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Life cycle costing for decision making in construction and demolition waste management: A critical review

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Abstract. Construction and demolition (C&D) waste poses many environmental issues. There are many issues due to C&D waste landfills and construction industry has to face many costs when managing C&D waste. Currently there are many research studies carried out focusing on the C&D waste management. Even the environmental impacts of C&D waste is significantly researched, there is a minimum focus on the economic impacts of C&D waste management. Therefore, this research study aims to review the research carried out in C&D waste management focusing on its life-cycle costs. VOSviewer was used to develop the bibliographic networks and analyse the literature. Researchers conducted searches separately and both in conjunction of these two research domains. Most of the C&D waste management research focused on recycling and recycled aggregates. There is a clear lack of research on costs and economic point of view on C&D waste management. Few studies on costs for C&D waste management merely presented cost comparisons for specific waste management plans. Research on economic evaluation and specifically on life-cycle costing perspective for in C&D waste management paradigm is highly desired. Recycling is highly regarded in C&D waste management research. However, the life-cycle perspective of the extended life of recycled material is rarely discussed. There is minimum research carried out on monetising social benefits of C&D waste management.

Keywords: Cost, Construction and demolition waste management, life-cycle cost.

1 Introduction

Life cycle cost (LCC) approach is widespread across many disciplines by now. After analysing over 7000 published papers related to LCC since 1966, Naves, et al. [1] illustrated that there is a growing use of LCC methodology in the industry, infrastructure, construction, building sectors and so on. LCC enables comparing different options based on the discounted cash flows of various costs incurring during the entire life-cycle of the project.

There are many definitions for LCC is put forward by many researchers, yet it can be simply identified as a tool for assessing the total cost performance of an asset over time, including the acquisition, operating, maintenance, and disposal costs [2]. According to Addis and Talbot [3 p. 1], LCC can be identified as

> *"the present value of the total cost of that asset over its operational life. This includes initial capital cost, finance costs, operational costs, maintenance costs and the eventual disposal costs of the asset at the end of its life. All future costs and benefits are reduced to present-day values by the use of discounting techniques."*

This definition by Addis and Talbot [3] can be adopted in C&D waste management as well. LCC for C&D waste management can be illustrated as the sum of the recurring costs during economic life of the considered project (i.e. building) from pre-decision, design, construction, completion and acceptance, until users stop using it and also including the sum of research development fee, manufacture fee, installation fee, operation maintenance fee and scrap back charges in the determining life cycle of the project or at a predetermined period of validity [4]. Therefore, LCC can be divided into five parts: decision costs, design costs, commissioning costs of construction, operating and maintenance costs and recycling scrap costs based on the stage of the life-cycle [5].

ISO 15686-5:2017: Building and construction assets – service life planning –Part 5: Life cycle costing standard [6] is the international standard governing life-cycle costing. Therefor, according to ISO satandards initial cost including the construction cost, operationa and maintenance cost and demolition costs are included in life-cycle cost calculation while excluding externalities and social benefits [6]. According to International Organisation for Standardization [ISO] [7], when externalities and social benefits are included, it is termed as 'whole life cycle cost' (WLCC). However, many research studies used words LCC and WLCC interchangeably.

Islam, et al. [8], carried out a systematic review on LCC implication on residential buildings. According to Islam, et al. [8], the outcomes of life cycle environmental impacts and cost are dominated by different life stages of buildings and LCC is dominated in construction phase. Zuo, et al. [9] presented a critical review of green building evaluation from life cycle perspective, in particular, the use of life cycle assessment and life cycle costing in green building evaluation. According to Zuo, et al. [9], the uptake of LCC is generally low and also suggested that, LCC is suitable for use in the early design phase. Further, there are other review articles on LCC for pavements [10] and sustainable cities [10]. Construction industry has a significant considerations on C&D waste management. Due to rapid urbanisation, C&D activities cause significant negative impacts to the environment and the society [11, 12].

Therefore, this review article aims to analyse the extent of using LCC as a decision making for C&D waste management. This research used science mapping approach for research domains LCC and C&D waste management. This is a novel technique with bibliometric literature analysis minimizing subjectivity and biasness [1, 13].

2 Research methodologies

For this review article, Scopus Elsevier database is used for retrieving articles. Therefore, researchers conducted searches separately and both in conjunction of these two research domains on February 2018. Initially, the publications relating to the two broader research areas namely; LCC and C&D waste management were extracted. Prior to refining the search results, C&D waste management search obtained 8,182 documents and LCC retrieved 18,574 publications. Afterwards both the search results were refined, based on the subject area, language and applicability. Finally, after refining, there were 927 research publications for C&D waste management and 10,363 documents for LCC.

