indicators' outer loading values, as well as values for internal consistency reliability, convergent validity and discriminant validity (Hair Joseph et al., 2019). Results for indicator reliability, internal consistency and convergent validity are shown in Table 4. Results indicate that the measurement model is valid.

For discriminant validity, heterotrait–monotrait ratio (HTMT) was calculated (Hair et al., 2019; Henseler et al., 2015). HTMT values were obtained from complete bootstrapping with 5000 iterations (Hair et al., 2017). Table 5 illustrates the results for HTMT. All values were below 0.85, so HTMT values among constructs are accepted (Hair Joseph et al., 2019). Once the measurement model assessment was finalised, the structural model was verified.

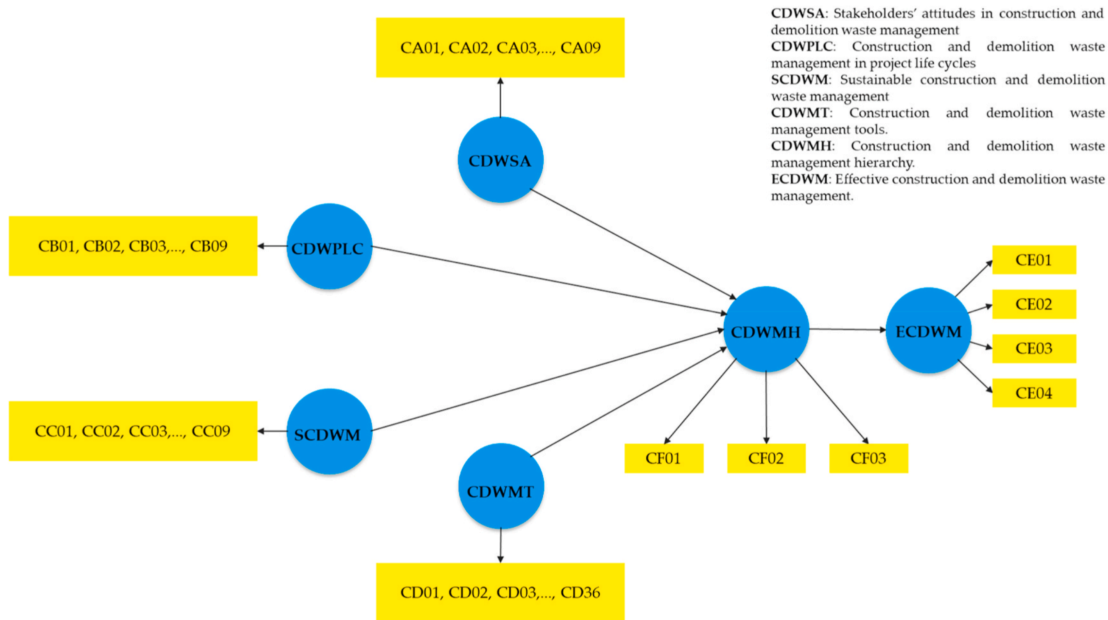

Fig. 2. Research model in SmartPLS.

Table 2
Profile of respondents.

Age	18–24	25–34	35–44	45–54	55–64	65 and above	
Number	1	12	20	4	4	0	
Percentage (%)	2.44	29.27	48.78	9.76	9.76	0	
Company role	Project manager	Contract manager	Site manager	Project consultant	General company manager	Site engineer	Environmental manager
Number	12	4	2	9	3	6	5
Percentage (%)	29.27	9.76	4.88	21.95	7.32	14.63	12.20
Highest qualification	Certificate	Diploma	Bachelor's degree	Master's degree	PhD		
Number	1	2	16	21	1		
Percentage (%)	2.44	4.88	39.02	51.22	2.44		
Experience	Less than 5 years	5–10 years	11–15 years	16–20 years	More than 20 years		
Number	17	8	9	4	3		
Percentage (%)	41.46	19.51	21.95	9.76	7.32		
Company field (multiple items allowed)	Multi-unit housing	Community	Industrial	Commercial	Civil engineering	Mining	Demolition/waste management
Number	13	6	13	14	22	4	7
Percentage (%)	16.46	7.59	16.46	17.72	27.85	5.06	8.86

Table 3
Full collinearity assessment.

