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Developing an Integrated Big Data - Life Cycle Framework for Selecting Construction Material Towards Sustainability in the Preliminary Design Phase

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Abstract

Integrating Life Cycle Cost (LCC), Life Cycle Assessment (LCA), and Social Life Cycle Assessment (S-LCA) has emerged as a pivotal approach for evaluating the multi-dimensional performance of construction materials. However, existing studies often treat these dimensions in isolation, failing to provide a holistic representation of sustainable development. Furthermore, while material selection in the preliminary design phase fundamentally dictates the sustainability trajectory of a project, there remains a critical research gap regarding standardized frameworks that integrate Triple Bottom Line (TBL) analysis for this early stage. To address this, the study employs a Systematic Literature Review (SLR) methodology, analyzing 28 relevant publications from ScienceDirect and Scopus between 2012 and 2025 to identify current trends, criteria, and methodological barriers. The main contribution of this paper is the development of an integrated Big Data Life Cycle framework. By leveraging Building Information Modeling (BIM) data from previous projects, the proposed framework utilizes analogous and parametric estimating to address data scarcity during the preliminary design phase. This framework enables decision-makers to conduct comprehensive Life Cycle Sustainability Assessments (LCSA) through Multi-Criteria Decision Making (MCDM), ensuring that material selection aligns with economic, environmental, and social goals from the project's inception.

Keywords
Life cycle cost; life cycle assessment; social life cycle assessment; construction material selection; Big Data

1. Introduction

When construction activities are carried out, they release carbon dioxide and other greenhouse gases into the atmosphere. The growth of the construction industry is responsible for substantial global energy and resource consumption, resulting in large global greenhouse gas emissions. Energy consumption is projected to increase by 53% in non-OECD countries over the next decade [1], which is expected to have a significant impact on the ecological balance and on climate change. Globally, there is a growing interest in sustainability within the construction industry. Shaffi concluded that sustainability is achieved while taking environmental, socioeconomic, and cultural concerns into account [2].

Several authors classified construction projects into six phases, including (1) Initiation, (2) Planning and design, (3) Tender/Bidding, (4) Construction, (5) Handover and operation, and (6) Close-out [3-6]. The six phases identified align with international project life cycle standards such as the RIBA Plan of Work or ISO 22263, ensuring the framework's applicability beyond a specific regional context. The material selection process is embedded within the planning and design phase, which is typically categorized into three distinct stages: pre-design, preliminary design, and detailed design. *Construction material selection* is the process of selecting the most suitable materials based on given criteria and standards. The selection includes five typical steps: (1) Identify the design requirements; (2) Identify element design requirements; (3) Identify candidate materials; (4) Evaluate materials; (5) Determine the satisfaction of evaluated materials; (6) Select materials [7].

The selection of construction materials is one of several factors that can affect the construction industry's sustainability [8], along with factors such as duration, cost, and quality [9]. Deng and Edwards [10] and Rockizki and Peggy [11] also highlighted the significance of material selection during the design phase. As a component of the early design phase, material identification identifies the primary potential materials contributing to the fulfillment of required functions [12]. Besides, Akadiri and Olomolaiye [13] and Govindan et al. [14] collected the sustainable criteria for material selection, imposing upon economic, environmental, and social aspects from previous studies. By taking these criteria into account, construction materials will be chosen. Similarly, Kiani Mavi et al. [15] identified major studies of sustainability in the construction industry. The study also suggested that improving tools for sustainable assessment is one of the main research trends, along with project management for sustainability and control of sustainable construction.

Life Cycle approaches, including Life Cycle Cost (LCC), Life Cycle Assessment (LCA), and Social Life Cycle Assessment (S-LCA), are used to assess economic, environmental, and social aspects of sustainability. The LCC is widely applied to reckon the total cost of materials in construction projects by breaking down the Life Cycle Cost of materials into cost items [16, 17]. For assessing the environmental impacts of material alternatives, the LCA is conducted to evaluate the factors affecting environmental performance, such as CO_2 emission and energy consumption [18-21]. Social performance is assessed by using the S-LCA to evaluate relevant factors, such as worker health and safety [22, 23]. However, economic, environmental, and social dimensions are only separate parts of sustainability, so the LCC, LCA, and S-LCA results provide only an incomplete picture of sustainable development. Integrating LCC, LCA, and S-LCA is essential for assessing sustainability performance by conducting trade-offs among their results [24].

