

Review

A Review of Reverse Logistics: An Upstream Construction Supply Chain Perspective

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Abstract: Construction industry activities, from material extraction to the end of the structure life, affect the environment negatively. For a sustainable construction process, economically, environmentally, and socially friendly practices are essential, and reverse logistics is one solution that can provide such an approach. In reverse logistics, obsolete products are reused in a new production, while reducing negative effects to the environment. In this study, we assess the current state of research on reverse logistics practices in the construction industry. The study presents a comparative data mining analysis, followed by a content analysis. The results show that the construction industry literature ignores the impact of reverse logistics practices on upstream construction activities. We argue that industry practitioners must take reverse logistics decisions in the early phases of the construction process by considering both upstream and end-of-life construction activities, and we recommend a reverse logistics decision framework for successful reverse logistics implementation. The findings of this research are significant for decision-makers in the industry. We urge that sustainable practices be employed in the industry. Furthermore, a quantitative analysis is suggested to strengthen the arguments made in this article.

Keywords: upstream construction supply chain; reverse logistics; waste management

1. Introduction

The construction industry is one of the most important sectors in any country, as it constitutes a large component of economic investment and positively impacts economic growth. Despite the economic significance of the industry, its supply chain activities from material extraction to end-of-life structure have negative environmental and social consequences. A typical construction supply chain consists of raw material providers, suppliers, contractors, subcontractors, architects, designers, engineers, clients, and the user [1]. Material extraction, production, and transportation activities at the upstream supply chain and end-of-life waste generation severely impact the environment.

The construction industry is recognized as a material intensive one. Half of the non-renewable resources taken from the ground are consumed by this industry worldwide [2]. It is the largest producer of non-toxic solid waste [3]. This industry generates over 500 million tons of waste per year in the European Union (EU) [4]. The waste that is dumped into streams, forests, or land contaminates water, causes erosion, and creates hazards [5]. Some governments adopted policies such as disposing waste through landfills to manage the construction and demolition waste (C&D). Canada utilizes 35% of its space for landfills of construction waste [6]. Over 50% of the waste in the United Kingdom (UK) is construction waste [6]. Landfilling is expensive; for example, the Hong Kong (HK) government spends HK\$ 200 million per year for on disposing and uses landfill spaces at a rate of about 3500 m³ per day [7]. Although landfilling is a simple and feasible approach for waste disposal, it leads to severe environmental pollution if not managed properly. The construction process is also energy-intensive,

and the industry uses large amounts of energy for material extraction, processing, and transportation [8]. During the period between 1980 and 2008, the extraction of construction minerals increased by 80% worldwide [9]. The production of cement, which is largely used in the construction industry, is highly energy-intensive, and contributes largely to global CO₂ emissions through fossil-fuel combustion for energy input and the decarbonization of limestone [10–12]. For every ton of cement produced, nearly one ton of CO₂ is produced. Cement contributes to 5% of the annual global production of CO₂ and, of this, 3% is produced by China alone due to its booming construction sector [13].

When upstream and end-of-life activities are compared, it is evident that the impact of upstream activities is more substantial than their end-of-life counterparts. As explained by Calkins [14], the effect of material production is two-fold; on one hand, it uses scarce resources, or locally available resources in substantially large quantities as inputs and, on the other hand, it produces emissions, effluent, and waste as outputs [14].

Different approaches can be adopted to reduce the resource consumption of the construction industry. The most obvious proposition is to not build; however, this is not feasible, as built environments are dynamic mediums that evolve over time to meet the demands of the society. Moreover, infrastructure development is a precursor to economic development [15]. Considering the urbanization trends of recent times and the number of people living in the developing parts of the world, it is likely that more construction projects will be undertaken in near future. The second best option is to maximize the useful life of existing structures and consider the reusability of construction products to reduce the demand for new materials. This practice can also reduce end-of-life waste.

