Review of the Quantitative Analysis Methods for Social Life Cycle Assessment in Construction

X. Y. Jiang, X. R. Yao, and S. N. Lyu

Abstract The life cycle sustainability assessment (LCSA) of construction activities has become a subject of considerable interest globally. However, researchers are mainly devoted to analyzing economic and environmental impact assessment of buildings, and there is a lack of a review of the studies on social impact assessment. Therefore, this study aims to review the quantitative methods for social life cycle assessment (S-LCA) in construction through the bibliometric method. Most of the studies on social impact analysis have adopted qualitative and quantitative methods and this study mainly focuses on the studies that used quantitative analysis methods for social life cycle assessment owing to the space limitation. This study found that the research interest in the life cycle sustainability assessment is gradually rising, primarily focusing on case studies, method comparisons, and new frameworks. However, because social impact assessment has significant limitations in the quantification of inventory, the choice of indicators, and the method of impact assessment, this study proposes that the development of social impact factors in the construction field requires to make more extraordinary efforts in the development of new methods, new software, new technologies, decision-supporting tools, and databases.

Keyword Social life cycle assessment · Social life cycle cost · Construction · Bibliometrics

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1 Social Impact Factors in Construction

With the progress and development of living standards, people's requirements for sustainability are gradually increasing. Sustainable development includes three dimensions: environment, economy and society. These three dimensions are interdependent and become the pillars of sustainability assessment, also known as the triple bottom line (TBL) of project sustainability as well. According to the United Nations Environment Programme (UNEP), "the buildings sector—a huge engine of the global economy—still accounts for a significant 36 percent of final energy use" [1]. Therefore, the life cycle sustainability assessment of the construction industry is a necessary link to meet sustainable development. At present, the concept of Life Cycle Sustainability Assessment (LCSA) is widely recognized, whose framework integrates three life cycle technologies: Environmental Life Cycle Assessment (LCA), Life Cycle Costing (LCC), and Social Life Cycle Assessment (S-LCA) [2–4].

S-LCA is a technology used to assess potential and verified social impacts during the product life cycle. Like economic assessment and environmental assessment, S-LCA supports sustainable development and is a useful tool for achieving sustainable development. However, due to the lack of effective data collection [5], the dynamic changes in social conditions, and the subjectivity of stakeholder evaluations, the research of S-LCA in construction is still in its infancy. S-LCA is still a young instrument that requires further development [6, 7]. Therefore, it is urgent and necessary to research S-LCA.

In 2009, at the ISO 26,000 (Social Responsibility) Conference of the National Organization for Standardization, the "Guidelines for the Social Impact of Product Life Cycles" (referred to as "Guide") published by UNEP and the Society of Environmental Toxicology and Chemistry (SETAC) were released [6], which provides a theoretical basis for S-LCA. Simultaneously, with the emergence of life cycle theory, increasing studies consider the social impact and social cost into the life cycle assessment. At present, the social impact assessment research in construction mainly focuses on the following three aspects: (1) using qualitative factors and quantitative methods to conduct case research and analysis [8–11], including proposing a new framework and verifying its feasibility [12, 13], (2) putting forward optimization methods [14–17], and (3) comparing multiple cases to obtain the best from them [18, 19].

Although the studies on S-LCA in construction have gain popularity, a thorough review of the application of research methods for S-LCA is lacking. To address this research gap, the aim of this article is to review the quantitative methods related to S-LCA in construction. The existing methods for S-LCA are mostly qualitative and quantitative methods, while this study mainly focuses on the review on quantitative methods due to the space limitation. This study will help researchers and stakeholders to develop a body of knowledge regarding S-LCA and stimulate their inspiration for the application of quantitative methods in S-LCA. It can help maintain the relationships between stakeholders and promote sustainable social development.

Meanwhile, the government can consider multiple aspects to make the best decision, the company can strengthen its reputation, and attract outside attention, and the public can increase satisfaction and happiness themselves.

2 Screening of Literature

This study uses four steps to screen the literature, including database selection, database search, preliminary screening, and fine screening.

Firstly, database selection. The author selects Scopus for screening.

Secondly, database search. Enter the search formula "*TITLE-ABS-KEY (((social OR society OR societal) AND ("life cycle assessment" OR "*life cycle cost*" OR "LCC" OR "LCA") AND (construction OR *building* OR *infrastructure* OR "civil engineering")) OR (("social assessment" OR "societal assessment" OR "social *impact*" OR "societal *impact*" OR "social *cost*" OR "societal *cost*") AND ("*life cycle*") AND (construction OR *building* OR *infrastructure* OR "civil engineering"))) AND SRCTYPE (j) AND DOCTYPE (ar OR re) AND LANGUAGE (English)* " in Scopus database. The search only covers journals published in English. A total of 1,132 articles were identified and the literature related to social factors in the construction field was first published in 1974.

