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Green building evaluation from a life-cycle perspective in Australia: A critical review

Jian Zuo[a,b,*], Stephen Pullen[c], Raufdeen Rameezdeen[c], Helen Bennetts[a], Yuan Wang[d], Guozhu Mao[d], Zhihua Zhou[e], Huibin Du[f], Huabo Duan[b]

[a] School of Architecture & Built Environment; Entrepreneurship, Commercialisation and Innovation Centre (ECIC), The University of Adelaide, Adelaide 5005, Australia
[b] Smart City Research Institute, College of Civil Engineering, Shenzhen University, 518060 Shenzhen, China
[c] School of Natural and Built Environments, University of South Australia, Adelaide 5000, Australia
[d] School of Environmental Science and Engineering, Tianjin University, Tianjin, China
[e] Tianjin Key Laboratory of Indoor Air Environmental Quality Control, School of Environmental Science and Engineering, China
[f] College of Management and Economics, Tianjin University, Tianjin 300072, China

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ABSTRACT

The last decades have witnessed a rapid development of green building developments at a global scale, as a measure to deal with various challenges related to climate change especially environmental issues. Australia is no exception. It is not unusual that extra resources such as cost are required for developing green buildings compared to conventional buildings. To justify extra upfront resources required for green building developments, a variety of tools have been developed such as life cycle assessment and life cycle costing. These two tools have been used in some projects in order to evaluate the cost and benefits of green buildings from a life cycle perspective. However, the uptake of life cycle assessment and life cycle costing are generally slow in the construction industry. This paper presents 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 in Australia is reviewed. Knowledge gap is presented and future research agenda is proposed.

1. Introduction

It is well recognised that there is a range of potentially detrimental effects associated with the construction industry. These include the impact of building energy use on greenhouse gas emissions, the depletion of non-renewable resources for construction, the effect on land use and biodiversity of increasing urbanization and the consequences for human health of building products and indoor environments [1–5]. There has been a growing public concern on these negative impacts associated with buildings across their life cycle.

These concerns have led to an increasing interest in improving the sustainability of the construction industry in Australia [6–9]. Alongside this has risen the need to assess the performance of buildings, extending from simply calculating operational energy use to evaluating the sustainability over the whole life cycle [10,11]. Sustainability has three aspects: environmental, social and economic. Although assessing social sustainability is very much in its infancy, there has been considerable focus on assessing the environmental and economic aspects of buildings through Life Cycle Assessment and Life Cycle Costing.

Life Cycle Assessment (LCA) is defined as "the compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle" [12]. Life Cycle Costing (LCC) is defined as "[a] process to determine the sum of all expenses associated with a product or project, including acquisition, installation, operation, maintenance, refurbishment, discarding, and disposal costs" (p.4) [13].

There is general acknowledgment that, for the construction industry, both LCA and LCC should be used. The combination is important when determining policy, for research purposes and when assessing the sustainability of individual construction projects. Yet these techniques have been confined largely to the realm of academia and research with claims that the process is too time-consuming and specialised to be more widely used.

This paper presents a critical review of the development of LCA and LCC with a particular emphasis on the Australian context. Though it

* Corresponding author at: School of Architecture & Built Environment; Entrepreneurship, Commercialisation and Innovation Centre (ECIC), The University of Adelaide, Adelaide 5005, Australia
E-mail addresses: sageorgezuo@yahoo.com.au, jian.zuo@adelaide.edu.au (J. Zuo).

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traces back the history of LCC to 1930's and that of LCA to early 1970's, the latter is gaining prominence due to increasing environmental consciousness surrounding buildings. Though these two tools complement each other in many ways helping developers, designers and users of buildings to make informed decisions, they are being used independently of each other. The separation of economic and environmental analysis limits the influence of LCA and LCC as important decision making tools for green buildings. In addition, the relationships and trade-offs between economic and environmental impacts are neglected with the independent use of these tools. Therefore, one of the main aims of this review is to explore existing literature to unearth studies that proposes a combined or integrated approach to deal with economic and environmental impacts of buildings so that investment and operational decisions on buildings could be made with greater certainty and commitment. It outlines ongoing work to combine LCA and LCC and to develop simplified tools for use in the construction industry. Agenda is proposed for future research.

2. Methodology

The research methodology for reviewing literature on green building evaluation included two stages: scoping and mapping review. Some authors use these two terms interchangeably [14]. By contrast [15], define that scoping review is a preliminary assessment of the size and quality of research in a topic area, and mapping review includes the mapping of existing research, identification of gaps, and a summary assessment of the available evidence that help to decide future research areas. This study, supporting the viewpoint of Booth et al. [15], is a two-stage systematic review. The scoping review was used as a preliminary work to inform the subsequent review [14–16]. This research, therefore, began with a scoping review to identify primary gaps within relevant studies of green building evaluation focusing mainly on a life-cycle perspective. The second stage, mapping review, aims to determine secondary gaps in green building evaluation literature. These primary and secondary gaps were used to recommend directions for future research.