Once the search results were refined, all the selected research publications were exported as command separated format (csv) files. Bibliometric software VOSviewer was used to develop the bibliographic networks [14]. According to van Eck and Waltman [15] the distance between two nodes in VOSviewer network approximately indicates the relatedness between them. Further, this software is suitable for visualizing larger networks and also includes text mining features. This software is now used in the construction related disciplines as well. Naves, et al. [1] use this software to review literature on Solar energy sector and LCC, Jin, et al. [13] used this for C&D waste review. Further, there are other research studies using VOSviewer such as for building information modelling (BIM) and public private partnerships (PPP) review articles [16, 17]. The main objectives from using VOSviewer are as follows; 1) To visualize and analyse the keywords in the main research domains and 2) to study the inter-relations ships between the keywords. The search combinations used for this research study is as follows:

- Search 1: Search with the key word ‘construction and demolition waste management’ in the title and abstract fields, limited to English language. Different variants of this word were used when searching for the relevant publications. As an example, various ways of writing ‘C&D waste’ is adopted such as “Construction and demolition waste”, “CDW” and so on. Each of these variants is separated by “OR” function. This search result resulted in publications from 1974 onwards.
- Search 2: Search with keywords “LCC” in title and abstract fields, limited to English language and Engineering discipline. As mentioned in the previous sections, LCC is often identified as WLC as well. Therefore, when conduction the search both of these words were used. This search result resulted in publications from 1960 onwards.
- Search 3: Search with keywords “cost” and “C&D waste” in title and abstract fields, limited to English. The LCC is excluded from this search. Similar to search one, different variants of search keywords were used.
- Search 4: Search with keywords “LCC” and “C&D waste” in title and abstract fields, limited to English. Other variants of cost other than the LCC and its variants were excluded from the search. Similar to previous search processes, different variants of search keywords were used.

3 Results and discussion

3.1 Brief analysis on reviewd articles

Bibiliometric analysis considered more than 10,000 research publications related to LCC. Due to the larger number of research articles, closely related highly cited 100 journals article from 2008 onwards were selected. These articles have the highest citations varying from 28 to 337 citations. When analysing these papers it is evident that most of these research studies are closely focused on the energy sector. There are many LCC studies comparing energy related options while using LCC as one of the technique for comparison [18-24]. In most of these research studies the energy savings from the proposed systems were calculated by using LCC. Further, most of these publications were focusing in renewable energy generation such as solar power, photovoltaic panels, wind power and so on. Most of the LCC studies were carried out for bridges and residential houses. Apart from that, LCC is combined with cost-benefits analysis [25-29] and there are studies on optimising the LCC [21, 30-36]. Case studies are also used for LCC calculations. Further, there are LCC studies coupled with life cycle assessment as well [8, 37-39]

Similar to the LCC analysis, C&D waste management research domain also included almost 1000 articles. Therefore, closely related highly cited 100 journals article from 2008 onwards were selected. These articles have the highest citations varying from 26 to 215 citations. Most of these research articles are closely related to recycling and sustainability. The C&D waste management significantly considered about the environmental impacts, thus sustainability has always become mostly considered. In the research domain of recycling, the C&D waste management significantly considered recycled aggregates. Further life-cycle assessment in C&D waste management is also discussed in the literature [40-42]. Construction waste disposal and waste minimisation through design are also widely discussed in these research studies [43-46].

3.2 LCC and C&D waste management

Keywords usually represent the main content of the research studies. According to Van Eck and Waltman [14] keywords represents the knowledge among the relationships of research themes. For the VOSviewer analysis the minimum occurrence of a keyword was set to 10 and initially 38 keywords out of 1896 met the threshold. Afterwards, the general items such as ‘C&D waste’, ‘waste management’ and ‘construction’ were excluded and the keywords with same meaning were combined together. Finally, a total of 18 keywords were selected and given in **Error! Reference source not found.**.

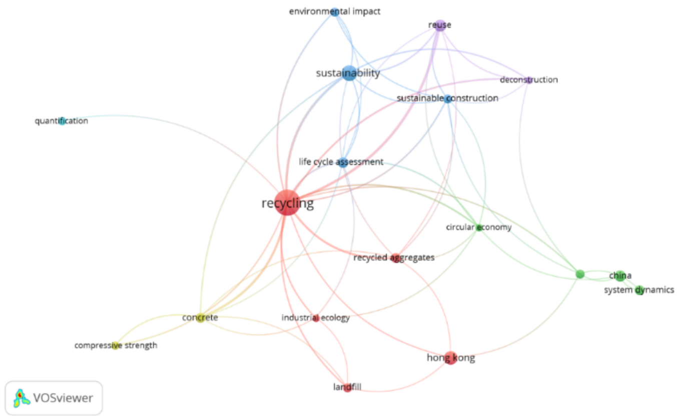

Figure 1: Mapping C&D waste management research

Based on **Error! Reference source not found.**, the most frequently studied areas are recycling, sustainability, reuse, life-cycle assessment, Hong Kong and recycled aggregates. Further, there are 6 clusters in this network and there are strong intra-cluster relationships among recycling and sustainability, recycling and concrete and recycling and deconstruction. Within the same cluster, there are strong relationships among recycling and recycled aggregates. There are many research studies on recycled aggregates and more specifically on concrete [47-49]. Further, the environmental impact is discussed in these research studies, and there are articles on life-cycle assessment as well. Bovea and Powell [40] conducted a research study on developing a life-cycle assessment to measure the environmental performance for C&D waste. Sustainability comprises of the triple-bottom-line, namely, environmental, social and economic sustainability. However, when analysing **Error! Reference source not found.**, it is evident that economic parameters are hardly discussed.

