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# Reverse supply chain conceptual model for construction and demolition waste

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**Abstract**

Construction and demolition waste (CDW) substantially contributes to environmental degradation because of its intrinsic characteristics of fast and high generation volume, low recycling rate, and low revenue margins. A systemic problem is that recycling facilities are not usually a part of a reverse supply chain (RSC) specific for CDW. This makes the recovery process costs prohibitive, especially where companies are unable to receive and process large volumes of waste continuously. This paper presents a systematic analysis of the extant literature and utilizes the results accrued to develop a conceptual RSC model for CDW. In so doing, the research seeks to provide clarity on this phenomenon, while simultaneously stimulating wider academic discourse and further research endeavours. A mixed philosophies epistemological design was adopted using both interpretavism and constructivism to undertake a qualitative systematic analysis of the literature. A process diagram was produced to represent the conceptual model (CM) and thematically group the nodes into three key swim lanes that delineate the boundaries between distribution, manufacturing, and sourcing and warehousing processes. Within each swim lane, stakeholders were incorporated as key actors. A further layer of nuanced complexity was added to illustrate the key actors involved in the process, government strategies, and activity flow paths. This novel CM offers both practical and theoretical contributions to existing knowledge and signposts a future research direction. Such work will demystify reverse logistics for managing CDW, and assist government policy-makers to develop informed policies that reduce the negative environmental impact of construction activities.

**Keywords**

Reverse logistics, construction and demolition waste, construction and civil engineering industry, reverse supply chain, conceptual model

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## Introduction

Construction demolition waste (CDW) is an enormous issue internationally. Each year, significant volumes of waste are generated, to be later recycled or reused and for the most part, delivered to waste disposal sites. In 2017, 569 million metric tonnes (Mt) of CDW were collected in the United States (United States Environmental Protection Agency, 2017) and for 2018, 45 millions of Mt were collected in Brazil (Associação Brasileira de Empresas de Limpeza Pública e Resíduos Especiais [Brazilian Association of Urban Cleansing and Waste], 2019). In Australia, 20.4 million Mt of CDW were generated for 2017, of which approximately 66% was recycled (Pickin et al., 2018). However, in the People's Republic of China (PRC), approximately 1.8 billion Mt of CDW is generated annually and yet, the recycling rate is a mere 5% (Xinhua, 2018). To understand contemporary developments and trends in the CDW field, Yuan and Shen (2011) conducted an analysis of CDW management publications from 2000 to 2010. Yuan and Shen (2011) report that among the 7732 articles published, only 87 (1.13%) refer to CDW management. This trend demonstrates the slow, yet steadily growing interest in CDW management. Lu and Yuan (2011) published a seminal paper on the status quo of CDW management and found that attention predominantly focused upon waste reduction (42.2%), generation (23.8%), and recycling (23.8%), while scant attention

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was given to CDW elimination (6.1%) and reuse (4.1%). CDW recycling is increasingly prominent because of three palpable socio-economic benefits, namely: (a) reducing demand for new resources by providing more affordable materials; (b) reducing transportation cost and production energy consumption; and (c) reusing waste that would otherwise be lost in landfills. However, both Lu and Yuan (2011) and Yuan and Shen (2011) overlooked reverse logistics (RL) as an enabler of more efficient and effective CDW management.

The implementation of RL embodies a revaluation process that returns post-consumer waste back into the supply chain (SC) to reduce waste landfilling and boost positive impacts of industrial activity whether economic, environmental, political or social (Valle and Gabbay, 2014). Leite (2009) proffers that RL is more easily implemented for industrial waste because the commercial value is higher when compared with other sources such as solid waste. Hosseini et al. (2013) completed the first review of RL in the construction and civil engineering industry (herein referred to as simply the 'construction industry' for brevity). Hosseini et al. (2013) performed a qualitative meta-analysis of the extant literature to highlight the factors that influence the adoption of RL. Hosseini et al. (2015) subsequently expanded upon this earlier work by identifying the barriers and advantages of RL implementation. Other researchers have since expanded the field of investigation. For example, Schamne and Nagalli (2016) investigated the literature on RL in the construction industry – the main barriers encountered and practices that motivated RL implementation. More recently, Pushpamali et al. (2019) examined the current focus of RL practices in the construction industry using comparative data mining and content analysis. This aforementioned prevailing body of knowledge has predominantly focused on analysing the RL practices within construction companies. Thus, previous reviews have failed to holistically focus upon the entire RL process and have overlooked other important nodes (e.g., landfills, CDW generation points, and recycling centres) within the reverse supply chain (RSC) for CDW.

Given this knowledge gap, this paper proposes a conceptual model (CM) of an RSC for the construction industry, based upon a systematic analysis of the prevailing RL literature.

This model provides the first blueprint for the entire RL process and consequently, affords government policy-makers with an invaluable opportunity to develop policies that reduce the negative environmental impacts of construction activities. For each node of the RSC, the CM includes information that delineates the key actors involved, their roles and objectives within each node and how nodes interact with other nodes in terms of materials, feedback and/or government subsidies flow.

This study also contributes to knowledge via a theoretical feedback model, which includes two learning loops – one dedicated to private and the other to public organizations. This model should help the exchange of knowledge between RSC actors in order to resolve inter-organizational and intra-organizational obstacles that hinder process optimization.

Concomitant objectives are to: distinguish best practices adopted within industry and apply these in one integral model; identify any barriers or enablers to the CM's successful implementation; and define and delineate research gaps in existing knowledge and propose suggestions for future research investigation.

## Research methodology

For this research, the epistemology adopted a mixed philosophies design (Newman et al., 2020; Roberts et al., 2019) set within an inductive research approach (Dixon et al., 2020). Specifically, the interpretivist philosophy was adopted (cf. Al-Saeed et al., 2019) to analyse the extant literature as part of a systematic literature synthesis, where each publication represented a unit of analysis (Chamberlain et al., 2019). A limitation of the interpretivist philosophy is that researchers are prone to the risk of introducing confirmation bias – a phenomenon often associated with hermeneutic research with its emphasis on subjective interpretations (Williams, 2000). Elements of constructivism were adopted too, to analyse the discourse within the prevailing literature using both generic and open-ended questions (Creswell, 2018; Mohamed et al., 2019). This provides greater freedom to construct informed opinions and views on the phenomena under investigation, hence enabling researchers to acquire a deeper understanding of them (Van Bergen and Parsell, 2018).

Inductive research undertaken (cf. Jebb et al., 2017) used grounded theory (Charmaz, 2014) to construct theories about reverse supply chain management (RSCM) of CDW. This approach could more explicitly elucidate the key constituent parts of the RL process including actors, key government strategies and process flows. Inductive research is well-established within the construction literature and has been used to: develop a socio-technical system framework for implementing block chain (Pärn and Edwards, 2019); conceptualize the state of the art of corporate social responsibility (Xia et al., 2018); and conduct a critical review of the extant literature using bibliometrics (Roberts et al., 2019). Cumulatively, this body of knowledge illustrates that the inductive research approach is an appropriate strategy for the current research investigation.

### *Research methods and design*

The systematic review (SR) was based upon the guidelines provided by Borrego et al. (2014), on the planning, conducting and reporting of SRs. First, the following research questions were formulated, namely: (a) what are the most efficient implementation practices of RL in the construction sector? (b) which are the most cited nodes of the RSC for CDW? (c) which are the most cited key actors of the RSC of CDW? and (d) which are the most cited flow paths of the RSC for CDW?