In theory, the process of planning, implementing, and controlling the flow back of materials from user to manufacturer or recovery point, or their proper disposal is defined as reverse logistics [16]. This concept first emerged in the manufacturing industry and was adopted by other industries due to its success. Notably, reverse logistics differs from mere waste management [17], and waste management is an outcome of successful reverse logistics implementation. Waste management refers to the efficient and effective collection and processing of waste, whereas reverse logistics is concerned with streaming the products that have a value to be recovered, and the result is entered into a (new) supply chain [16]. Hosseini et al. [17] distinguished between reverse logistics and waste management with the help of an input process output (IPO) perspective. In waste management, input refers to the used material without value, while, in reverse logistics, the input involves new products, used products, and used materials with value. Input materials that are meant for cannibalization, recycling, and rest go to landfills. However, in reverse logistics, input products and materials are directly reused and resold, repaired, refurbished, remanufactured, cannibalized, and recycled, and the rest go to landfill. The result of waste management is the reduction of the negative environmental impact; the primary output of reverse logistics is economic gain while considering the environment at the same time.

Researchers emphasized that the implementation of reverse logistics practices generate economic, environmental, and social benefits. Reverse logistics is economically beneficial, as it saves the cost of materials by reusing materials, earning revenue from the recovered materials, lowering the cost of waste disposal, procurement, inventory, transportation, and the maintenance of new products. The adoption of reverse logistics is environmentally beneficial, as it reduces non-toxic solid waste and CO₂ emission by reducing energy consumption, using less raw materials, and adhering to legislative requirements. Socially, reverse logistics implementations reduce impact on neighbors, improve the image of the business, generate several jobs, and reduce all kinds of pollution [17–19]. The forms of reverse logistics options prevalent are as follows: (a) direct reuse: products are directly reused without any repair when they are in good condition; (b) repair: failed products are repaired to restore to working order; (c) refurbish: products are disassembled, inspected, replaced, and repaired where necessary and upgraded to a different quality level; (d) remanufacture: products are disassembled, required parts are replaced, and quality standards are changed to be similar to a new product; and (e) recycle: products and parts are processed as materials that can be reused in new construction [20–22].

Notably, integrating end-of-life strategies into the early design phases is an important factor for successful reverse logistics implementation, because the volume and the condition of materials that can be recaptured at the end of the building life are determined by the type and quality of materials used in new construction [23]. Therefore, reverse logistics decisions should be made at an early decision phase and from strategic to tactical and operational levels. Hence, at a strategic level, timing the introduction of a new product should be considered with the return flow. At the tactical levels, collection of return should be considered and managed. At the operational level, the forecasting of returns is vital in inventory management [24].

Chileshe et al. [25] indicated that the level of reverse logistics implementation in the construction industry is still limited. Nunes et al. [26] argued that the application of reverse logistics in Brazil construction sector is toward waste minimization through recycling. Arif et al. [27] justified that reverse logistics are implemented in India by resending recovered materials and components to suppliers and/or manufacturer to manage waste. Chileshe et al. [25] identified that the focus of reverse logistics implementation at the project level is to reduce waste. It seems that the concept of reverse logistics is mainly discussed in the construction industry literature with the focus on end-of-life waste management.

Therefore, it is high time to examine the focus of reverse logistics implementation in the construction industry. The aim of this research is to review the current reverse logistics-related literature and investigate the actual focus of reverse logistics practices. Firstly, a data mining tool was used for a comparison between non-construction industry and construction industry literature, and then a content analysis was conducted for further analysis.

2. Materials and Methods

This study was conducted in two stages. Firstly, data mining tools were used to identify major themes and concepts in the reverse logistics literature. To obtain a valid and reliable analysis, a comparison analysis was conducted on non-construction industry and construction industry literature. From the non-construction industry literature, the authors compiled a collection of 60 high-impact journal papers (with a minimum of 10 citations each) related to reverse logistics for the period between 2007 and 2017 in ABI/INFORM collection as (ab(reverse logistics) or ab(reverse supply chains) or ab(closed loop supply chains)) and (stpe.exact("Scholarly Journals") and pd(20070101-20171231)) (S1). From the construction industry literature, 54 articles were selected in a systematic way (S2), as explained in the second steps. Leximancer 4.50 software was used for data mining and to generate concepts maps. The data mining process was required at several steps: (1) uploading all the files and running maps, (2) editing the concepts and removing unnecessary or meaningless concepts, (3) adjusting the visibility and theme size for a meaningful outcome, and (4) analyzing the themes and their relationships.