Thirdly, preliminary screening. Since the initial search includes almost all articles, including the word "society" in the construction literature, it is necessary to exclude literature irrelevant to social influence factors and evaluation methods. By screening the title and abstract, the literature related to the structure or clean energy is deleted. Finally, 396 articles remain, which are mainly published in the journals regarding green sustainability and construction projects, such as International Journal of Life Cycle Assessment, Journal of Construction Engineering and Management, and Building and Environment.

Finally, fine-screening. The documents selected in the previous step are downloaded, and the method and discussion part are screened so as to delete the documents not mentioning social factors or irrelevant to the research topic of this study. 220 papers remained for in-depth research and discussion. These documents mainly focus on the social influence in construction projects, social evaluation indicators, social evaluation methods, social costs, and optimization.

By analyzing the above literature, the result indicates that social impact analysis is mostly developed based on two research methods: qualitative analysis and quantitative analysis. Qualitative analysis describes the social impact and the social benefits of construction, while quantitative analysis uses mathematical language to describe impact factors, generally including the measurement of social indicators and social impact methods. There is a lack of the review on research methods of the social impact in construction. Thus, this study mainly discusses and analyzes the social impact assessment methods in the construction field from the quantitative aspect.

3 Quantitative Analysis Methods of S-LCA in Construction

Most researchers use the LCA framework to evaluate the sustainable development factors and potential impacts of buildings [20–25]. ISO14040 provides a standardized framework for implementing LCA. LCA consists of four main phases: goal and scope definition, life cycle inventory (LCI), life cycle impact assessment (LCIA), and life cycle interpretation. It takes social factors as a part of the LCA impact assessment. The life cycle inventory analysis stage includes obtaining social indicators based on previous literature studies, expert interviews, and other methods, and then measuring and calculating the indicators through field data from the National Bureau of Statistics and public data. The research framework of S-LCA is similar to LCA, and the difference is that S-LCA only focuses on social impact. The general framework for S-LCA is shown in Fig. 1 [6] and includes three stages.

1. The first stage is to clarify the purpose and objectives of the research, formulate critical reviews according to different goals, and then define the building functions and function units to determine the scope. ISO 14,040 [26] specifies: "The scope should be sufficiently well defined to ensure that the breadth, depth, and detail of the study are compatible and sufficient to address the stated goal." Besides, because one of the goals of using S-LCA is to promote society's conditions improvement, it is necessary to pay attention to the views of stakeholders and decision-makers. Thus, five main stakeholders are proposed in the "Guidelines", including workers, local communities, society, consumers, and value chain participants.
2. In the second stage, the social life cycle inventory analysis should be carried out, including collecting data in the inventory stage, modeling the system, and

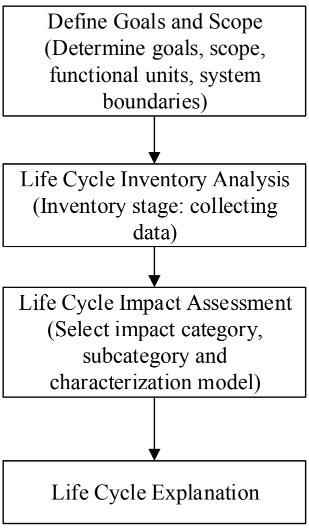


Fig. 1 Quantitative analysis framework of S-LCA

then obtaining sLCI's results. It is necessary to ensure the validity, relevance, and completeness of the data.

3. The third stage is to conduct the social life cycle impact assessment (sLCIA), including selecting impacts and its subcategories, contacting list data and its subcategories and the impact categories, and then calculating the results of characterization. In this stage, it requires to characterize, normalize, and weight the data. Among them, characterization is to transform the social information into interpretable indicators, which can reflect a range of effects. Normalization is to rescale the characterization results to a comparable range based on National Statistical Data, that is, from -1 to 1 or 0 to 1. For example, freedom of association and collective bargaining (FACB) scores between 0 and 10 [13].
4. In the last stage, the interpretation of the social life cycle is carried out, which is to put forward some recommendations for this research evaluation. The current mainstream method for S-LCA research in the construction field is to conduct specific research on buildings in different regions based on the framework of the "Guidelines" [8, 9, 13, 18, 19, 27–37]. In the process of S-LCA analysis, it generally uses methods such as brainstorming, expert scoring, hot spot analysis, and principal component analysis to establish the indicator system [8, 18, 35], and determine the weights of indicators through analytic hierarchy process, interviews and questionnaire surveys [8, 9, 12]. Finally, the scores can be calculated.