To collect articles, three inclusion criteria were prescribed, namely: (a) papers must be published in English; (b) the research reported must analyse the logistics of a CDW transportation

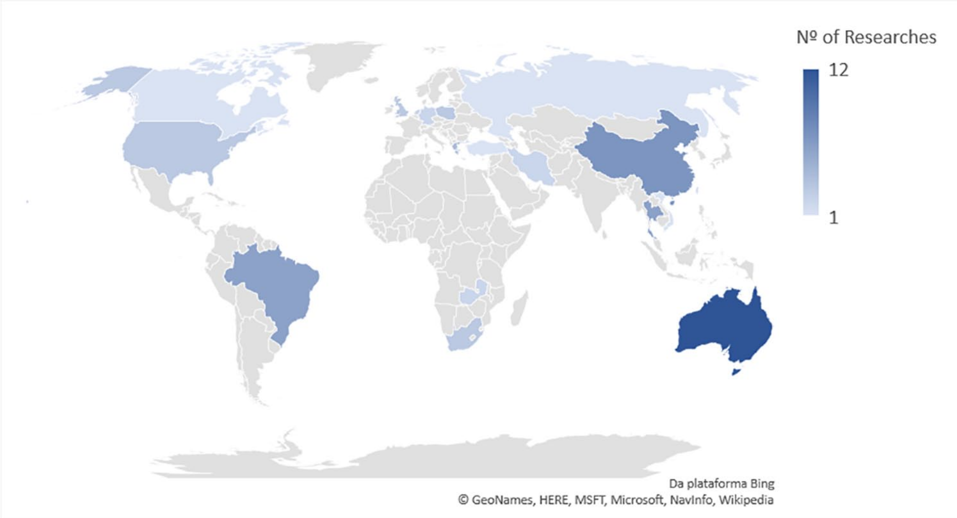


**Figure 1.** Distribution of the researches by authors' country of origin.

activity; and (c) papers must analyse a CDW movement activity on a RSC. To identify relevant papers, the search protocol proposed by Wu et al. (cf. 2014) was adopted. A desktop search was undertaken using the 'title/abstract/keyword' fields. Keywords were combined as follows: 'logistics' AND 'construction and demolition waste'; 'logistics' AND 'demolition waste'; 'logistics' AND 'construction waste'; 'reverse logistics' AND 'construction and demolition waste'; 'reverse logistics' AND 'construction waste'; 'reverse logistics' AND 'demolition waste'; "reverse logistics' AND 'construction industry'; 'supply chain' AND 'construction and demolition waste'; 'supply chain' AND 'construction waste'; and 'supply chain' AND 'demolition waste'.

The search was performed using 'Scopus' to ensure maximum coverage of the prevailing body of knowledge. In the first iteration, completed in January 2019, 278 publications were found but following a manual screening process, 170 duplicates were removed to leave 108 potential scientific papers. A manual filtration and screening of the articles' titles, keywords and abstracts (using the inclusion criteria previously elucidated upon) revealed that only 59 publications (from the initial 108) were within the scope. However, only 54 papers were available online. Using these 54 papers as a basis, a non-probability snowballing process was performed to create a comprehensive pool of studies on the topic. All references cited within these articles were individually collected. A total of 1560 papers were initially found and then, duplicates were eliminated prior to reading and analysing the titles, keywords and abstracts. Finally, 47 new publications were included in the detailed analysis stage.

These resulted in a pool of 101 papers to be used as the basis of a detailed content analysis. At this stage, the introduction, methodology, findings and conclusion were read to determine whether the publication fell within the scope of this research. This analysis resulted in 49 papers being rejected, leaving 52 papers for the data extraction stage.

To organize the references and to support the process of data extraction and results analysis, the software 'Start 2.3' tool was used. Start 2.3 supports the SR process by organizing information accrued such as the research questions, search and selection strategies, and inclusion and exclusion criteria.

## Descriptive bibliometric analysis

The first article in the pool was published in 1998 but the interlude between this work and the next paper published was six years (namely 2004) – refer to Figure 1. From 2004 onwards, research grew at a slow pace until 2013 when a notable surge in publications was observed: 1.55 per year (2004 to 2012) to six publications per year (2013–2018). Figure 1 illustrates that active researchers are geographically dispersed but major masses of cohesive research are generated in Australia, Brazil, the PRC and the United States.

In contradiction to Yuan and Shen (2011) and Lu and Yuan (2011) who found that developed countries/regions were the largest contributors to CDW management research, studies on RL in the construction industry have a relatively uniform geographical distribution. Figure 1 reveals that among the 18 countries with publications, 10 are developed countries and eight are considered developing or emerging. The same pattern is observed in the top five countries, two are developed (Australia and Greece) and three are emerging (the PRC, Brazil and Thailand) according to the International Statistical Institute (2018). Furthermore, the top three countries (namely: Australia, the PRC and Brazil) accounted for 48.07% of all identified publications, with Australia and the PRC having a longer-term track record of CDW management (cf. Lu and Yuan, 2011; Yuan and Shen, 2011).

Scientific journals are the main method of research dissemination, representing 75% (39 papers) of the publications. Of the eight journals with more than one publication, seven are not construction management focused – indicating that environmental scientists and ecologists represent the vanguard of scientific investigation. This final set were categorized into survey, case study, literature review or experiment (cf. Yuan and Shen, 2011). Most authors (61.53%) use a case study, confirming the previous observations of Yuan and Shen (2011) and Hosseini et al. (2015).

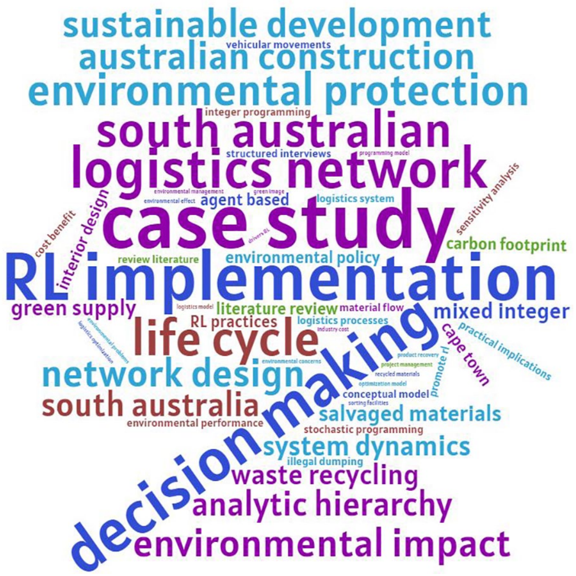


**Figure 2.** Word cloud analysis of the collected 52 papers.

## Content analysis

The operational aspects of implementing RL efficiently (cf. Dowlatshahi, 2000), were adapted as a framework to define the clusters of analysis, namely: cost–benefit analysis; RSCM; remanufacturing and recycling; transportation; and warehousing. Content analysis was performed by examining the 52 papers' titles, abstracts and keywords, and then grouping papers into arbitrary thematic clusters – refer to Figure 2. The web-based content analysis software 'Voyant Tools' was then used. Several articles were included in two or more clusters because they spanned various operational aspects of RL; for example, Fu et al. (2017) propose a model of an RSC based on the trade-off between cost and recycling rate, and included both 'cost–benefit analysis' and 'RSCM' aspects. The number of papers per cluster is: RSCM (frequency ($f$) = 35); cost–benefit analysis ($f$ = 32); transportation ($f$ = 11); warehousing ($f$ = 10); and remanufacturing/recycling ($f$ = 10).