VIF values for full collinearity						
	CDWMH	CDWMT	CDWPLC	CDWSA	ECDWM	SCDWM
CDWMH	–	2.167	2.24	2.018	2.163	1.989
CDWMT	3.149		3.059	3.439	2.202	2.883
CDWPLC	1.738	1.679		1.61	1.698	1.676
CDWSA	1.833	2.01	1.937		1.943	2.055
ECDWM	2.803	1.921	2.901	2.757		2.803
SCDWM	2.206	2.148	2.24	2.42	2.457	

5.4. Structural model assessment

To assess the structural model, PLS-SEM was initially run to calculate VIF values for collinearity assessment (after refining data), coefficient of determination for endogenous constructs (R^2) and effect size (f^2). VIF values were ideal as they were below 3 (Hair Joseph et al., 2019). Coefficient of determination (R^2) was calculated to assess the exploratory/predictability power of the research model. Considering R^2 and R^2 adjusted values, CDWMH (0.641 for R^2 and 0.602 for R^2 adjusted) was considered substantial, whereas ECDWM (0.375 for R^2 and 0.359 for R^2 adjusted) was considered moderate. Regarding the effect size (f^2), the effect of CDWMH on ECDWM (0.515) was considered large, whereas the effects of CDWSA on CDWMH (0.125), CDWMT on CDWMH (0.122) and SCDWM on CDWMH (0.054) were medium.

However, the effect of CDWPLC on CDWMH (0.013) was considered low (Hair Joseph et al., 2019).

In the second step, the structural path coefficients were gained through the bootstrapping method considering a two-tailed test with a significance level of 0.1 and 5000 iterations, through which the t-values of 1.65 and above was considered as a threshold for hypothesis acceptance (Hair Joseph et al., 2019; Mojtahedi and Oo, 2017). For H_1, H_3, H_4 and H_5, the t-values were 2.111, 1.692, 1.721 and 6.145, respectively. However, the t-value for H_2 was 0.697, which is below the accepted value of 1.65. Therefore, H_2 was not accepted. Finally, predictive relevance for endogenous constructs (Q^2) was measured using a blindfolding procedure which measures the predictive suitability of the model with D = 7 as the Omission Distance (Hair Joseph et al., 2019; Hair et al., 2017). Both endogenous constructs (CDWMH and ECDWM) were considered acceptable with values of 0.358 and 0.167, respectively as their Q^2 values were higher than zero. Results for the structural model assessment are shown in Table 6.

Table 5
Discriminant validity.

HTMT (bootstrapping)					
Constructs	CDWMH	CDWMT	CDWPLC	CDWSA	ECDWM
CDWMT	0.706				
CDWPLC	0.494	0.419			
CDWSA	0.698	0.613	0.511		
ECDWM	0.704	0.796	0.528	0.644	
SCDWM	0.702	0.648	0.556	0.695	0.721

6. Discussions

The final results including exogenous and endogenous constructs, hypotheses and the t-values of paths are highlighted in Fig. 3. Findings are discussed below.

6.1. *H_1: The impact of CDWSA on the CDWMH*

The first hypothesis (H_1) which reflects the impact of stakeholder

Table 4
Indicator reliability, internal consistency, and convergent validity of the research model.

