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An overview of the literature on decision-making support models for deconstruction logistics

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Abstract

The construction sector is not only a major consumer of virgin materials but also a major contributor to waste generation. Therefore, it is important to rethink current waste management practices by applying, for example, circular economy principles such as deconstruction practice. Considered a more-resource-friendly alternative compared to standard demolition, deconstruction involves dismantling a building with the aim of maintaining the highest possible value for its materials and maximizing their recovery potential. This study reviews the literature to identify and analyze recent studies reporting on operations planning and logistics optimization problems related to deconstruction. It describes the studied problems and the approaches proposed to address them. Finally, it identifies the limitations of current research in the field and suggests perspectives for future research.

Keywords:
Construction, renovation and demolition (CRD); circular economy; decision-making; deconstruction; logistics; planning; optimization.

1. Introduction

Some 50% of annual global consumer waste and 60% of annual global waste generation are attributable to the construction sector [1]. To reduce this significant amount of waste from the construction, renovation and demolition (CRD) sector, more and more deconstruction projects are incorporating circular economy (CE) principles. While deconstruction is an increasingly popular CE approach in the sector, it remains a relatively recent one in the scientific literature on operations planning and logistics optimization. For Ossio and al. (2023) [2], circular construction is a multidisciplinary system that aims to recover materials and give them a second life while allowing the regeneration of natural environments.

Here, a literature review identifies and analyzes research that has put forward mathematical optimization models to plan and manage deconstruction project operations. Our work pursues the research presented in [3] and [4], where the authors recommend the development of a decision-support tool to help optimize the waste logistics of deconstruction projects. This earlier work mapped the processes required to carry out a deconstruction project focused on the reuse of materials, identified the challenges that may arise and set out solutions to overcome them within the context of deconstruction projects led in the Gaspésie region in Québec (Canada). This paper also provides a description of the article selection method (Section 2.1) and an analysis of the cited articles (Section 2.2). In Section 2.2, the articles are grouped according to two themes: planning and scheduling and transportation and network design. Finally, the discussion and conclusion (Section 3) outline research perspectives.

2. Literature review

2.1. Article selection

The first step in the search for scientific articles was to analyze the papers mentioned in the literature review carried out in [4]. A search for new articles with keyword combinations such as *waste deconstruction*, *transport optimization* and *deconstruction optimization* was then carried out in Google Scholar between May 2023 and August 2023. The references of each article were then analyzed to find other relevant articles (snowballing). At that stage, five were selected for the literature review. Then, from September 2023 to January 2024, other articles were recommended by researchers in the field, leading to the identification of new keywords using the articles that were previously selected and analyzed: *waste, optimization, deconstruction, planning, circular economy* and *logistics*. Next, synonyms were set out for each keyword using the Termium Plus and Vitrine linguistique websites (i.e. linguistic databases of the Canadian and Québec governments). ChatGPT was also used to generate 10 synonyms for each keyword, yielding a total of 50 synonyms, 19 of which were retained. In their literature review, Allam and Nik-Bakht (2023) [5] affirm that there are three classification periods for published scientific articles on deconstruction. The first period, from 1974 to 1999, is known as the demolition age. The second, from 2000 to 2014, is the nascence of deconstruction, and the last, which is ongoing since 2015, is the era of circular construction. Based on this article, the start of the period for this review was set to 2010. The article search was carried out on the Engineering Village website using the Compendex, Inespec and Knovel databases. The initial search formula included search equations such as (*waste OR material OR discarded) AND (optimi* OR simulation OR management) AND (deconstruction OR dismantling OR dismantlement) AND (planning OR routing OR configuration) AND (circular economy OR reuse OR recycle OR recover) AND (logistic OR reverse OR transportation)*. A total of 355 articles were found using this method. Titles and abstracts were filtered. As the filtering progressed, the search formula was updated to add the *not* option and remove keywords such as *cellulose, battery powered vehicle* and *uranium.* A main keyword was added towards the end of the search to get more articles targeting the construction sector with the keywords *building, renovation* and *construction*. Only English-language articles were considered, resulting in a total of 18 papers. After reading article [4] the search rule was modified following a recommendation by authors to add *selective demolition* and *selective dismantling* as synonyms for deconstruction. That prompted 27 articles on the Engineering Village website. After reviewing the 27 papers, 6 were retained for analysis in addition to the 5 articles found in the first stage, for a total of 11 articles.