Performing content analysis based solely upon the word count is subjective because several words can have different meanings and/or be used in other contexts. Therefore, the cluster analysis was undertaken using two-word phrases analysis. Ambiguous terms that lack comprehension were excluded from the clustering process, for example, 'this study' and 'with the'. In addition, keywords defined in the protocol (e.g., construction sites, solid waste, and CDW management) were also excluded because these words were ubiquitous and were too generic for specific content analysis. For all five clusters, this research only included the 200 most frequent occurring two-word phrases for analysis.

### *Operational aspect: RSCM*

The RSCM represented the largest cluster, which contained 67% of published papers. It includes several mathematical models of RSCs with different objectives; for example, Rahimi and Ghezavati (2018) sought to maximize profit and social impact as a means to reduce environment impact, Xanthopoulos et al. (2009) sought to maximize profit for the deconstruction process at the end of a building's life, and Listeş and Dekker (2005) use a location model for recovering sand from CDW.

This cluster has a sample of 8486 words. Of the top 200 two-word phrases, only 58 were included for analysis – refer to Table 1. The top two clusters (namely *reverse logistics* and *methodologies*) account for 60.3% of the mentioned phrases and indicate extensive efforts to implement RL from an RSC perspective (cf. Hiete et al., 2011). Conversely, concerns over environmental aspects account for only 22.33% of the references.

### *Operational aspect: Cost–benefit analysis*

The second biggest cluster is '*cost–benefit analysis'* – with 61% of papers. Most studies in this cluster represent practical quantitative applications. For example, Sobotka and Sagan (2016) examined cost-saving RL and waste management activities, Sea-Lim et al. (2018) investigated the feasibility of RL operations of steel waste recovery, and Oliveira Neto and Correia (2019) examined the economic advantages of adopting RL for recycling CDW in Brazil. Qualitative studies include: Chileshe et al. (2018) who investigated the drivers of RL implementation in the South Australian construction industry; and Rameezdeen et al. (2016) who examined the barriers faced by South Australian construction companies when attempting to implement RL operations.

The sample – 8042 words and 64 unique two-word phrases – were analysed (see Table 2). The cluster '*methodologies*' was first with 33.73%, while second and third were *reverse logistics* and *environment* both with approximately 24% each. This finding suggests that most cost–benefit studies analyse RL feasibility and environmentally-driven operations (cf. Fehr and Marques, 2013).

### *Operational aspect: Transportation*

A third smaller cluster, with only 11 papers (21%), is '*transportation*'. Most studies in this cluster mathematically model practical applications of RL in construction, namely: Tam et al. (2014) who modelled CDW management practices using system dynamics; and Shakantu et al. (2012) who proposed a model for integrating construction materials delivery and CDW removal logistics within the same vehicle.

Here the sample contained 2628 words and 55 unique two-word phrases – refer to Table 3. Excluding 'miscellaneous' (i.e., terms that do not represent a relevant concept), the most mentioned word is '*environment*' ($f$ = 39), followed closely by a new category '*transportation*' ($f$ = 35). Most studies that analyse transportation operations focus largely on *environment factors*. Additionally, while '*reverse logistics*' was the first and second in the two previous sections, it now resides in the third place – most likely because several studies that modelled the CDW flow along the RSC, fail to associate the model with RL practices. Hiete et al. (2011), for example, proposed a model for planning a

**Table 1.** Phrase frequency of the reverse supply chain management cluster.

| Item number | Cluster | Phrase(s) | Frequency | Percentage |
|---|---|---|---|---|
| 1 | Reverse logistics (RL) | RL implementation (*f* = 15); logistics network (*f* = 13); network design (*f* = 10); green supply (*f* = 8); RL practices (*f* = 6); implementation reverse (*f* = 5); promote RL (*f* = 5); logistics implementation (*f* = 5); logistics project (*f* = 3); logistics processes (*f* = 3); recovery network (*f* = 3); dynamic supply (*f* = 3); backfill supply (*f* = 3); recycling network (*f* = 3); drivers RL (*f* = 3); and logistics optimization (*f* = 3) | 91 | 30.33 |
| 2 | Methodologies | Case study (*f* = 17); life cycle (*f* = 7); agent based (*f* = 6); linear programming (*f* = 5); stochastic programming (*f* = 5); integer programming (*f* = 5); sensitivity analysis (*f* = 5); literature review (*f* = 5); structured interviews (*f* = 5); optimization model (*f* = 4); conceptual model (*f* = 4); simulation analysis (*f* = 4); location model (*f* = 3); particle swarm (*f* = 3); swarm optimization (*f* = 3); centralized optimization (*f* = 3); cluster analysis (*f* = 3); and carbon footprint (*f* = 3) | 90 | 30.00 |
| 3 | Environment | Waste recycling (*f* = 7); sustainable development (*f* = 6); salvaged materials (*f* = 6); environmental protection (*f* = 5); waste treatment (*f* = 5); environmental performance (*f* = 5); environmental effect (*f* = 4); product recovery (*f* = 4); environmental policy (*f* = 4); recycling construction demolition waste (*f* = 3); recycling rate (*f* = 3); environmental problems (*f* = 3); potential recyclers (*f* = 3); recyclers customers (*f* = 3); environmental footprint (*f* = 3); and recycling waste (*f* = 3) | 67 | 22.33 |
| 4 | Miscellaneous | Decision-making (*f* = 11); South Australian (*f* = 11); Australian construction (*f* = 9); South Australia (*f* = 8); sorting facilities (*f* = 4); social effects (*f* = 3); government subsidy (*f* = 3); and cost–benefit (*f* = 3) | 52 | 17.33 |
| Totals | – | – | 300 | 100.00 |

**Table 2.** Phrase frequency of the cost–benefit analysis cluster.

| Item number | Cluster | Phrase(s) | Frequency | Percentage |
|---|---|---|---|---|
| 1 | Methodologies | Case study (*f* = 15); life cycle (*f* = 12); analytic hierarchy (*f* = 7); agent based (*f* = 6); carbon footprint (*f* = 6); integer programming (*f* = 5); sensitivity analysis (*f* = 5); linear programming (*f* = 5); system dynamics (*f* = 5); stochastic programming (*f* = 5); literature review (*f* = 4); optimization model (*f* = 4); review literature (*f* = 4); systems analysis (*f* = 4); simulation analysis (*f* = 4); location model (*f* = 3); particle swarm (*f* = 3); centralized optimization (*f* = 3); equation modelling (*f* = 3); correlation analysis (*f* = 3); dynamic model (*f* = 3); and multiperiod optimization (*f* = 3) | 112 | 33.73 |
| 2 | Reverse logistics (RL) | Implementation of RL (*f* = 23); logistics network (*f* = 13); network design (*f* = 10); green supply (*f* = 8); logistics project (*f* = 4); material flow (*f* = 4); dynamic supply (*f* = 3); logistics model (*f* = 3); logistics system (*f* = 3); recycling network (*f* = 3); RL practices (*f* = 3); and backfill supply (*f* = 3) | 80 | 24.10 |
| 3 | Environment | Environmental protection (*f* = 10); environmental impact (*f* = 9); sustainable development (*f* = 8); environmental policy (*f* = 6); waste recycling (*f* = 5); environmental performance (*f* = 5); salvaged materials (*f* = 5); environmental effect (*f* = 4); environmental management (*f* = 4); product recovery (*f* = 4); green image (*f* = 4); recycling construction demolition waste (*f* = 3); recycling rate (*f* = 3); environmental problems (*f* = 3); environmental policies (*f* = 3); and salvaged items (*f* = 3) | 79 | 23.80 |
| 4 | Miscellaneous | Decision-making (*f* = 10); interior design (*f* = 6); South Australian (*f* = 5); Australian construction (*f* = 5); cost–benefit (*f* = 5); industry cost (*f* = 4); steel waste (*f* = 4); sorting facilities (*f* = 4); deconstructing buildings (*f* = 3); social effects (*f* = 3); government subsidy (*f* = 3); transportation cost (*f* = 3); total costs (*f* = 3); and economic aspect (*f* = 3) | 61 | 18.37 |
| Totals | – | – | 332 | 100.00 |