Accordingly, research questions were developed to analyze the integration of LCC, LCA, and S-LCA in construction material selection: (1) How to integrate LCC, LCA, and S-LCA in construction material selection *in buildings and infrastructure*? (2) Which method and criteria are most applied for LCC, LCA, and S-LCA in construction material selection in buildings and infrastructure? (3) Is it necessary to integrate LCC, LCA, and S-LCA for selecting construction materials in the preliminary design phase? (4) What barriers exist and need to be overcome in future research?

Despite the critical influence of early-stage decisions on project outcomes, a significant gap remains in structured methodologies that integrate Triple Bottom Line sustainability into the preliminary design phase. Therefore, the main objective of this study is to develop a comprehensive integrated Big Data - Life Cycle framework for construction material selection. By leveraging historical Building Information Modeling data and analogous estimation techniques, this framework specifically aims to bridge the gap that currently hinders Multi-Criteria Decision Making in the initial design stages. To achieve this, the paper first conducts a systematic literature review (2012-2025) to synthesize existing LCC, LCA, and S-LCA integration methods. Subsequently, it identifies key barriers in the preliminary phase to inform the proposal of a data-driven solution.

2. Research Methodology

This article is a literature review in the area of material selection and Life Cycle analysis. The main objective of this study is to identify publications that combine all LCC, LCA, and S-LCA in construction material selection during the period from 2012 to 2025.

To provide an overview of recent methodological developments, a Systematic Literature Review (SLR) method was conducted. The SLR method is not a descriptive summary of articles; it calls for a synthesis of publications to develop an integrated understanding of a specific topic [25]. The databases (ScienceDirect and Scopus) were chosen and queried for a literature review conducted from October 6, 2023, to December 16, 2025. These data sources were chosen due to their popularity as well as relevance to the study topic.

Relevant keywords and scientific databases were identified to find suitable articles addressing construction material selection and Life Cycle analysis. The main fixed keywords were “Life Cycle Cost”, “Life Cycle Assessment”, “Social Life Cycle Assessment”, “material”, “select”, while the changing keywords were “construction”, “build”, or “infrastructure”. The search resulted in a list of 764 articles in total, including 709 publications in ScienceDirect and 55 publications in Scopus (see Table 1).

Table 1 Summary of searching keywords.

Keywords	Scopus	Science Direct
"Life Cycle Cost", "Life Cycle Assessment", "Social Life Cycle Assessment", "**construction**", "material", "select"	27	303
"Life Cycle Cost", "Life Cycle Assessment", "Social Life Cycle Assessment", "**build**", "material", "select"	3	190
"Life Cycle Cost", "Life Cycle Assessment", "Social Life Cycle Assessment", "**infrastructure**", "material", "select"	25	216
Total	**55**	**709**

However, there are so many overlapping publications in selected sources. After removing duplicates, a bibliometric analysis was conducted with 302 publications. The relevance of the articles, based on their types, titles, and abstracts, was assessed, and 188 irrelevant articles were excluded. The reason is that the following criteria were used to exclude articles: (1) they did *not include the combination of LCC, LCA, and S-LCA*, (2) they were *not about construction material selection in buildings and infrastructure*, and (3) they were *not research articles, review articles, or book chapters*. After that, all articles were thoroughly analyzed (86 articles were excluded), and 28 articles were selected for further review.