Based on the results of the first analysis (concept maps), a comprehensive and systematic literature review was conducted to create a subset of the construction and engineering project management literature for the content analysis. The systematic literature review involved compiling existing articles on reverse logistics in the construction sector, assessing the input of each to the field, analyzing the data for each, and describing the authors' findings, allowing the readers of this review to gain a clear understanding of what is and is not known [28]. The aim of the content analysis was to obtain an in-depth analysis further focusing on reverse logistics in the construction industry. Five steps, as outlined by Denyer and Tranfield [28], were followed when developing the systematic literature review: (1) formulation of questions, (2) location of studies, (3) selection and evaluation of studies, (4) analysis and synthesis, and (5) reporting of the results.

(1) Formulation of questions

The main question of the review was as follows: “What is the focus of reverse logistics implementation in the construction industry, and is the focus primary on upstream construction activities or on end-of-life waste management?”

(2) Location of articles

Different electronic literature databases were used to search for the articles, covering engineering, scientific, and management fields, since the concept of reverse logistics is still new to the construction industry. They comprised Scopus, ABI/INFORM complete, and Google Scholar. Articles were found using the advanced search feature with the key terms described below.

Scopus	TITLE-ABS-KEY (construction AND industry) AND TITLE-ABS-KEY (reverse AND logistics) OR TITLE-ABS-KEY (reverse AND supply AND chain) OR TITLE-ABS-KEY (closed AND loop AND supply AND chain)) AND DOCTYPE (ar) AND PUBYEAR > 2006 AND PUBYEAR < 2018));
ABI/INFORM Complete	((ab(construction industry) AND ab(reverse logistics) OR ab(reverse supply chain) OR ab(closed loop supply chain)) AND pd(2007–2017);
Google Scholar	Advanced search option was used with specific key terms: “reverse logistics”, “reverse supply chain”, and “closed loop supply chain” and exact phrase “construction industry” during 2007–2017.

(3) Selection and evaluation of studies

Journal and conference papers with the terms “reverse logistics” and/or “reverse supply chain” and/or “closed loop supply chain” were selected for the review; however, books, reports, dissertations, magazines, unpublished working papers, non-English documents, and documents that cannot be downloaded were excluded to maintain the integrity and consistency of findings over the chosen ten-year period. Of these, 723 papers were downloaded and saved in the computer hard disk and were reviewed by title, abstract, and key words. To ensure reliability and cover all the literature, both forward and backward searches were conducted. Finally, 54 articles were selected for the study. The flow of the document selection process is illustrated in Figure 1.

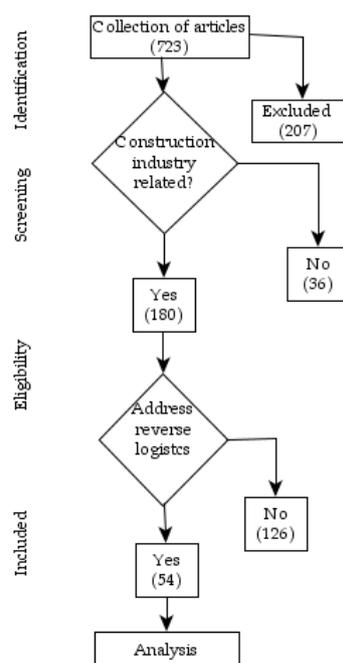


Figure 1. The flow of article review.

(4) Analysis and synthesis

MS Excel was used to record the author, year, and type of publication for the descriptive analysis. Content analysis, which “enables the researcher to analyze textual information and systematically identify its properties, such as the presence of certain words, concepts, characters, themes, or sentences” [29] (p. 352), was conducted to analyze the collected papers. The text was coded, categorized and analyzed by using conceptual analysis; the relational analysis was then built on this. Nvivo 12 software was used to code and organize the data to examine the relationships between them. As the main purpose of the review was to examine the focus of reverse logistics in the construction industry, codes were created to identify the focus while examining the selected literature. If the focus of the literature matched with an existing code, the same code was used, whereas, if the reader identified that the focus of any paper did not fall into any current code, a new code was created.

(5) Reporting the results

The outcomes of both the conceptual analysis and the relational analysis were used to infer the argument. Tables and figures were used to depict the results.