2.2. Article analysis

Figure 1 indicates that all the articles that were analyzed were published between 2011 and 2023. Almost half were published in the last three years. Figure 2 specifies the countries where case studies were conducted (nine in total), if any. The study [6] analyzed building deconstruction in Brazil (BR), Canada (CA), China (CN), Nigeria (NG) and Switzerland (CH). China and Canada are the most frequently mentioned countries (three case studies each). Finally, two articles do not mention a specific country where the proposed models were tested.

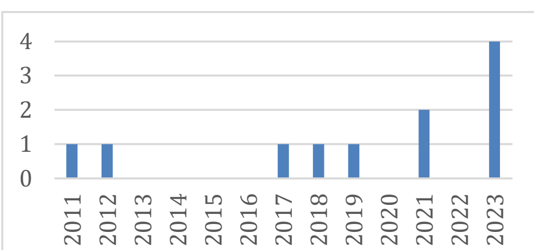

Figure 1: Years of publication of the articles that were analyzed

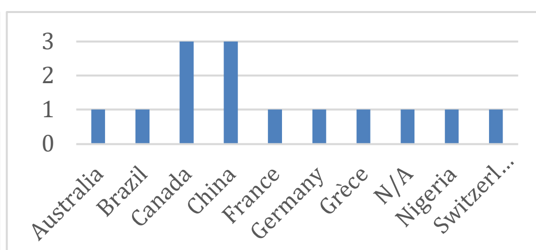

Figure 2: Countries where case studies were conducted

Table 1. Summary of the main characteristics of the logistics optimization problem

Article	Topic	Decision	Country	Model	Objective(s) of the model
[1]	Planning and scheduling	Determine the method to extract a material. Scheduling activities.	Canada	Multi-objective	Minimize net extraction costs and total project duration.
[6]	Planning and scheduling	Determine which deconstruction/demolition method to use.	CA, CN, BR, NRA, CH	Multi-objective	Minimize net material extraction costs.
[7]	Planning and scheduling	Determine how to handle certain types of materials and the necessary workforce.	France	Multi-objective	Minimize project duration and cost and maximize recovery rates.
[14]	Planning and scheduling	Determine the method to use for a specific material. Project scheduling.	Canada	Multi-objective	Minimize net material extraction costs and project duration.
[12]	Planning and scheduling	Determine materials processing (reused or recycled) and destination.	Greece	Multi-objective	Maximize profit (reuse) and minimize costs (decontamination, demolition and transport).
[10]	Material – destination allocation	Determine where the materials will end up.	China	Simulation	Reduce GHG emissions.
[13]	Transportation and network design	Identify a recycling center and determine its capacity.	N/A	Multi-objective	Maximize profit and minimize environmental impacts.
[15]	Transportation and network design	Establish a recycling center and determine if CDW will be recycled at a plant.	China	Multi-objective	Minimize environmental impacts generated by recycling centers.
[16]	Transportation and network design	Allocate material flows, location and number of recycling centers.	Germany	Multi-objective	Minimize transportation costs. Minimize disposal costs. Minimize the number of recycling centers in a region.
[17]	Transportation and network design	Determine a truck's next destination.	Hong Kong	Mono-objective	Minimize distances traveled.
[18]	Transportation and network design	Determine the volume to transport during each period and which recycling center to open.	Australia	Multi-objective	Minimize total costs.

Most of the papers start by referring to global (or country-specific) statistics on construction industry waste. For example, Quéheille et al. (2023) [7] refer to the European Union's target minimum construction and deconstruction waste recovery rate of 70%. Some articles also mention the lack of traceability when adding or removing materials from buildings after construction, which impedes planning during deconstruction [8,9]. The rest of the analysis was conducted based on two topics: 1) planning and scheduling of deconstruction activities and 2) transportation and network design. Article [10] is the only paper that is not directly related to one of the topics. It is also the only one to rely on discrete-event simulation as a decision-support model to assess four sources of greenhouse gas (GHG) emissions and determine the best scenario to mitigate them from among the three that were analyzed. The four sources of GHG emissions come from construction and demolition waste (CDW) transportation, materials processing, materials disposal and the benefits of reuse, recycling and energy recovery. The first scenario that was analyzed looks at how the recycling rate of CDW influences GHG emissions by modifying the percentage of inert waste recycling. The second scenario considers the influence of the combustible waste incineration rate, and the third evaluates the influence of waste reduction during the construction phase. Scenario 2 reports the lowest GHG reduction (from 0.27% to 1.36%), followed by the first scenario (0.84% to 3.37%). The third scenario produces the best results: from 3.81% to 12.71%.