Number	Indicator	Outer loadings*	Indicator reliability**	Construct	CA[a]	CR[b]	AVE[c]
1	CA02	0.736	0.542	CDWSA	0.888	0.911	0.595
2	CA04	0.771	0.594				
3	CA05	0.842	0.709				
4	CA06	0.795	0.632				
5	CA07	0.795	0.632				
6	CA08	0.746	0.557				
7	CA09	0.708	0.501				
8	CB01	0.783	0.613	CDWPLC	0.911	0.931	0.691
9	CB02	0.831	0.691				
10	CB03	0.785	0.616				
11	CB04	0.909	0.826				
12	CB05	0.847	0.717				
13	CB06	0.827	0.684				
14	CC01	0.777	0.604	SCDWM	0.931	0.942	0.644
15	CC02	0.777	0.604				
16	CC03	0.783	0.613				
17	CC04	0.836	0.699				
18	CC05	0.871	0.759				
19	CC06	0.844	0.712				
20	CC07	0.806	0.650				
21	CC08	0.726	0.527				
22	CC09	0.792	0.627				
23	CD19	0.836	0.699	CDWMT	0.948	0.954	0.615
24	CD20	0.876	0.767				
25	CD21	0.871	0.759				
26	CD22	0.753	0.567				
27	CD23	0.753	0.567				
28	CD24	0.772	0.596				
29	CD29	0.758	0.575				
30	CD30	0.74	0.548				
31	CD31	0.796	0.634				
32	CD32	0.766	0.587				
33	CD33	0.76	0.578				
34	CD35	0.738	0.545				
35	CD36	0.755	0.570				
36	CE01	0.871	0.759	CDWMH	0.847	0.906	0.763
37	CE02	0.597	0.356				
38	CE03	0.853	0.728				
39	CE04	0.782	0.612				
40	CF01	0.807	0.651	ECDWM	0.783	0.862	0.614
41	CF02	0.899	0.808				
42	CF03	0.91	0.828				

[a] CA: Cronbach's alpha – Cronbach's α = $(\frac{M}{M-1})\times(1-\frac{\sum_{i=1}^{M} S_i^2}{S_t^2})$- [b] CR: Composite reliability – Composite reliability (P_c) = $(\frac{(\sum_{i=1}^{M} l_i)^2}{\sum_{i=1}^{M} l_i + \sum_{i=1}^{M} var(e_i)})$- Acceptance range: $(0.60 < x < 1)$ [c] AVE: Average Variance Extracted – AVE = $(\frac{\sum_{i=1}^{M} l_i^2}{M})$- Acceptance range: (AVE>0.5).

* Acceptance range: X > 0.7.

**Acceptance range: X > 0.5.

attitudes on the CDWMH is accepted as its t-value is 2.111 (Hair Joseph et al., 2019). Results indicate that stakeholders involved in CDWM in large construction companies in Australia, including head-contractors, consultants, and sub-contractors, significantly affect the CDWMH. However, it was revealed that head-contractors have a strong attitude to reducing waste rather than reusing and recycling, which might be related to their preference for profit maximisation rather than CDWM itself (Forghani et al., 2018; Li Hao et al., 2008; Manowong, 2012; Udawatta et al., 2015a), and their insufficient knowledge and awareness about processes for reusing and recycling CDW (Jin et al., 2017). Likewise, for consultants, the finding aligns with the results of (Jin et al., 2017; Kpamma and Adjei-Kumi, 2011; Osmani et al., 2008), in which architects and engineers are believed to have a vital role in reusing and recycling CDW. Sub-contractors were also influential in CDWM, especially in reusing and recycling as they are the main parties that confronting and dealing with CDW directly (Lockrey et al., 2016; Saunders and Wynn, 2004) and have a great preference for profit extracted from CDW (Udawatta et al., 2015a).

6.2. H_2: The impact of CDWPLC on the CDWMH

The second hypothesis (H_2) which reflects the impact of the life cycles of CDW project on the CDWMH is rejected as its t-value is below the accepted threshold (t-value: 0.697) (Hair Joseph et al., 2019). In contrast to previously reported findings, the CDWPLC, including the planning and design phase (Esa et al., 2017a), procurement phase (Silva et al., 2017), and construction and demolition phase (Ding et al., 2016) was not found to affect CDWM in the Australian construction industry. The findings are inconsistent with the related literature. For instance, Hardie et al. (2007) revealed the pivotal role of a written site waste management plan in minimizing CDW during the construction and demolition phase of commercial construction projects. Likewise, Brennan et al. (2014) identified many challenges with inefficient strategies of CDWM, such as ineffective management of waste during the construction and demolition phase. Other studies have also considered the significance of CDWM during procurement and planning and design phases (e.g., Dejkovski, 2016; Lu et al., 2017; Udawatta et al., 2015b). One possible explanation for this inconsistency can be attributed to imbalance perception of CDWM stakeholders towards different life cycles of a project in CDWM. In another word, while CDWM during planning and design phase as well as procurement phase have received appropriate attention from stakeholders, CDWM in construction and demolition phase has been ignored. This imbalance trend was also noticed during statistical tests where pertinent indicators to construction and demolition phase were removed.