3. Results

3.1. Chronological Summary

Out of 54 papers, 36 were journal papers while 18 were conference papers and conference proceedings. Figure 2 displays the chronological summary of the selected papers. It is clear that there was increasing interest in the topic of reverse logistics among researchers over the 10-year period depicted. This is indicated by 11% of papers published in 2009 and 22% published in 2016. The primary reason behind this trend is possibly the increasing awareness about sustainable and environmentally friendly practices among academics and industry stakeholders.

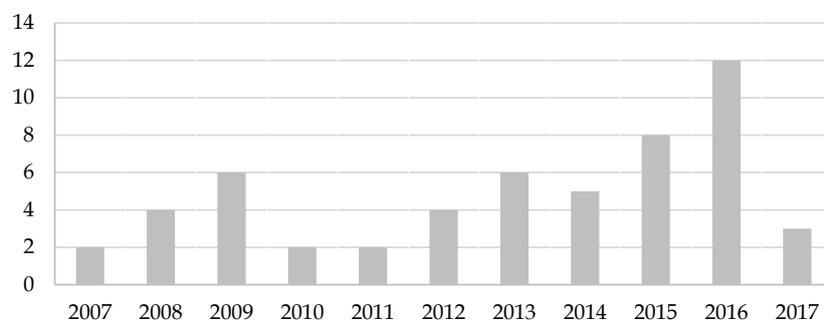


Figure 2. Years of publication.

3.2. Data Mining Output

Firstly, we made a comparison between the reverse logistics literature in the non-construction industry (more matured industries) and the construction industry. This was done using a data mining software to obtain overall insight into the reverse logistics literature in the two groups, and creating a concept map, as indicated in Figures 3 and 4. The main themes in the non-construction industry literature were “production”, “networks”, and “cost” (Figure 3; Tables S1 and S2), whereas “waste” became a major concept (74%) in the construction industry literature (Figure 4; Tables S3 and S4). Further examination revealed that the theme “material” intersected the theme “waste”. Meanwhile, the theme “recycled” strongly intersected the themes “waste” and “material”. Recycling appeared to be the main reverse logistics strategy in managing waste in the construction industry. These figures are evidence that, while more matured industries focus on reducing costs through producing and creating networks for reverse supply chains, the construction industry is trying to reduce waste by recycling waste materials.

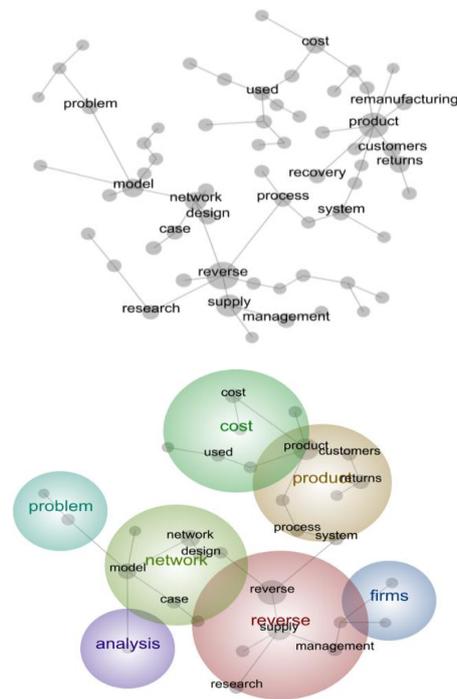


Figure 3. Concept map for the non-construction industry.

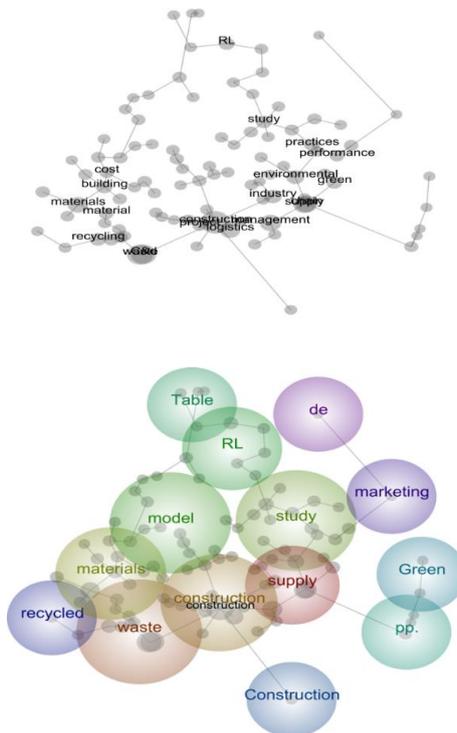


Figure 4. Concept map for the construction industry.