**Table 3.** Phrase frequency of the transportation cluster.

| Item number | Cluster | Phrase(s) | Frequency | Percentage |
|---|---|---|---|---|
| 1 | Miscellaneous | Cape Town (*f*=6); case study (*f*=6); analytic hierarchy (*f*=5); illegal dumping (*f*=5); sorting facilities (*f*=4); South Africa (*f*=4); decision-making (*f*=3); china construction (*f*=2); direct reuse (*f*=2); economic factor (*f*=2); landfill (*f*=2); landfill charges (*f*=2); materials handling (*f*=2); natural aggregate (*f*=2); paper waste (*f*=2); processing cost (*f*=2); Quebec Canada (*f*=2); and sorting technology (*f*=2) | 55 | 35.71 |
| 2 | Environment | Environmental policy (*f*=6); technical metabolism (*f*=4); embodied energy (*f*=4); environmental protection (*f*=3); green image (*f*=3); waste recycling (*f*=3); environmental performance (*f*=2); recycled aggregates (*f*=2); recycled materials (*f*=2); recycled wood (*f*=2); recycling rate (*f*=2); materials recycling (*f*=2); waste minimization (*f*=2); and wood recycling (*f*=2) | 39 | 25.32 |
| 3 | Transportation | Materials delivery (*f*=5); vehicular movements (*f*=5); empty running (*f*=4); transportation cost (*f*=4); back loading (*f*=3); spare capacity (*f*=3); truck empty (*f*=3); delivery vehicles (*f*=2); transport distances (*f*=2); transportation energy (*f*=2); and vehicle movements (*f*=2) | 35 | 22.73 |
| 4 | Reverse logistics (RL) | Logistics network (*f*=4); system dynamics (*f*=7); flow modelling (*f*=2); logistics decisions (*f*=2); logistics system (*f*=2); network design (*f*=2); recycling network (*f*=2); and RL implementation (*f*=2); RL network design (*f*=2) | 25 | 16.23 |
| Totals | – | – | 154 | 100.00 |

regional CDW recycling network but do not mention the term RL in the title, abstracts or keywords.

### *Operational aspect: Warehousing*

The ‘*warehousing*’ cluster is relatively small (*f*=10 papers). Given that warehousing work consists of materials-management activities, the papers included all mentioned some form of CDW handling, which translates to CDW sorting processes. Consequently, 19% of papers mention CDW warehousing activities. Akin to the ‘*transportation*’ cluster, 80% of papers mathematically modelled practical applications of RL in construction. Studies included: Rahimi and Ghezavati (2018) who developed multi-period multi-objective models to design and plan a RL network under uncertainty for recycling CDW; and Trochu et al. (2018) who sought to determine the location and capacities of sorting facilities to ensure regulatory compliance. This cluster resulted in a sample of 2410 words and 42 unique two-word phrases – refer to Table 4. The ‘*methodologies*’ cluster came first, closely followed by ‘*reverse logistics*’ – cumulatively representing 57.26% of the frequency. This indicates that studies that include CDW sorting processes make use of RL practices.

### *Operational aspect: Remanufacturing/recycling*

Akin to the ‘*warehousing*’ cluster, the ‘*remanufacturing/recycling*’ cluster also had 10 papers (19%), all of which included mathematically modelled applications of RL. These included: Kucukvar et al. (2014) who developed an assessment model to investigate the net carbon, energy and water footprint of CDW recycling; and Chong and Hermreck (2010) who examined the transportation energy use for recycling CDW and the actual recycling rate on construction projects. This cluster contained a sample of 2555 words and 47 unique two-word phrases – refer to Table 5. For the first and only time, the ‘*environment*’ cluster is the most mentioned (*f*=59), with 40% of the sample. This reveals that CDW remanufacturing or recycling studies are largely environmentally oriented (cf. Oliveira Neto and Correia, 2019).

## The main nodes of the CDW RSC

To build a cogent CM, this research first mapped all the main RSC nodes mentioned in the collected literature. It was assumed that each node represents a relevant type of discrete operation within the RSC. Hence, each node adds value to the material flowing through the RSC network that is interconnected by flow-paths which represent a logical corridor between locations along which materials and/or information flows (Sehgal, 2009). The scientific literature currently disagrees on which nodes should be included in the RSC – thus, further substantiating this present study. Figure 3 presents all nodes cited by authors within the extant literature and a categorization of each node. Notably, there are four common nodes for all authors, namely: ‘*generation point*’; ‘*recycling centre*’; ‘*landfill*’; and ‘*consumer node*’ of recycled CDW. The flow-paths were designed and inserted within Figure 3, according to the same scientific literature.

The current literature was able to identify and categorize most existing nodes in the CDW RSC. However, Figure 3 reveals that the vast majority of articles only focus their attention on four

**Table 4.** Phrase frequency of the warehousing cluster.

| Item number | Cluster | Phrase(s) | Frequency | Percentage |
|---|---|---|---|---|
| 1 | Methodologies | Case study (*f* = 6); systems analysis (*f* = 6); stochastic programming (*f* = 5); analytic hierarchy (*f* = 5); linear programming (*f* = 3); life cycle (*f* = 2); integer programming (*f* = 2); stochastic models (*f* = 2); uncertainty analysis (*f* = 2); economic analysis (*f* = 2); and system dynamics (*f* = 2) | 37 | 29.84 |
| 2 | Reverse logistics (RL) | Network design (*f* = 9); logistics network (*f* = 7); RL implementation (*f* = 5); logistics system (*f* = 3); waste streams (*f* = 2); logistics centers (*f* = 2); material flow (*f* = 2); recovery network (*f* = 2); and RL network design (*f* = 2) | 34 | 27.42 |
| 3 | Environment | Environmental protection (*f* = 4); recycled wood (*f* = 4); green image (*f* = 3); environmental policy (*f* = 3); product recovery (*f* = 3); environmental effect (*f* = 2); sustainable development (*f* = 2); environmental activities (*f* = 2); sustainable consumption (*f* = 2); and direct reuse (*f* = 2) | 26 | 20.97 |
| 4 | Miscellaneous | Sorting facilities (*f* = 4); sorted waste (*f* = 2); processing cost (*f* = 2); sorting technology (*f* = 2); decision-making (*f* = 2); economic factor (*f* = 2); transportation cost (*f* = 2); Quebec Canada (*f* = 2); economic aspect (*f* = 2); disposal capacity (*f* = 2); landfill disposal (*f* = 2); and paper waste (*f* = 2) | 27 | 21.77 |
| Totals | – | – | 124 | 100.00 |