Except for the "Guidelines", in Europe, the European Technical Commission compiled EN16309 in the social dimension of the sustainable performance evaluation framework of EN15643-3 in 2014, established a framework suitable for the social performance evaluation of European buildings [10, 38], and provided evaluation methods and requirements for the social performance of buildings. This method is mainly used in the whole life cycle social evaluation of buildings that comprehensively consider health and comfort standards. The steps include: (1) determining the evaluation purpose; (2) clarifying the evaluation object; (3) establishing the relevant scenes of the building use stage; (4) determining the evaluation aspects and indicators, (5) reporting and exchanging evaluation results and data sources; and (6) verifying the consistency and reliability of the results. For the evaluation of the social performance of buildings, the standards refer to quantitative methods. However, if without them, researchers would use a checklist method to evaluate standards. The social performance categories of buildings specified therein include barrier-free, adaptability, health and comfort, impact on the community, maintenance and maintainability, as well as safety and security.

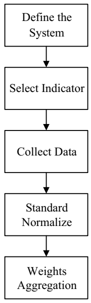
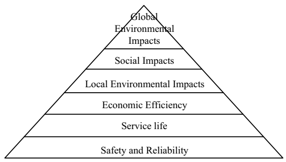
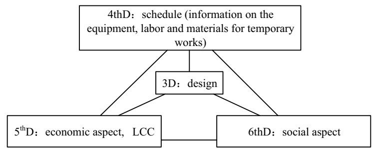
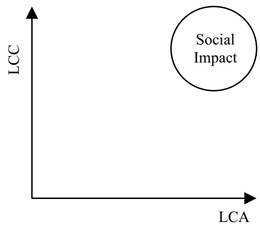
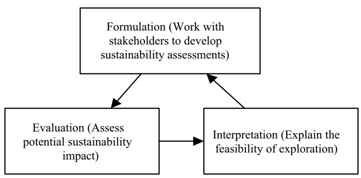
To fully understand the specific impact of construction projects on the environment, economy, and social development, as well as quantify the social impact, researchers combine LCA with TBL and other theories, propose an input–output life cycle assessment (I-O LCA) based on the economic benchmark input–output table [39, 40], the sustainability assessment framework based on economic input–output (EIO-LCA) [41–43] and the hybrid LCA model [16, 44]. The input–output analysis provides a static image of the relationship among different economic sectors within a year and express with currency. Therefore, the social problems of each economic sector can be calculated [40, 45] by: (1) using the technical coefficient matrix, satellite matrix, and social footprint coefficient matrix in I-O LCA to implement this model on MATLABs; (2) using the technical coefficient matrix, Make matrix and Use matrix in EIO-LCA; and (3) using social accounting matrix (SAM) in hybrid LCA. Finally, it can use the economic input–output table to calculate the final demand and indirectly measure the social impact. Such methods are suitable for quantitative models of national and regional analysis, but due to the economic input–output table fails to reflect its operation, it is impossible to conduct a complete life cycle analysis of goods (except vehicles, ships, and aircraft used in public transportation).

To be consistent with sustainable development, the improved eco-efficiency(EE) framework and sustainable development assessment methods [46] are used to integrate environmental, economic, and social indicators into a single measurement standard. The main steps include: (1) proposing the EE measurement, including the ratio of economic indicators/environmental indicators and economic indicators/social indicators; (2) selecting indicators, (3) using linear integration of multiple indicators to perform data envelopment analysis (DEA) on the EE measurement, which is to promote the integration of environmental, economic and social indicators to obtain sustainability scores, and (4) carrying out a sensitivity analysis on the weighting scheme.

Some researchers develop new frameworks for social assessments based on different building characteristics and purposes. Six categories of research methods (RMs) were summarized and the main assessment process and scope of application are shown in Table 1.