2.2.1. Planning and scheduling

To show the importance of project planning, Volk and al. (2015) [11] mention that the main sources of uncertainty are the time required to complete activities, resource availability and resource location on site. Therefore, upstream task scheduling could reduce uncertainties and decrease project lead times. Several other authors highlight the importance of planning before the start of a deconstruction project. Indeed, of the 11 articles analyzed, 6 consider task scheduling. Xanthopoulos et al. (2012) [12] indicate that a comprehensive assessment of the building's components is required in the initial study phase to optimize the deconstruction process. The second phase involves the implementation of the upstream deconstruction measures that are planned. The authors place significant emphasis on the substance of the first phase, since a deconstruction project generates a great deal of waste and the sorting and handling of the materials must be organized efficiently. Article [12] develops a multi-objective model to maximize the profits from material reuse. Covering only the first phase (planning), the proposed model optimizes the deconstruction, demolition and planning processes. For material transportation, the model by Xantopoulous et al. (2012) [12] determines whether to ship a component for reuse or to a recycling center, thus making it possible to determine the optimal destination for the CDW. The model also estimates the total potential revenue from the sale of demolition waste, recycled materials and reused materials. Deconstruction and handling costs are also considered in the objective function. Only Xantopoulous et al. (2012) [12] and study [13] seek to maximize profit, while the others minimize project costs. Upstream planning also helps determine the best dismantling processes for deconstruction. Faced with a lack of tools to support deconstruction planning, researchers in France [7] developed a multi-objective optimization model with 17 decision variables that minimizes project costs and maximizes the material recovery rate. For example, the model makes it possible to determine the number of workers required to complete a project. Another decision variable considers the treatment to be applied to the wood harvested during deconstruction. To validate the model, the authors tested it on a real case. When they presented the model's theoretical results to the project's head engineer, he stated that the solution was not feasible. Specifically, the recommendation was to install two cranes, but the site could only accommodate one. The model was adjusted and then yielded a viable solution (i.e., new task scheduling). The optimization models in [1, 14] minimize total project completion time. The schedules that were generated may be used to determine the best method to extract materials. The article [12] confirms that schedules make it possible to extract components with minimum loss, in addition to facilitating their recovery and reclamation. To avoid improbable cases (e.g., deconstructing the foundation before deconstructing the roof), article [14] affirms that following an order of priority in the extraction chronology is mandatory.

Still, an economic problem arises regarding the upstream planning of deconstruction projects. As pointed out in [1], there is no clear central market to sell reused or recycled materials, and that makes it difficult to determine applicable resale prices and the demand for the materials. The aim of article [14] was to provide a methodology to generate a quantitative estimate of the impact of construction waste diversion and reduce the project's carbon impact. The methodology is based on North American standards and regulations to determine the impact of current policies. To do so, the experts developed a decision-support tool to test six different policy scenarios. For example, one policy imposes the reuse of certain materials or a certain mass of building, and another requires that deconstruction projects recover the materials that are extracted. To that end, the authors analyzed the building information model (BIM) of five different buildings with unique characteristics including a North American-style single-family home and a low-rise office building. They found that it was possible to drastically reduce waste and the carbon footprint and still achieve a positive financial return. Even so, they concluded that current policies have a different impact on every building type. The last important factor that can impact planning and scheduling is government regulations and standards. This is mentioned in article [6], which also points out that there is no evidence public policies (local, regional, national or otherwise) have any real impact and that it generally takes several years to assess their effectiveness. A multi-objective model was developed and five deconstruction projects were analyzed in Brazil, Canada, China, Nigeria and Switzerland. The model minimizes the total cost of the project, indicates the total mass of recovery and provides the sales revenue that could be generated. The authors note that Switzerland and Canada are the countries with the most support for deconstruction projects owing to the current standards in effect. Switzerland has the highest extraction costs, followed by Canada. In terms of resale profits, Switzerland and Canada were at the top of the list. The authors conclude that it is important to consider the total volume reused and not the quantity, which could be misleading since smaller materials are reused more than larger ones (e.g., reusing 1,000 screws is less significant than reusing two doors in terms of weight).