**Table 5.** Phrase frequency of the remanufacturing/recycling cluster.

| Item number | Cluster | Phrase(s) | Frequency | Percentage |
|---|---|---|---|---|
| 1 | Environment | Waste recycling (*f* = 14); environmental impact (*f* = 11); environmental protection (*f* = 4); recycled materials (*f* = 4); recycling plants (*f* = 4); environmental damage (*f* = 3); product recovery (*f* = 3); sustainable development (*f* = 3); waste treatment (*f* = 3); environmental advantages (*f* = 2); environmental performance (*f* = 2); environmental pollution (*f* = 2); greenhouse effect (*f* = 2); and recycling rate (*f* = 2) | 59 | 40.41 |
| 2 | Methodologies | Case study (*f* = 7); life cycle (*f* = 6); carbon footprint (*f* = 6); stochastic programming (*f* = 5); technical metabolism (*f* = 4); embodied energy (*f* = 4); linear programming (*f* = 3); multiperiod optimization (*f* = 3); water footprints (*f* = 2); location model (*f* = 2); mathematical models (*f* = 2); stochastic models (*f* = 2); and environmental footprint (*f* = 3) | 49 | 3356 |
| 3 | Miscellaneous | Interior design (*f* = 6); decision-making (*f* = 3); disposal costs (*f* = 2); transport costs (*f* = 2); transport distances (*f* = 2); resource consumption (*f* = 2); total costs (*f* = 2); and social effect (*f* = 1) | 18 | 12.33 |
| 4 | Reverse logistics | Network design (*f* = 7); logistics network (*f* = 6); recycling network (*f* = 3); and recovery network (*f* = 2) | 20 | 13.70 |
| Totals | – | – | 146 | 100.00 |

nodes, namely: CDW generation points; recycling centres; landfills; and consumption points. This has the potential to weaken the RSC analysis due to the excessive aggregation of existing nodes in the chain. Few authors detail the nodes, or even include the government as an important RSC node.

Another weakness was the absence of identifiable actors involved in each node, and a more detailed description of how these nodes and actors interact with each other. Most researchers only created a generic graphic representation of the CDW RSC to facilitate understanding of the mathematical model it represents (Barros et al., 1998; Gan and Cheng, 2015; Hiete et al., 2011; Zhou et al., 2013).

## CM of an RSC for CDW

Premised upon the content analysis findings, a new CM for an RSC for CDW is proposed (refer to Figure 4) that is founded upon the theoretical definition of an SC model.

Dekker et al. (2013) explain that there are several prevailing viewpoints on the plethora of roles and responsibilities key actors embrace in an RL system. Some actors (such as government) are responsible for coordinating the reverse chain (Rebehy et al., 2019), while others merely perform tasks, for example, waste transportation companies (Shakantu et al., 2012). Because each actor has distinctive objectives, they may compete within a given

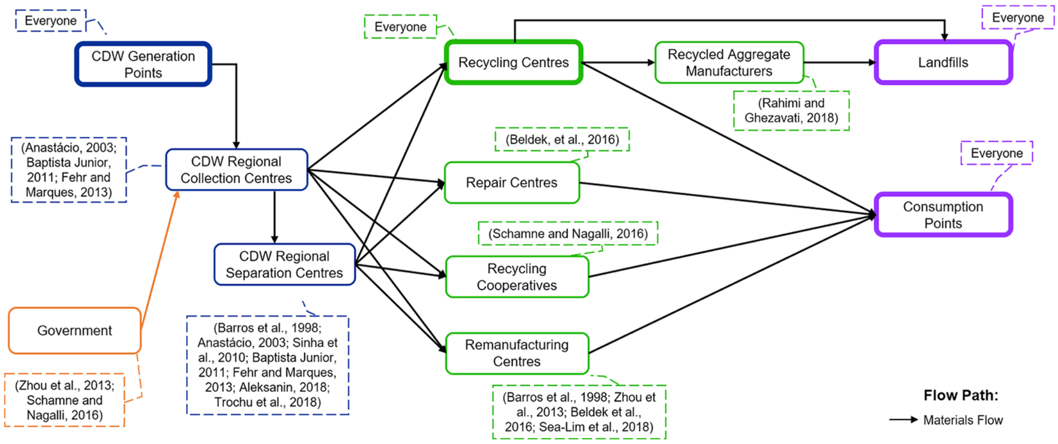


**Figure 3.** Most cited nodes of the reverse supply chain in the construction industry.

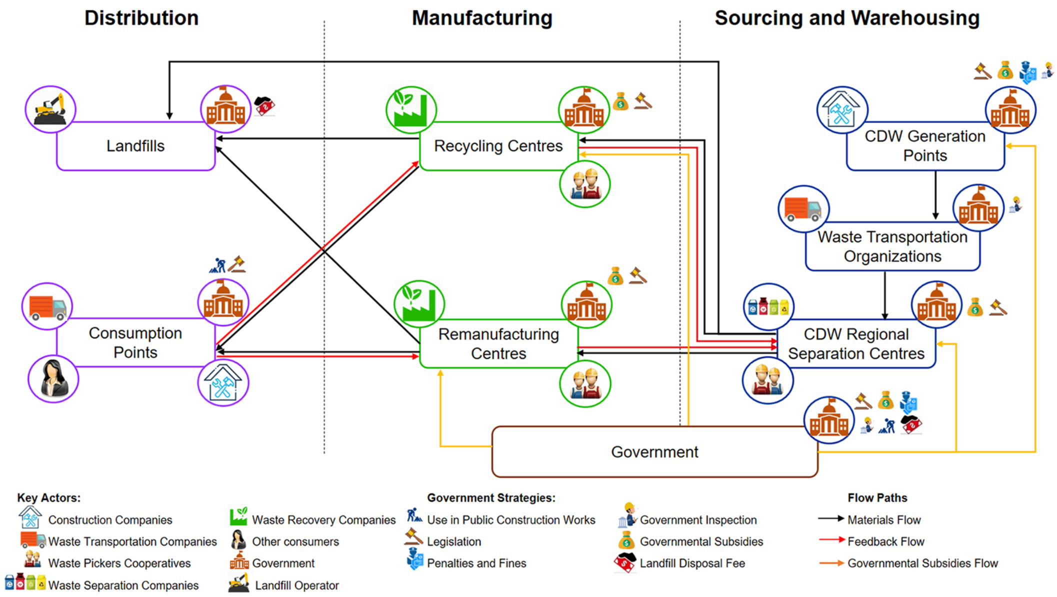


**Figure 4.** Conceptual model of reverse logistics in waste management.

node. Therefore, this model is presented in an 'infographic map' format (read from right to left) to illustrate the various nodes, flow-paths, actors and key government strategies involved within the RSC. These nodes are linked via flow-path arrows that denote either: *materials flow* – to describe the waste recovery flow through the RL; *feedback flow* – to represent the information flow regarding the quality standard(s) and any feedback mechanisms between nodes; and *government subsidies flow* – to define and delineate the different kinds of administration incentives for the construction industry's RSC. Three swim lanes included depict three iterative stages of the system and are arbitrarily entitled: (a) sourcing and warehousing; (b) manufacturing; and (c) distribution – such nomenclature best defines activities within each swim lane.

## *Swim lane 1: Sourcing and warehousing*

Sollish (2011) defines 'sourcing' as the process of locating and employing suppliers that add maximum value to the buyer's product or service. Hence, this first stage was named after the waste supply process coming from the first node in the RSC: CDW generations points. However, it also includes warehousing operations at the 'CDW regional separation centres'. Keller and Keller (2013) explain that those operations contribute to the RSC by adding value through consolidating multiple orders and sequencing materials from multiple third-parties logistics providers for recycling/remanufacturing centres' production lines.