6.3. H_3: The impact of SCDWM on the CDWMH

The third hypothesis (H_3) which reflects the impact of SCDWM on the CDWMH is accepted because its t-value is above the accepted threshold (t-value: 1.692) (Hair Joseph et al., 2019). Of the four exogenous constructs in this study, this construct was the only one for which none of its indicators were removed. This emphasizes the significance of SCDWM, including economic, environmental, and social aspects of CDWM in the Australian construction context. This finding is aligned with the findings from previous studies. For instance, social aspects of CDWM such as safety and health concomitant with CDW sorting, handling, transportation, recycling, and disposal, as well as awareness of illegal dumping of CDW by the public were shown to have a great impact on CDWM (e.g., Wahi et al., 2016). Meanwhile, economic aspects of CDWM, including incentive policy for CDWM, costs of materials and resources, landfill tax, costs of disposal, costs of transportation, and costs associated with reusing and recycling strategies have also been substantiated by some other researchers (e.g., Li and Du, 2015; Marzouk and Azab, 2014). Lastly, the environmental aspects of CDWM, such as concerns with preserving natural resources, greenhouse gas emissions mitigation, preserving water, air, and soil from pollution, and global warming concerns have also been proved critical in reducing, reusing, and recycling CDW (e.g., Crawford et al., 2017; Jain et al., 2020).

6.4. H_4: The impact of CDWMT on the CDWMH

The fourth hypothesis (H_4) which reflects the impact of CDWMT on the CDWMH is accepted because its t-value is above the accepted threshold (t-value: 1.721) (Hair Joseph et al., 2019). Initially, it was revealed that some CDWMT, including BIM, RFID, GIS, GPS, Big Data, lean and green rating system have a low impact on the CDWMH in the Australian construction industry. Except for the green rating system, which has been applied in CDWM in the Australian context (Zillante et al., 2020), the application of other mentioned tools in the Australian construction industry is limited. Although this finding is consistent with the application of CDWMT in Australia (Kabirifar et al., 2021), it is dissimilar with the global trend of utilizing these tools in CDWM (e.g., Karaz et al., 2021). Meanwhile, the results showed that other CDWMT, including circular economy, zero waste, site waste management plan, prefabrication and modularization have a great impact on the CDWMH. This finding is consistent with the related literature. For example, reuse, reduce and recycle methods are the key principles of circular economy (Huang et al., 2018) and in a study by Pomponi and Moncaster (2017), some dimensions for circular economy research such as environmental, social, economic, governmental, technological and behavioural factors were considered effective for CDWM. Similarly, zero waste (Zaman and Lehmann, 2011), site waste management plan (Ajayi et al., 2015), prefabrication (Tam and Hao, 2014) and modularization (Quale et al., 2012) were also shown to be effective in CDWM.

6.5. H_5: The impact of the CDWMH on ECDWM

The fifth hypothesis (H_5) which reflects the impact of the CDWMH on ECDWM is accepted as its t-value is above the accepted threshold (t-value: 6.145) (Hair Joseph et al., 2019). The CDWMH was shown to be the most effective method to manage CDW (Huang et al., 2018; Kabirifar et al., 2020b), however, recycling strategy received more attention rather than reusing and reducing strategies. Results indicated that the CDWMH comprising reuse, reduce and recycle strategies has a great impact on ECDWM. The finding is consistent with the findings from the

Table 6
Results for the structural model assessment.