The review process of this research is adapted from the model of Booth et al. [15]. Web of Science, ProQuest and Scopus databases were used for searching in both stages. Scholarly journal articles, and conference papers published in English were selected for the review. The first stage followed the three-step process. First, the selection of relevant literature was based on examining the titles and abstracts. The search rules were used to find specific words or phrases in the title, abstract, and keywords of potential articles during this stage. Second, the selected studies then were investigated to remove duplicates from the databases. Third, the remaining studies were assessed in full-text to select appropriate articles for reviewing. The exclusion criteria included irrelevant project types, out of focus knowledge areas and building evaluation techniques that do not take a life-cycle perspective. Citation and reference lists searching techniques were used in the second stage to search some crucial studies that may not have been captured in the first stage of the search [15]. That also included reports and case studies that were not captured through the above databases.

This study examined in detail all relevant review literature pertaining to this topic. While there were a number of review articles, only few of them focused on both life cycle assessment and life cycle costing. None of those review articles looked at a way of combining these two approaches in order to produce a unified approach for green building evaluation. The closest of all review articles to the current focus is by Islam et al. [17], where the authors investigate LCA and LCC approaches used in residential buildings. The tools, frameworks and processes of LCA and LCC applied to residential buildings were comprehensively discussed. The main focus of this review article was to highlight the reasons for drastically varying outcomes of past studies pertaining to LCA and LCC. It discusses the significance of system boundary, choice of building typology, construction techniques, and assumptions on these outcomes. LCC in addition was found to be very sensitive to the discount rate used in the analysis. A case study of LCA and LCC is conducted on a typical townhouse in Australia and compared it with similar past studies to discuss the implications of system boundary and assumptions on study outcomes. While LCC was found to dominate during construction stage and LCA during construction and operational stages, there is no reason why these two tools cannot be combined. However, the review article has not ventured in to this gap in the existing literature. Similar reviews on LCA and LCC deal with these two concepts independently without venturing into a discussion on a combined approach [18–20]. Kamali & Hewage [21] suggested that LCA and LCC can be combined in assessing the building performance from a life cycle perspective. Similarly [22], pointed out both LCA and LCC should form part of multi-objective optimization model to assist building developers' decision making process. Whitehead et al. [23] also indicated that automated system provides a useful tool to facilitate speedy data entry of costing and environmental information. Østergård et al. [24] argued that it is imperative to conduct simulation of building performance (e.g. costing, thermal comfort, energy, water, etc.) during the early design stage to assist decision making. However, neither of these studies attempted to specify associated critical challenges and corresponding measures.

3. Life cycle assessment

3.1. Early history

Life cycle assessment is often called cradle to the grave assessment as it assesses the environmental aspects and potential impacts of a product, process or service over its whole life [19,25,26]. For buildings this covers resource extraction and production of materials, through the construction and operation of the building to its disposal [27,28]. Cradle-to-cradle assessment takes this further with recycling and reuse built into the assessment [29,30].

Arising in the late 1960s amid growing concerns about pollution and energy use, LCA can be traced back to a few early studies of packaging [31]. The studies coincided with an interest in systems analysis which recognises the need to look at the whole life of a product and consider not only the energy used in production but also the resources used and waste generated. By the 1980s the number of studies taking this approach had increased although with no consistency of method or theory. Guinee et al. referred to the period 1970–1990 as the "decades of conception of LCA" [32]. Buyle et al. [33] suggest that the first study of buildings that adopts a life-cycle approach is a paper written by Bekker [34]. Since 1990s, LCA gradually forms an integral part of legislations and policy interventions at a global scale in a bid to reduce the environmental impacts of various sectors such as packaging industry [35]. However, there have been some debates on the accuracy of these LCA results [36]. Since the 21st century, LCA has been adopted as a motivation mechanism in government policies to promote sustainable development [37–39]. The current supporting policies place more focuses on encouraging life cycle thinking [40–43].

When LCA approach is adopted, building is regarded as a system where material flow and energy flow are quantified throughout various life cycle stages [44,45]. Compared to conventional approaches, LCA has advantages of sustainability assessment at more than one stage and interactions between stages [46–48]. The last two decades have witness the rapid growth of LCA application in sustainable building evaluations at the global scale LCA processes.

In broad terms an LCA involves: "compiling an inventory of relevant energy and material inputs and environmental releases; evaluating the potential environmental impacts of those inputs and releases, and interpreting the results to better inform decision-makers" (p. 2) [49]. Inputs and outputs can be determined through process analysis, the use of input-output tables or hybrid analysis.