*CDW generation points.* This node acts as a CDW supplier for the whole chain and hence, represents the source of waste (Hiete et al., 2011) and can also be defined as: construction projects (Sinha et al., 2010); or deconstruction works (Schamne and Nagalli, 2018). This node adds value because it transforms materials arising from construction activities into CDW to create the basic input within the RSC. Because this node is usually managed by construction enterprises, '*construction companies*' are identified as key actors who typically operate the production of CDW in the most cost-effective manner (Gan and Cheng, 2015;

Zhou et al., 2013). However, government represents another proactive actor who performs essential public administration duties within this node and preserves the environment via compliance with international climate change agreements (Rebehy et al., 2019). Therefore, public administration targets (that drive sustainable CDW production and management) are achieved via four different strategies, namely: (a) legislative instruments; (b) subsidies; (c) fines; and (d) inspection.

Legislative instruments enforce: a level of deconstruction (Chinda, 2017); a level of recycling (Barros et al., 1998); CDW management public policies (Schamne and Nagalli, 2018); and/or other CDW management laws (Rinsatitnon et al., 2018). Laws to enforce a level of deconstruction are imperative, as Xanthopoulos et al. (2012) verified that deconstruction of buildings is typically more costly than demolition. Regarding the second legislative instrument, Trochu et al. (2018) found that given the associated costs, CDW is only recycled when there is a legal imposition. Governmental subsidies and tax benefits for builders (cf. Hiete et al., 2011) and/or other incentives are also necessary (cf. Chong and Hermreck, 2010; Liang and Lee, 2018). The last two strategies (namely: penalties and fines, and government inspection) are necessary to support the legislation strategy (Chinda, 2017; Tam et al., 2014). Chileshe et al. (2015) suggest that the government stimulate contractors to practise RL via incentives and tax benefits, but also facilitate the dispatch of deconstruction licenses. However, the actors ‘contractors’ and ‘government’ have conflicting objectives because enforcing a level of deconstruction goes against the cost-effective production of CDW.

Hosseini et al. (2014) noted that contractual obligations exert tremendous financial pressure upon the contractor and demolition contractor to expediently remove unwanted buildings and clear the site for new construction. Hosseini et al. (2014) argue that high visibility projects (e.g., government projects) are unsuitable for RL because such projects have a tight schedule, zero tolerance policy for safety and quality risks. Conversely, Chinda et al. (2013) note that ‘*limited project schedule*’ is a decisive factor in adopting RL. Chileshe et al. (2016b) proffer that at the project level, it is important to perform deconstruction rather than demolishing at the end of a building’s life-cycle. However, Chileshe et al. (2016b) also noted that this process is only efficient if the whole industry provides appropriate services, with nearby facilities for the required functioning. Xanthopoulos et al. (2012) add that the deconstruction process could be profitable only in small percentages (5–25%) or for buildings constructed using a higher value steel structure. Materials’ flow that exits this node is characterized as a bundle of raw CDW, which is collected and directed to the next node (Sinha et al., 2010).

*Waste transportation organizations.* This node adds location value onto the CDW. That is because waste transportation organizations are instrumental in efficiently moving raw CDW through the RSC (Chinda and Ammarapala, 2016; Schultmann and Sunke, 2007). This can be achieved by reducing the distance among collection, sorting and recycling points (Trochu et al., 2018). Operational responsibility for transportation can reside with a private company (Aleksanin, 2018; Shakantu and Emuze, 2012) or public administration (Schamne, 2016). Chong and Hermreck (2010) and Hiete et al. (2011) argue that RSC efficiency is augmented when operations are located at a regional level. That is, operations are limited by the CDW composition, technological capacities available at recycling plants and available options for using recycled products locally. Nunes et al. (2009) found that by locating CDW recycling centres near urban conurbations, transportation costs are reduced as these centres act as both CDW supply and demand points for recycled materials. Furthermore, the creation of an interconnected network of small CDW disposal points distributed throughout urban conurbations better caters for small CDW generators (e.g., individual houses) (Nunes et al., 2009). Indeed, the government, as a major stakeholder within this node, also executes the ‘*government inspection*’ strategy. Although there is no specific legislation strategy applied in this context, government control and monitoring activities assist in preventing illegal or improper CDW dumping (Lockrey et al., 2016). There is no ‘*governmental subsidies flow*’ entering this node, because waste transportation companies usually charge contractors for collecting waste. Additional funds may also be raised via the cash payments received from separation centres for waste delivery (Chong and Hermreck, 2010; Trochu et al., 2018).

*CDW regional separation centres.* This node was included because the CM assumes that the separation process should occur off-site, due to several reasons which are now elucidated upon. Rameezdeen et al. (2016) cite work safety regulations in Australia, while Sea-Lim et al. (2018) state that specific sorting technology and specialized staff are needed to sort waste efficiently in limited time. Others such as Listeş and Dekker (2005) and Chong and Hermreck (2010) explain that CDW is often handled, separated and processed multiple times in different locations and transported to different facilities, making on-site sorting activities redundant.

Chinda et al. (2013) found that specific separation technology is an important sub-criterion of economic criteria that influences the decision as to which RL practices are adopted. Other researchers advocate off-site sorting of CDW at recycling centres (Hiete et al., 2011). Contrary arguments however abound on this topic. Tam et al. (2014) explain that on-site separation is ideal because it reduces the amount of CDW discarded into landfills. Chileshe et al. (2016a) confirm the importance of on-site CDW screening as a critical factor in facilitating RL adoption. Sinha et al. (2010) found that significant amounts of CDW are not separated at source; consequently, CDW is frequently mixed with municipal waste, making them bulky, difficult to treat and inadvertently increasing CDW transportation and handling costs. Nunes et al. (2009) state that on-site CDW separation is problematic because recycled materials do not have homogeneous physical or chemical characteristics – this prohibits their use in concrete structures.

Sobotka and Czaja (2015) concur and add that the quality of the separation process affects the quality of the recycled waste. Wang et al. (2004) and Lockrey et al. (2016) both noted the same issue and found that separation on construction sites is not realized due to a lack of technology, capacity and resources. These aforementioned studies suggest that the efficiency in separation practices influences the amount of CDW generated after segregation. Wang et al. (2004) therefore propose increasing the separation process efficiency through training, planning and exchange of experience. Moreover, Rahimi and Ghezavati (2018) and Beldek et al. (2016) argue that the higher the on-site CDW separation level, the higher the profit, the lower the environmental impact and the greater the social impact. This is because, it is cheaper to separate CDWs at generation points, which in-turn reduces the amount of waste sent to landfills, and ultimately increases job creation at installed and expanded recycling centres.

Sobotka and Czaja (2015) first argued in favour of on-site separation based on social aspects, more specifically on worker security. Sobotka and Czaja (2015) claim that meticulous and systematic emptying of the waste container prevents hazardous waste from occurring in the workplace. Sobotka et al. (2017) claim that selective waste collection is key to the development of RL chains. With just simple on-site processing (mobile crushing, cleaning, etc.) and through differentiated dispatch between recycling plants, the RL chain can expand significantly. Thus, depending on the country's regulations, this node is unnecessary for the RL network, since its main operation might occur at the '*CDW generations nodes*', at the '*recycling centres*' or at the '*remanufacturing centres*'. Regardless, this node aims to add value to CDW through the material separation process in accordance with the quality standards required by the recycling/remanufacturing centres (Chong and Hermreck, 2010; Wang et al., 2004). Quality standards are required since the inherent composition of CDW makes it difficult for the RL because the size and quality of waste is generally not standardized and often contains unexpected hazardous substances (Schultmann and Sunke, 2007). Based on this CM's premise of off-site separation, it is assumed that sorting operations can be undertaken by private companies (Trochu et al., 2018), public administration (Sinha et al., 2010), or waste pickers cooperatives (Schamne and Nagalli, 2018). All three key actors within this node share the same objectives to plan, execute and control the CDW sorting process according to the required quality standard. Where '*waste separation companies*' or '*government*' are running this node's operation, collaboration with '*waste pickers' cooperatives*' (as a viable work-force) is also advised. The inclusion of these actors enables the integration and employability of skilled labour for greater productivity, efficiency and social responsibility (Schamne and Nagalli, 2016).