Hypotheses	Structural path	VIF	R^2 and R^2 adjusted*	Q^2	f^2**	T-value	Decision
H_1	CDWSA - > CDWMH	1.736	R^2 (CDWMH): 0.641	CDWMH: 0.358	0.125	2.111	Accepted
H_2	CDWPLC - > CDWMH	1.383	R^2_{Adj} (CDWMH): 0.602	CDWMH: 0.167	0.013	0.697	not accepted
H_3	SCDWM - > CDWMH	2.025	R^2 (ECDWM): 0.375		0.064	1.692	Accepted
H_4	CDWMT - > CDWMH	1.753	R^2_{Adj} (ECDWM): 0.359		0.122	1.721	Accepted
H_5	CDWMH - > ECDWM	1.000			0.515	6.145	Accepted

*$R^2_{adj} = 1- (1-R^2) \times \frac{n-1}{n-k-1}$.

**$f^2 = \frac{R^2_{included-} R^2_{excluded}}{1 - R^2_{included}}$.

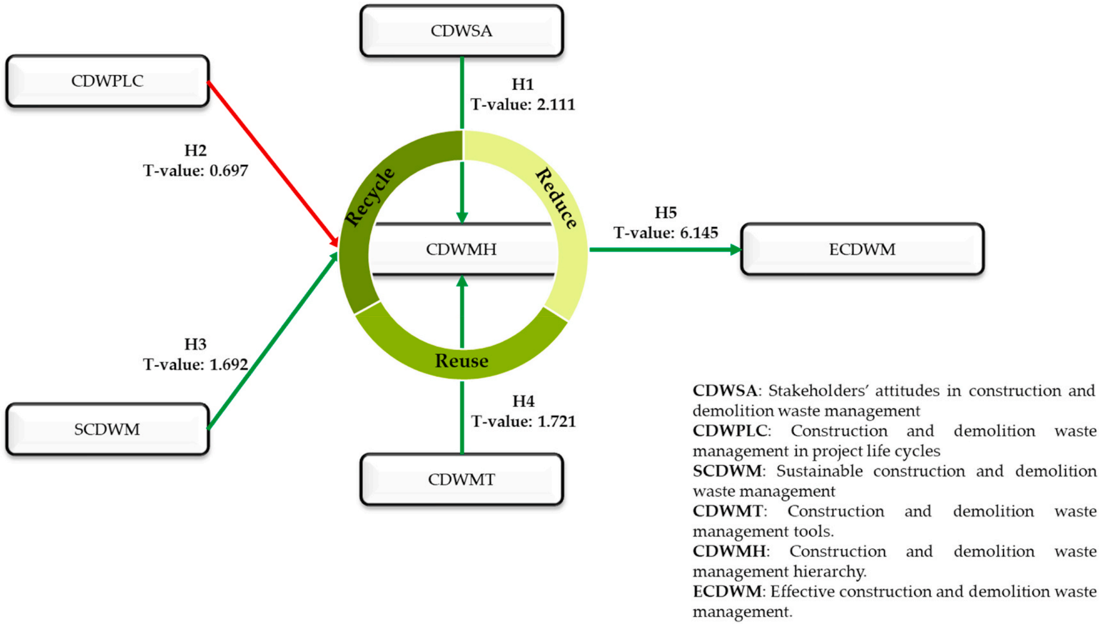

Fig. 3. T-values for research model.

literature (e.g., Ghisellini et al., 2018). Several other researchers have also considered the application of reduce, reuse, and recycle strategies for CDWM solely or combined. For instance, a mix of reuse and recycle strategies (Jin et al., 2017), the application of a reduce strategy solely (Ding et al., 2016), a recycle strategy solely (Liu et al., 2020), and in the form of the 3R principles (Huang et al., 2018) in CDWM were studied.

6.6. Manifestation of contributing factors to ECDWM

The impact of contributing factors to ECDWM, including CDWSA, CDWPLC, SCDWM, and CDWMT is manifested and measured as four separate indicators reflecting the measurement of ECDWM consistent with the literature (Kabirifar et al., 2020a; Kabirifar et al., 2020b).