2.2.2. Transportation and network design

To reduce GHG emissions, several articles seek to cut travel time between worksites and recycling centers. In article [15], the authors developed a genetic algorithm to determine the ideal locations for recycling centers and the required production capacity of each one. They devised a multi-objective model that minimizes the environmental impact generated by recycling centers and minimizes the total cost of setting up a logistics network for recycling centers. The study [16] seeks to optimize the design of a regional recycling center network using a multi-objective model and compares 19 scenarios. For example, one of the scenarios includes a fee to send waste to landfill, while another charges a similar fee but with a value two and a half times higher. Another variable parameter is the transportation unit costs. In this article, the objectives are to minimize the costs related to transportation, materials recycling, investments in a recycling center project and landfilling and include the revenues from the sale of recycled products. To assess the results obtained for the different scenarios, several performance indicators were used, including the disposal rate of CDW sent directly to landfill and the indirect disposal rate (a material undergoes further treatment before being disposed of). These indicators are formulated as objective functions. The economic indicator include the cost of transporting and processing the various materials. Unlike the objective function, this indicator details the total cost. Article [13] also discusses a multi-objective model to maximize project profits and minimize the environmental impacts when designing and planning a logistics network of waste recycling centers. The model considers 17 types of decision. Some relate to the anticipated recycling centers and their processing capacity, as well as to the possibility of this capacity increasing over time. Other decisions involve the quantity of CDW transported between worksites and recycling centers. To validate the model, the authors analyzed nine scenarios generated with a combination of four parameters (fine aggregate, coarse aggregate, probability and investment rate), each with three sets of values. Only article [17] proposes a single-objective optimization model to determine the route that minimizes the distances travelled by trucks. The analysis is based on historical waste road transportation flows in Hong Kong using public data from 2015 on every truck trip. Using their model to increase the efficiency of CDW transportation, the authors reduced the distance travelled by trucks but observed an increase in the number of trips. Inefficiency was caused by 1) illogical choice of processing center based on location, 2) disorganized routes and 3) underloaded trucks. In the study [18], CDW transportation was planned in each period to minimize costs. A period may be a month or a year, depending on the planning horizon. In the proposed multi-objective model, estimates evaluate certain parameters that impact transportation costs (e.g., fuel costs). Two types of decision are considered: the quantity to be transported from the site and the number of units of material stored during each period. The costs include transportation costs, CDW processing costs (dismantling and reclamation), storage costs, green fees (e.g., material landfill fee) and government funding.

3. Discussion and conclusion

This literature review brought to light studies on logistics optimization in deconstruction projects. The articles that were analyzed mainly focus on problems about planning and scheduling the tasks of a deconstruction project and transportation and network design. The planning and scheduling of deconstruction projects helps minimize costs and project duration [1,6,7,11,14]. Two papers developed single-objective optimization models, nine explored multi-objective models and only one relied on simulation. Of the eleven articles that include an optimization model, only two maximize profit. After analyzing all the articles, several needs related to logistics planning in deconstruction projects emerged. First and foremost is the need to determine ahead of time the human and material resources (e.g., tools, machinery, employees) required on site to carry out a deconstruction project [7]. As for transportation, it is relevant to determine the number of trucks and trips required to transport the deconstruction materials to their respective destinations based on their purpose (reuse, recycling or landfill) [13,15,17,18]. In addition, a clear observation became apparent: government measures are needed to support the practice of deconstruction and create a stable market to sell recycled and reclaimed materials. Article [16] sets out indicators to carry out a more in-depth analysis in addition to the results obtained for the objective functions. In the analysis of articles [1,6], the authors point out that municipal deconstruction measures are already in place in cities like Victoria and Vancouver (Canada) and Seattle (USA), though they remain few and far between. One such measure is issuing a deconstruction permit more quickly than a demolition permit. It would therefore be relevant to add the keyword *policy* and its synonyms (e.g., *regulation* and *standard*) to our future searches to find studies that analyze the impact of regulations that favour deconstruction. Finally, the articles that were analyzed contained very little information on materials storage, inventory management and materials handling planning and movement on site, which were raised in [4] as important issues that require day-to-day management. Another element to consider is the option to sell a certain percentage of the deconstruction materials directly to residents in the area where the project is underway. Discussions with experts involved in the deconstruction projects in Gaspésie revealed the significance of this aspect, though it may come at the expense of potential revenues generated when materials are recycled or sold to other (industrial) customers. One of the limitations of our study is that not all available databases were consulted for review and therefore the research will continue using other databases and the new keywords discussed earlier.

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