The stakeholder '*government*' also has different strategies to implement depending on the role it plays in the separation process. When assuming responsibility for the sorting process, it applies the '*legislation*' strategy through the 'quality standards for the CDW delivered to the recycling/remanufacturing centres' tactic (Schultmann and Sunke, 2007). Chong and Hermreck (2010) noted that most materials sent for recycling were returned because they failed the prerequisite quality requirements standard for the recycling plants. Wang et al. (2004) found that the quality of CDW from different generating sources can influence the decisions of recycling plants to process waste in various products with different efficiencies. Furthermore, Fehr and Marques (2013) state that the disposal rate for CDW arriving at a receiving centre should be based on the quality of the batch waste sorting. This is because, well-sorted waste pays lower rates than poorly sorted material, since the latter increases on-site operating expenses. Sobotka et al. (2017) affirm that waste receiving costs vary widely among recyclers – in the order of 100% or more.

When the '*CDW regional separation centres*' are managed by a private business, the '*government subsidies*' strategy should be utilized via '*other incentives*' tactics (Liang and Lee, 2018). The two feedback flows entering this node represent an important information type flow of quality standards required by the recycling/remanufacturing centres (Wang et al., 2004). One of the material's flow-paths refers to unrecoverable CDW. Fu et al. (2017) and Xu et al. (2018) verified that after the separation process, irredeemable CDW may transpire due to waste contamination and/or lack of recycling technology.

*Government.* This node is the first and only one with operations in two different stages: '*sourcing and warehousing*'; and '*manufacturing*'. Like '*CDW generations nodes*', it constitutes a generic representation of public administration. Public administration is otherwise known as a: department/agency of environmental protection (Aidonis et al., 2008; Wang et al., 2004; Zhou et al., 2013); federal ministry of environment, state environmental agencies (Rebehy et al., 2019); senior environment protection office (Chileshe et al., 2016a); or municipal administration (Fehr and Marques, 2013). The government node adds value by providing financial subsidies for four other nodes of the RSC of CDW. Those incentives help reduce the operational cost of each of the four benefited nodes, since RL practices are not usually economically sustainable (Liang and Lee, 2018). As a key stakeholder, the '*government*' must coordinate all six strategies that drive RL within the CM (Rebehy et al., 2019). This last node has four exit flows, all related to the different kinds of government incentives for the RSC of CDW.

## Swim lane 2: Manufacturing

In this swim lane, the process of transforming the CDW physical properties occurs, either through '*recycling*' or '*remanufacturing*'. Because both nodes have similar characteristics, their description was combined.

*Recycling/remanufacturing centres.* These nodes are incorporated into the model as generic representations of CDW recovery facilities. The actual size and complexity of a facility depends upon available regional technology and the quality of sorting processes, as performed on the previous node (Hiete et al., 2011;

Wang et al., 2004). Similar to the '*CDW regional separation centres*' node, these facilities can be managed by private '*waste recovery companies*' (Rahimi and Ghezavati, 2018; Xu et al., 2018) or '*government*' (Nunes et al., 2009) – both have similar goals of planning, executing and controlling the CDW recovery process, in conformity to required quality standards and at the lowest possible cost.

Akin to the '*CDW regional separation centres*' node, the key actor '*waste pickers cooperatives*' should be included as the workforce (Schamne and Nagalli, 2016). However, the environmental impact of the CDW recovery process is problematic. Chong and Hermreck (2010) found that the energy footprint associated with transporting CDW is significant – specifically, more energy is needed to direct materials to a recycling facility vis-à-vis transporting it directly to landfills (cf. Hiete et al., 2011). Quality standards for recovered CDW constitute a major issue in the construction industry too. Chileshe et al. (2016b) verified that the absence of 'quality control compliance for reclaimed products' is a barrier to RL adoption. Accordingly, the stakeholder '*government*', regardless of operating the centres or not, should use the '*legislation*' strategy through the 'quality standards for recycled CDW' tactic (Chileshe et al., 2015; Sinha et al., 2010). However, when the public administration is not responsible for the CDW recovery process, they must implement the 'government subsidies' strategy (e.g., tax benefits) for recycling/remanufacturing centres. Zhou et al. (2013) propose that government subsidies can improve the profit of recycled CDW in the SC. Fu et al. (2017) compared the influence of government incentives or fines in an RL network and determined that incentive subsidies are more effective, especially when the RSC profitability is low. Schamne and Nagalli (2016) proffer that supplying financial subsidies to recycling plants represents a viable public policy that stimulates the growth of CDW recycling in European countries.

The entry feedback flow path indicates the information type flow of relevant quality standards required by the '*consumption points*' (Sinha et al., 2010), and the exit flow represents the quality standards that recycling/remanufacturing centres require from the CDW regional separation centres (Wang et al., 2004). The last three process flows illustrate the materials' transportation movement. The sorted CDW received from the previous node enters the recycling/remanufacturing centres and after the recovery process, exits as recovered CDW which are distributed to different consumption points. The second exit material flow consists of waste generated by the CDW recovery production process that is landfilled.

## Swim lane 3: Distribution

The final swim lane represents the distribution of products and different kinds of waste, for example, products that can be recycled or remanufactured. Waste distributed can also include unrecoverable CDW, such as heavy metal scrap and some types of plastic (Fu et al., 2017; Xu et al., 2018).

*Landfills.* This node is characterized as the final waste storage space produced at various nodes within the RSC. Its operation can be managed by private companies (Yuan, 2014), the government (Beldek et al., 2016; Sinha et al., 2010) or even by a public–private partnership contract (Saadeh et al., 2019). Both '*government*' and '*landfill operator*' actors, when responsible for its operation, share the same objective which is to plan, execute and control the CDW disposal process. Xu et al. (2018) state that the recycling ratio of CDW is directly influenced by the disposal fee – this illustrates that government can leverage the volume of CDW recycling to protect the environment through the landfilling fee. This happens because it is cheaper for contractors to dispose of CDW directly to landfills than to implement RL (Chileshe et al., 2016a; Hosseini et al., 2014; Rameezdeen et al., 2016). Therefore, '*government*' should use the '*landfill disposal fee*' strategy in order to promote RL implementation (Tam et al., 2014). Government can use this strategy directly, when it is also responsible for the landfill operation, or indirectly when private companies manage the landfills. Notably, an unreasonable increase of landfill disposal fees can engender larger volumes of waste being illegally dumped. Because this node is one of the final destinations of materials that travel through the RSC, it only has materials entry flows and all of them consist of waste.

### Consumption points

These nodes represent the final consumption points of the recovered CDW. Because recovered CDW varies in type, it is represented on the model as generic representations of different final clients that consume the output product of this RSC. The quantity and type of consumption points correlate with the regional demand (Chong and Hermreck, 2010). Hence, when responsible for its operation, the three key actors of this node '*other consumers*', '*construction companies*' and '*government*' pursue the same objective of employing the recovered CDW as some kind of materials input into their production processes and in the most cost-effective manner.