- RM1: A conceptual framework based on the life cycle integrated C&D waste management system is developed for the assessment of waste and demolition generated by buildings [47].
- RM2: A life cycle design (LCD) method is proposed to solve the lack of long-term performance and social effects of structural design, which builds a pyramid model, taking social evaluation as the fifth layer and using the historical data of similar projects to predict the possible social impact of the target project through the comparison method[48].
- RM3: An integrated 6D CAD system is developed to automatically assess the sustainability of the building's life cycle, taking economic, social, and environmental impact as the sixth dimension, and using computer-aided systems to evaluate and calculate social impact[12].
- RM4: A sustainability evaluation method HBSAtool-PT that combines questionnaire pairwise comparison and analytic hierarchy process analysis for multi-criteria analysis is proposed for medical buildings[49].
- RM5: In order to compare retrofit alternatives from the sustainable perspective, the Renobuild method is developed, with the horizontal axis representing the environment and the vertical axis representing the life cycle cost, at the same time, the social factors are represented by circles[50]. The larger the circle, the

Table 1 Research methods and evaluation process

Categorizes	Methodology	Evaluation process	Scope of application	Ref
RM1	C&D waste management framework		Life cycle assessment of construction and demolition waste management	[47]
RM2	Life-Cycle Design (LCD) method		Structural design process	[48]
RM3	6D CAD model		Design aid	[12]
RM4	HBSAtool-PT	Index selection → index evaluation	In healthcare building projects	[49]
RM5	Renobuild		Evaluation of renovation alternatives	[50]
RM6	Constructive Sustainability Assessment (CSA) framework		Help decision-makers make decisions	[51]

more beneficial it is to society. Thus, the best choice should be the big circle in the upper right corner of the picture.

- RM6: A constructive sustainability assessment (CSA) framework is proposed by combining life cycle thinking with research and innovation principles, which uses circular and iterative methods to conduct a comprehensive social assessment, enabling sustainable development assessment to be applied to emerging technologies and become part of a broader review method[51].

At present, general data are obtained from the National Statistical Yearbook, Social Hotspot Database (SHDB), development reports, network research, and company field reports. The measurement of quantitative indicators can be obtained from some international conventions and statistics, such as the proportion of child labor from UNCEF and WB, the wage and gender index from OECD, standard working hours from LD, forced labor from ILO, the information on intangible cultural heritage from UNESCO, and the burden of health diseases from WHO.

In addition, in some studies, researchers convert social influencing factors into costs and calculate life cycle costs, which are often used in roads and bridges [52–54]. It generally includes user delay costs, vehicle operating costs, and accident costs.

Finally, a series of decision-making models are developed to optimize case studies using dynamic evaluation, such as the multi-standard decision-making (MCDM) model improving the impact of sustainable development on determining the best pavement design strategy [16], the sustainable evaluation comprehensive value model MIVES [55], a risk decision framework that considers sustainability and flexibility for infrastructure [56], the MARS-H that uses graphical consideration indicators to evaluate different analytical solutions [57], an MODM random compromise programming model developed to find the best allocation [16], and the Pareto curve used to evaluate the optimal solution [17, 31, 58].

4 Discussion and Recommendations

Being a relatively new technique, LCSA is limited in several aspects, in particular in the S-LCA part. These include the quantification of inventory, selection of indicators, and methods of impact assessments. [6, 59] The shortages of S-LCA could even lead to the question that whether LCSA is an appropriate method for quantifying sustainability[3]. Therefore, the study of S-LCA is an urgent problem.

Through the bibliometric method, as well as the review and research of relevant literature on social impact factors in the construction field, it is clearly shown that the status of social factors in sustainable development is gradually rising and attracts more and more attention. At the same time, the use of S-LCA is becoming frequent in construction decision-making. This is because S-LCA can provide an effective decision-making framework for the government, designers, developers, and other decision-makers. Besides, it can consider some social influences in the development of the construction life cycle to realize the development of high quality and quantity of buildings. In addition, S-LCA still has the possibility and necessity to continue to be developed and improved. The consideration of social influence factors will be more perfect, and more frameworks will be developed for different buildings to meet various architectural needs. However, due to cultural differences in different places, stakeholders' views on the same thing will be quite inconsistent. Thus, the social life cycle assessment is very regional, so it is difficult to use a certain assessment to represent a certain type of building.

In order to solve some of the above problems, the current development of social influencing factors in the construction field requires greater efforts in the development of new methods, new software and new technologies, decision support tools, and databases. Due to the subjectivity of stakeholders, it is difficult to use the fixed indicators, weights, and coefficients to evaluate the social influencing factors. The author recommends that it can develop a relatively complete social evaluation database for specific locations to facilitate the collection, supplementation, verification, updating, and summary of subsequent studies. In addition, it is recommended to consider the three sustainable pillars of environment, economy, and society to formulate a comprehensive decision-making framework and set different decision sets for different stakeholders. The above measures are so as to make faster methods and decisions that are beneficial to themselves and society, and to help the government formulate reasonable policies to better promote sustainable development.

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