7. Research implications and limitations

This study addressed the conceptual gaps in previous studies of CDWM by presenting and explaining a unique assessment framework for ECDWM. The uniqueness of the proposed conceptual framework can be explained with respect to its contributing factors and its assessment method. This framework comprised of a broad classification of factors that effectively affect CDWM including CDWSA, CDWPL, SCDWM, and CDWMT. Additionally, the concomitance of these factors with CDWMH, brough a unique form of measurement, in which not only the significance of these factors could be measured, rather the impact of them could be reflected and measured based on the preference of application in terms of reducing, reusing, and recycling strategies. It is worth mentioning that although the impact of CDWPLC on CDWMH was not empirically supported, this factor should not be ignored as many studies have highlighted the importance of CDWM during the project life cycles.

In Australia, the National Waste Policy provides waste laws and regulations for avoiding waste generation, reducing waste, dealing with waste as a resource, ensuring that waste reuse, treatment and disposal are conducted scientifically (Pickin et al., 2020). However, the volume of generated CDW in Australia is increasing because many drivers related to waste generation such as the urban population continues to grow. The empirical findings of this study could be beneficial not only for CDWM organisation-based stakeholders, but for all stakeholders involved in CDWM such as governmental bodies and developers by paying simultaneous attention to the factors that effectively affect CDWM. Stakeholders and policy makers who seek to manage CDW should understand that careful attention to stakeholder attitudes, different phases of project life cycle, sustainability considerations and managerial tools and techniques are essential for implementing CDWMH (reduce, reuse, and recycle strategies) at the organisational level while also enhancing the effectiveness of CDWM.

Besides, useful insights were provided for both industry professionals and academics involved in CDWM. Industry professionals can benefit from this research by adopting the factors that revealed effective in CDWM in their waste management plans for maximum waste management output. Academics can also benefit from this study by setting this study as a benchmark for their future studies on CDWM due to the broadness of this study in classifying factors that effectively affect CDWM and its measurement tool.

This study presented empirical evidence that contributes to knowledge about managing construction and demolition waste, but the research findings should be interpreted with respect to the limitations of this study. One of the main limitations of this study was its small sample size due to the hardship associated with data collection from Australian construction companies. Also, although a broad classification of factors that affect CDWM effectively was presented in this study, there is still a great need to address and include some sub-factors that may be effective in CDWM (e.g., GDP per capita, specific regulations, etc.). Finally, despite the reliability and validity of results, the measurement indicators for the constructs should be constantly updated in order to elaborate a framework to enhance the effectiveness of CDWM.

8. Conclusion

This research investigated the effective management of CDW considering the CDWMH including reduce, reuse, and recycle strategies by developing a conceptual framework. The results (path coefficients) from a survey of Australian construction industry professionals revealed that three contributing factors to ECDWM including CDWSA (t-value: 2.111), CDWMT (t-value:1.721) and SCDWM (t-value:1.692) have great impacts on the CDWMH, respectively. However, the CDWPLC was shown to be ineffective on the CDWMH (t-value: 0.697). This issue needs more attention from CDW stakeholders to consider the planning and design, procurement, and construction and demolition phases in their CDWM plans. This issue should also receive attention from the

Australian government by defining relevant stakeholders for CDWM in its policy as well as assigning relevant stakeholders to CDWM in construction projects from initiation to demolition.

This research provided useful insights for ECDWM in the Australian context, however future studies could strengthen the results. First, due to the challenges of data collection in Australia with respect to the confidentiality of data and approachability of people in the organizations, only large construction companies and their key stakeholders were approached, and medium and small construction companies were ignored. Second, it is recommended to study CDWM regulations and its impacts on ECDWM in detail. Also, future studies circular frameworks with more emphasis on reusable/recyclable materials. ECDWM will likely be key to transitioning to the circular economy approach and reaching sustainable development goals.

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Kamyar Kabirifar: Writing – original draft, Conceptualization, Formal analysis, Methodology, Software. **Mohammad Mojtahedi:** Writing – review & editing, Visualization, Software, Data curation, Supervision, Methodology. **Cynthia Changxin Wang:** Writing – review & editing, Visualization, Supervision, Methodology. **Vivian W.Y. Tam:** Writing – review & editing, Visualization, Supervision.

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.

Appendix A. Supplementary data

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