As the fourth stakeholder, '*waste transportation companies*' have the potential to benefit from the operation of this node. Schultmann and Sunke (2007) found that empty cargo transportation is a common problem in logistics activities. This problem results from: the bespoke characteristics of the construction industry; the complex and heterogeneous structure of the product; the uncertain and non-static accumulation of waste in deconstruction projects; and scattered product locations. Chinda and Ammarapala (2016) complemented this characterization of the problem by stating that combining material delivery and collection activities can reduce the economic and environmental impacts of transportation activity in RL. Lockrey et al. (2016) report that building material suppliers also assume responsibility for cleaning, collecting, transporting and even disposing of CDW, to avoid transporting empty cargo upon return of material deliveries. To quantify this solution, Shakantu et al. (2012) conducted a pilot study, aimed at utilizing the idle capacity of material delivery vehicles through RL on construction sites. This approach enhances productivity without increasing vehicle fleet sizes. In the proposed model (Shakantu et al., 2012), the results demonstrated a 42% reduction in vehicle transportation with empty loads. One problem faced by this node was addressed previously, as recovered CDW is usually perceived as being low quality (Chileshe et al., 2016b) and is usually more expensive than raw materials (Chileshe et al., 2014; Lu and Yuan, 2011). Consequently, the stakeholder '*government*' should apply the '*legislation*' strategy through laws to promote utilizing the recycled CDW tactic. Chileshe et al. (2018) verified that a combination of increased regulation to use reclaimed materials with a decrease in their prices would better promote RL among contractors in South Australia. Additionally, this actor could apply the 'use in public construction works' strategy. Nunes et al. (2009) state that the government is the largest consumer of construction materials in Brazil and therefore should adopt public policies that encourage recycled CDW consumption. These policies could be applied directly when government authorities execute public projects or indirectly through contractual clauses, when public projects are outsourced (Fehr and Marques, 2013). Since the '*consumption points*' is one of the ultimate materials destinations, it does not have exit material flows – all entry flows are presumed to be recovered CDW.

## Discussion

A major contribution of this study is the CM developed that encapsulates all relevant information, previously overlooked in the literature, about the CDW RSC. It addresses the inherent weaknesses within the current literature by bringing together all major pertinent information on nodes, key actors at each node, flow paths among the nodes and government strategies that are necessary at each node. Other emergent details are also identified, including: how each node adds value to the material flow; parties responsible for managing the operations of each node; the different responsibilities and objectives that each key actor has at each node; and government strategies towards promoting RL practices in the CDW RSC.

In addition to the above contributions, this research provides a clear picture of the complex network of RL-related problems and solutions that reside at nodes or key actors from an operational perspective. Viewing the holistic landscape of RL from these vantage points, makes this study the first of its kind. Findings also provide a deeper understanding of the: interactions that occur between nodes within the CDW RSC; contributions that each node makes towards the CDW revaluation process; and conflicting objectives that can exist between key actors within the same node. The study's findings illuminate the challenging nature of implementation of RL practices in the RSC, and illustrate the financial and operational interests from eight different key actors in this network. The government emerges as the most important key actor of the RSC, being the only one with responsibilities at all the nodes. Using six different strategies, public administration should promote RL practices to all of the RSC nodes and key actors as the literature suggests that RL is only implemented in law binding (Chinda, 2017; Xanthopoulos et al., 2012) and financially subsidized contexts (Fu et al., 2017; Zhou et al., 2013). Interestingly, the literature suggests the use of government subsidies only on three nodes: CDW generation points; CDW regional separation centres; and recycling/remanufacturing centres. This could indicate that the profitability of RL implementation is low on these nodes and thus, requires financial help from the public administration (cf. Hiete et al., 2011).

As discussed, the study's key contribution is to provide the first review on the topic of RL in the construction industry through an operation lens and with particular focus on key actors of the CDW RSC (i.e., waste recovery companies, waste transportation companies, waste separation companies and landfill operators). The barriers to adopt RL in the CDW RSC found in this current research corroborate the list of barriers mapped by Hosseini et al. (2015). However, the CM extends the findings of previous studies by defining these barriers across different nodes and determining key actors of the RSC. At present, there is no indication of communication channels between the RSC links.

Other major findings will appeal to practice, that is, by demonstrating that actors and nodes do not share information and/or experiences. As the RSCM success has been associated with the frequency and quality of the exchanged communications, a feedback model is proposed to solve this issue.

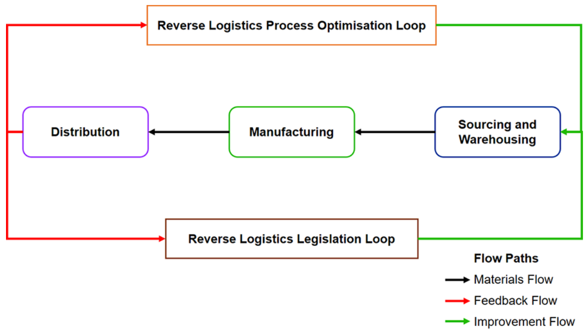


**Figure 5.** Feedback loop model.

### *Practical implications: A feedback loop model*

The model designed is based upon a concept termed 'learning supply chain (LSC)'. LSC is defined as an integrated supply chain that has a dynamic capacity to accumulate knowledge (or intellectual capital) and apply it collectively to all links in the SC. Palpable benefits include: an increase in coordination among members; better management of true demand uncertainty across the SC; an increase in innovation; and a reduction of total costs (Peterson, 2002). Given the governments' immediate priority to implement and operate the RSC of CDW, the feedback model (Figure 5) includes two learning loops – one dedicated to private and the other to public organizations. It is imperative for public administration to have a dedicated learning loop to assess the effectiveness of enforced strategies over time. The model contains all the nodes and actors within the RSC described in Figure 4 and has three flow-paths, namely: materials flow; feedback flow; and improvement flow. The model's feedback flow represents knowledge gathered and accumulated through the RSC operationalization. The improvement flow shows the exchange of knowledge between RSC actors aiming to solve inter-organizational and intra-organizational problems. The integration between actors, and subsequent knowledge sharing, can be achieved by creating various kinds of relationships such as: joint ventures; joint marketing arrangements; and collaborative initiatives in systems and processes (Peterson, 2002). Further testing and development is required to validate this model and measure its impact in practice.

## Conclusions

From a broader perspective, this study introduces a novel network-based perspective to better comprehend and manage the RL SC within the construction industry. Such a model provides a blueprint for managing a controlling CDW within an RL SC. Despite this and the contributions to various theoretical areas, the study's findings must be balanced against several inherent limitations. One limitation of this study stems from the design of the research protocol which focused on the term RL in identifying the related studies in construction research. Studies that have used other complementary terms (and using different languages) for referring to the same concept might not have been included within the pool of studies that formed the dataset of this research study. Consequently, future work may be required to address this potential deficiency.

Other future research should seek to definitely provide compelling evidence to establish the environmental advantages of adopting RL in the construction industry. While the environmental benefits of RL have been touted in the literature, there is little evidence or detailed quantification of these environmental benefits. Another topic that requires further investigation is treating RL processes in the construction industry from an SC perspective and through graph and network theory analysis. To complete such work, more case studies are needed to identify the level of integration, collaboration and capacity to collect and share knowledge in the RSC. Moreover, future work should also seek to recognize the conflicting objectives that different key actors of the CDW RSC may have. Examining the decision-making process for all the RSC key actors employed at different nodes is therefore a fertile ground of research for future studies on the topic.


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