Research on LCC was also analysed using VOSviewer with the minimum occurrence of a keyword to 10. After excluding and combining the similar meaning key words, total of 17 keywords were selected and reported in Figure 2.

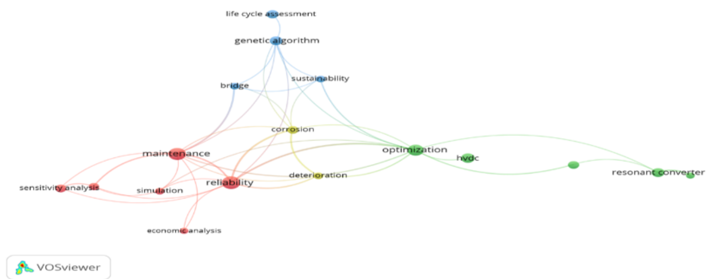

Figure 2: Mapping LCC research

According to Figure 2, there are 4 clusters in the network and maintenance and optimisation are prominent in LCC research. Further, there are strong intra-cluster relationships between maintenance and bridges, optimization and reliability and optimisation and sustainability. It is interesting to note that even though sustainability and life-cycle assessment is captured in this network map there is no indication on C&D waste management when LCC is considered.

The first search result on C&D waste management illustrated that there is minimum concern on the cost and economic considerations. This fact was further proven by the third and the fourth research results. Third search focused on cost and the C&D waste management. Figure 3 presents the network for the third search results. It has 17 key words in 3 clusters.

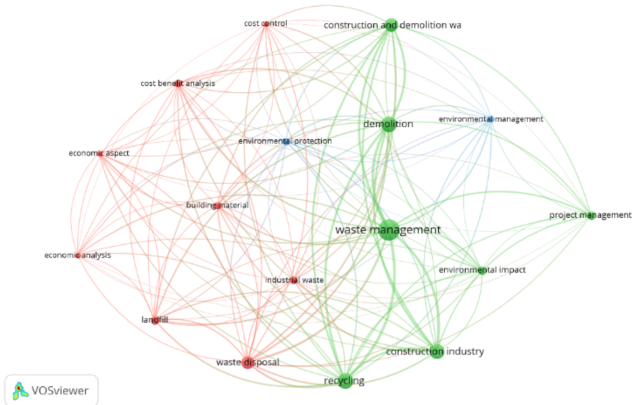

Figure 3: Mapping cost and C&D waste management research

According to Figure 3 there are no strong relationship among parameters of cost and C&D waste. Although, cost is identified as one of the key word for most of the research papers, it is evident that, no rigorous calculations on cost or economic factors researched in any of these papers. After refining the search there are 181 research papers considered for this analysis, yet there had been no or minimal consideration of cost. There were couple of research on cost effective waste management plans [50-53], cost-benefit analysis on a specific project or option [54, 55] and so on.

It is interesting to note that there is only two research articles identified through the fourth search result. Hu, et al. [56], proposed a life cycle sustainability analysis and validated it for concrete recycling. Therefore, though this research paper is selected and for LCC and C&D waste management, it is specifically focused on concrete recycling. Further, Di Maria, et al. [57] combined life cycle assessment (LCA) and LCC methodologies to analyse the environmental and the economic drivers in four alternative C&D waste end-of-life scenarios; namely, landfilling, downcycling, advanced recycling and recycling after selective demolition. According to Di Maria, et al. [57], landfilling is the scenario bearing the highest total economic costs due to high landfill tax and recycling after selective demolition bears the second highest cost. This research study was the only research study that was published directly related to LCC and C&D waste management.

4 Conclusions

This research study focused on reviewing the literature on the LCC and the C&D waste management. There are many research studies carried out in both those areas of research yet, there are minimum research combing LCC and C&D waste management. C&D waste pose a significant threat to environment and has become one of the mainly discussed topic in the construction. There are many research carried out focusing on the environmental impacts on the C&D waste management but fails to consider its economic impacts. Recycling is one of the highlighted areas C&D waste management research. Recycle aggregates are highly discussed, yet the economic impacts are once again disregarded. Recycled aggregates and recycling basically extends the life-cycle of the building materials. The economic impact of this extended life of building materials is highly desired. Further, in C&D waste management research, there is significant discussion on the positive impacts on the environment, yet monetising those social benefits is rarely or never discussed. These are the areas that require further research.

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