In the second step, we further examined the focus of reverse logistics in the construction industry to get a better understanding with the help of content analysis.

3.3. Focus of Reverse Logistics

As depicted in Table 1, the main focus of reverse logistics in the construction was identified in nine categories: as a cost component, reverse logistics in a broader view, with deconstruction,

energy concerns over transportation, environmental concerns, flexibility in the supply chain, network designing, secure natural resources, and waste management. As seen in Table 1, the main concern of reverse logistics is waste management. Few articles considered secure natural resources through reverse logistics practices. Further analysis revealed that the main focus of reverse logistics in the construction industry can be broadly categorized into three perspectives as waste management, environmental thinking, and broader economic, environmental, and social perspectives (Table 2). Regarding waste management, articles directly addressed the resolving construction and demolition waste and its issues. Under the category of environmental thinking, papers discussed reverse logistics in terms of reducing the environmental effects of construction activities. From a broader perspective, reverse logistics was discussed as the reaping of benefits from economic, social, and environmental aspects. In other words, the results of the content analysis indicated that the current focus of reverse logistics literature in the construction industry is primarily on end-of-life waste management.

Table 1. Focus of reverse logistics.

Article	a	b	c	d	e	f	g	h	i
Hosseini et al. [17]		x							
Chileshe et al. [18]									x
Hosseini et al. [19]		x							
Chileshe et al. [25]		x							
Nunes et al. [26]		x							
Arif et al. [27]									x
Aidonis et al. [30]									x
Aidonis et al. [31]									x
Al-Aomar and Weriakat [32]		x							
Arif et al. [33]									x
Beldek et al. [34]									x
Bock and Linner [35]			x						
Bock and Linner, [36]			x						
Chileshe, et al. [37]					x				x
Chinda [38]		x							
Chinda and Ammarapala [39]									x
Chinda et al. [40]									x
Dim et al. [41]				x					
Ding et al. [42]									x
Fabbe-Costes and Jahre [43]						x			
Fu et al. [44]									x
Gomes et al. [45]									x
Hosseini et al. [46]					x				
Ketikidis et al. [47]					x				
Kim et al. [48]					x				
Mathiyazhagan and Noorul [49]					x			x	
Negi et al. [50]								x	
Netro et al. [51]									x
Ojo et al. [52]					x				
Ojo et al. [53]					x				
Qiuliang et al. [54]	x								
Rameezdeen et al. [55]					x				
Sabai [56]									x
Schamne et al. [57]									x
Schultmann and Sunke [58]									x
Shakantu, and Emuze [59]				x					
Shakantu et al. [60]				x					
Simon et al. [61]									x
Sinha and Taneerananon [62]							x		
Sobotka and Czaja [63]		x							
Sobotka and Segan [64]					x				
Stokić and Radovanović [65]				x					
Sunke [66]							x		
Thipparat [67]					x				
Vidalakis and Sommerville [68]				x					
Woo et al. [69]					x				
Wu et al. [70]					x				
Xanthopoulos et al. [71]			x						
Ma et al. [72]									x
Yuan [73]									x
Xu et al. [74]									x
Zampese et al. [75]					x				
Zhou et al. [76]					x				
Zhuonan [77]									x

a: as a component of cost; b: in a broader view; c: with deconstruction; d: energy in transportation; e: environment concern; f: flexibility in the supply chain; g: network designing; h: secure natural resource; i: waste management.

Table 2. Focus of reverse logistics implementation in the construction industry.

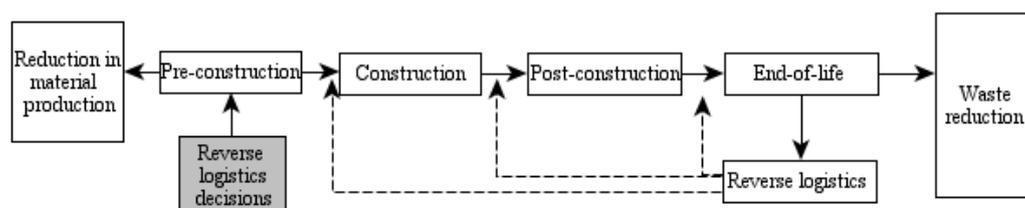
Purpose of Reverse Logistics	Article
Waste management	Chileshe et al. [18]; Arif et al. [27]; Aidonis et al. [30]; Aidonis et al. [31]; Arif et al. [33]; Beldek et al. [34]; Bock and Linner [35]; Bock and Linner [36]; Chileshe, et al. [37]; Chinda and Ammarapala [39]; Chinda et al. [40]; Ding et al. [42]; Fu et al. [44]; Gomes et al. [45]; Netro et al. [51]; Qiuliang et al. [54]; Sabai [56]; Schamne et al. [57]; Schultmann and Sunke, [58]; Simon et al. [61]; Sinha and Taneerananon [62]; Sunke [66]; Xanthopoulos et al. [71]; Ma et al. [72]; Yuan [73]; Xu et al. [74]; Zhuonan [77]
Environmental thinking	Chileshe, et al. [37]; Hosseini et al. [46]; Ketikidis et al. [47]; Kim et al. [48]; Mathiyazhagan and Noorul [49]; Negi et al. [50]; Ojo et al. [52]; Ojo et al. [53]; Rameezdeen et al. [55]; Sobotka and Czaja [63]; Thipparat [67]; Woo et al. [69]; Wu et al. [70]; Zampese et al. [75]; Zhou et al. [76]
Broader perspective (Economic, environmental, and social perspective)	Hosseini et al. [17]; Hosseini et al [19]; Chileshe et al. [25]; Nunes et al. [26]; Al-Aomar and Weriakat [32]; Chinda [38]; Dim et al. [41]; Shakantu, and Emuze [59]; Shakantu et al. [60]; Sobotka and Czaja [63]; Stokić and Radovanović [65]; Vidalakis and Sommerville [68]; Fabbe-Costes and Jahre [43]

4. Discussion

4.1. Decision Framework

Hosseini et al. [17] argued that the primary outcome of reverse logistics is the gaining of economic benefits. Nevertheless, compared to other industries, the construction industry consumes more substantial quantities of natural resources, which are scarce and limited, and which deplete over time. Therefore, the preservation of natural resources for future generations is a timely requirement. In the construction process, upstream material production and transportation impact the natural and social environment negatively by depleting natural resources, emitting pollutant gases, and generating waste. Thus, reverse logistics practices must be adopted primarily to reduce the environmental and social impact caused by upstream construction activities and not just for the economic gain.

Although we argued that reverse logistics must be employed, particularly focusing on upstream construction activities, these aspects are rarely addressed in the literature, most of which only focuses on end-of-life waste management. As we emphasized previously, reverse logistics does not merely refer to waste management. Therefore, more studies are required to analyze the impact of reverse logistics on upstream construction activities. Hence, we propose a decision framework for reverse logistics with both forward and reverse flows in order to reap its environmental, social, and economic benefits, as illustrated in Figure 5. According to the framework, reverse logistics decisions must be made during the pre-construction activities where planning and designing take place.

**Figure 5.** Proposed framework for reverse logistics decisions in construction.

4.2. Comparison of Reverse Logistics Strategies

The derived concept map for the construction industry literature indicated that recycling is a popular theme in the industry. In the reverse logistics literature, recycling is one approach among others, such as reusing, repairing and reusing, refurbishing, and remanufacturing. It is wise to make decisions regarding suitable reverse logistics options before implementing these practices. In comparison with other options, the direct reuse of used materials reduces the need for new materials, while the repairing and reusing, refurbishing, remanufacturing, and recycling of used materials more or less require new materials. However, while making a decision regarding reverse logistics options, we must consider not only the contribution made for reducing material production in upper stream construction activities, but also the time and effort required to reuse the product.

When comparing the effort required to prepare the material for reuse in new situations under different options, we can assume the illustration provided below (Figure 6). In comparison with all the options available for reverse logistics, recycling requires the most effort and it consumes and requires more resources and energy. For example, Nunes et al. [26] pointed out that, in Brazil, most of the reverse flow materials are inert mineral wastes related to plaster, concrete, bricks, and ceramic screens, and more recycling centers are required there. Skinner et al. [78], who examined the effect of different reverse logistics disposition strategies on economic performance, operational service, and operational responsiveness, found that recycled methods affected operational responsiveness, but interestingly found that the effect was negative. Therefore, we argue that the selection of reverse logistics options is crucial and must be made wisely at the planning and designing phases. We encourage industry practitioners to focus on options that require less effort, such as reusing and repairing, instead of traditional recycling.

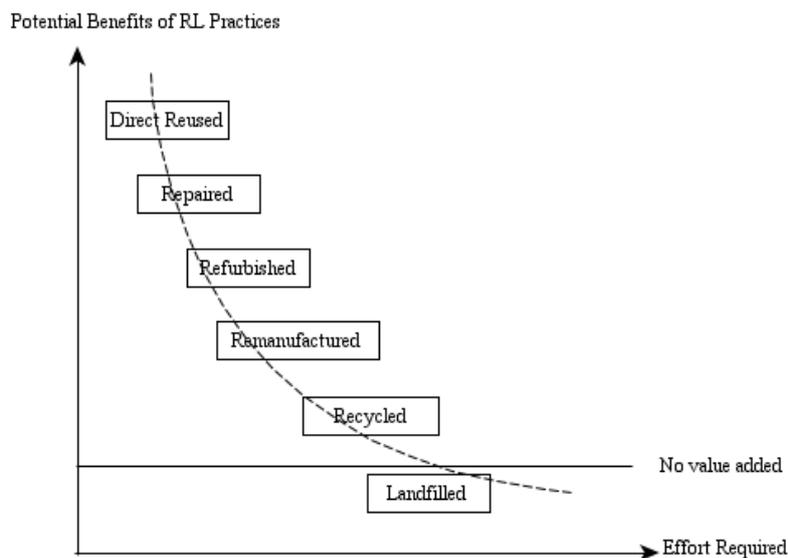


Figure 6. A comparison of reverse logistics strategies.

5. Conclusions

This study examined the current reverse logistics practices in the construction industry. Since this is a material-intensive industry, the implementation of reverse logistics is important. Nevertheless, the study revealed that reverse logistics practices are limited to managing wastes in the industry. Reverse logistics is not synonymous with waste management. It is merely a process that yields economic, environmental, and social benefits, and waste management is an outcome of the effective reverse logistics implementation. The review highlighted the positive effect of reverse logistics practices on upstream construction activities, which can be achieved by preserving existing resources and by reducing harmful emissions and waste generation. The study emphasizes the importance of

reverse logistics decision-making in the early phases of the construction process. Furthermore, it stressed the importance of making appropriate decisions regarding reverse logistics options without blindly following the common practices in the industry. The support of all industry stakeholders is crucial for the successful implementation of reverse logistics. The slow uptake of these practices can critically impact the future of the construction industry as the depletion of natural resources and environmental pollution worsen. Therefore, industry decision-makers must make their decisions with future long-term life-cycle considerations instead of merely focusing on current waste problems. Waste issues can be addressed automatically when implementing the approach offered by reverse logistics.

However, further research is required, especially quantitative analysis to study the effect of reverse logistics practices at upstream supply chain activities, as this research was limited to the selected literature that was reviewed. Although our recommendations can provide directions to be considered by the construction industry in the implementation of reverse logistics in an upstream supply chain perspective, further research is required to examine the direct role of reverse logistics in the overall construction supply chain performance. Future research in this area could provide empirical evidence supporting the optimal implementation of reverse logistics systems in the construction context and reap its benefits, which are already realized in industries such as manufacturing.

Supplementary Materials: The following are available online at <http://www.mdpi.com/2071-1050/11/15/4143/s1>: S1: References for Data Mining Analysis (non-Construction Industry); S2: References for Data Mining Analysis (Construction Industry); Table S1: Major themes in non-construction industry literature; Table S2: Major concepts in non-construction industry literature; Table S3: Major themes in non-construction industry literature; Table S4: Major concepts in non-construction industry literature.

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