The systematic reduction from 302 to 28 articles (only 9.2%) highlights a significant research gap; At the same time, many studies discuss sustainability, but very few successfully integrate all three LCSA pillars (LCC, LCA, and S-LCA) within the construction sector. This justifies the need for the integrated framework proposed in this study. For example, an article from Sanchez-Garrido et al. [26] is unsuitable for the systematic review primarily because it violates EC1 by failing to integrate all three pillars of sustainability. Although the study conducts rigorous environmental (LCA) and social (S-LCA) assessments, the authors explicitly acknowledge the omission of a Life Cycle Cost due to a lack of detailed economic data. Similarly, Firoozi et al. [27] violate EC1 by focusing exclusively on environmental impacts (LCA) without integrating Life Cycle Cost or Social Life Cycle Assessment. Although the study provides valuable insights into infrastructure sustainability and digital technologies, it fails to deliver the comprehensive TBL evaluation required by the proposed methodology. Consequently, since the research does not simultaneously address the economic, environmental, and social dimensions of material selection, it must be excluded from the final analysis. Despite the established importance of the triple bottom line, recent studies predominantly focus on a single dimension in isolation, lacking a comprehensive assessment that simultaneously integrates economic, environmental, and social factors. After removing duplicates and conducting an initial screening of 302 unique records, studies were further excluded during an intensive analysis based on three primary criteria (see Table 2): EC1 (Incomplete sustainability pillars), which removed research failing to simultaneously integrate LCC, LCA, and S-LCA to maintain a strict Triple Bottom Line perspective; EC2 (Out-of-scope sector), which excluded papers not specifically focused on construction material selection for buildings or infrastructure to ensure data consistency within the construction industry; and EC3 (Publication quality), which prioritized high quality academic evidence by excluding short conference abstracts, posters, and non-peer-reviewed reports. This highly selective approach highlights a critical research gap, while sustainability is widely discussed, very few studies successfully integrate all three LCSA pillars in the construction sector, thereby justifying the necessity of the proposed integrated Big Data - Life Cycle framework.

Table 2 Structure of literature reviews.

Review questions	(1) How to integrate LCC, LCA, and S-LCA in construction material selection in buildings and infrastructure? (2) Which method and criteria are most applied for LCC, LCA, and S-LCA in construction material selection in buildings and infrastructure? (3) Is it necessary to integrate LCC, LCA, and S-LCA for selecting construction materials in the preliminary design phase? (4) What barriers exist and need to be overcome in future research?
Literature Research	*Keywords*: "Life Cycle Cost", "Life Cycle Assessment", "Social Life Cycle Assessment", "**construction**", "material", "select" "Life Cycle Cost", "Life Cycle Assessment", "Social Life Cycle Assessment", "**build**", "material", "select" "Life Cycle Cost", "Life Cycle Assessment", "Social Life Cycle Assessment", "**infrastructure**", "material selection." *Databases*: Scopus; ScienceDirect
Exclusion Criteria	**(EC1) They did not include the combination of LCC, LCA, and S-LCA**: This criterion excludes any study that does not simultaneously integrate Life Cycle Cost, Life Cycle Assessment, and Social Life Cycle Assessment. It ensures the review strictly adheres to the Triple Bottom Line definition of sustainability, providing a holistic evaluation rather than isolated or fragmented results. **(EC2) They were not about construction material selection in buildings and infrastructure**: Research not specifically focused on construction material selection for buildings or infrastructure projects is excluded. This maintains data consistency regarding life cycle inventories and technical requirements unique to the Architecture, Engineering, and Construction industry. **(EC3) They were not research articles, review articles, or book chapters:** The review excludes short conference abstracts, posters, editorials, and non-academic reports to prioritize high-quality academic evidence. This ensures that the synthesized data is grounded in rigorous, peer-reviewed scientific methodologies and reliable findings.
Evaluation Tools	Microsoft Excel

Then, the remaining 28 articles were classified into two groups (1) review articles (6 papers) and (2) non-review articles/or methodology articles (22 papers). After that, data from 22 methodological publications were compiled in a Microsoft Excel spreadsheet for chart and table elaboration. According to these groups, the publications were analyzed, and they drew a general picture relating to material selection and Life Cycle analysis (see Figure 1). Table 2 illustrates the structure of literature reviews.

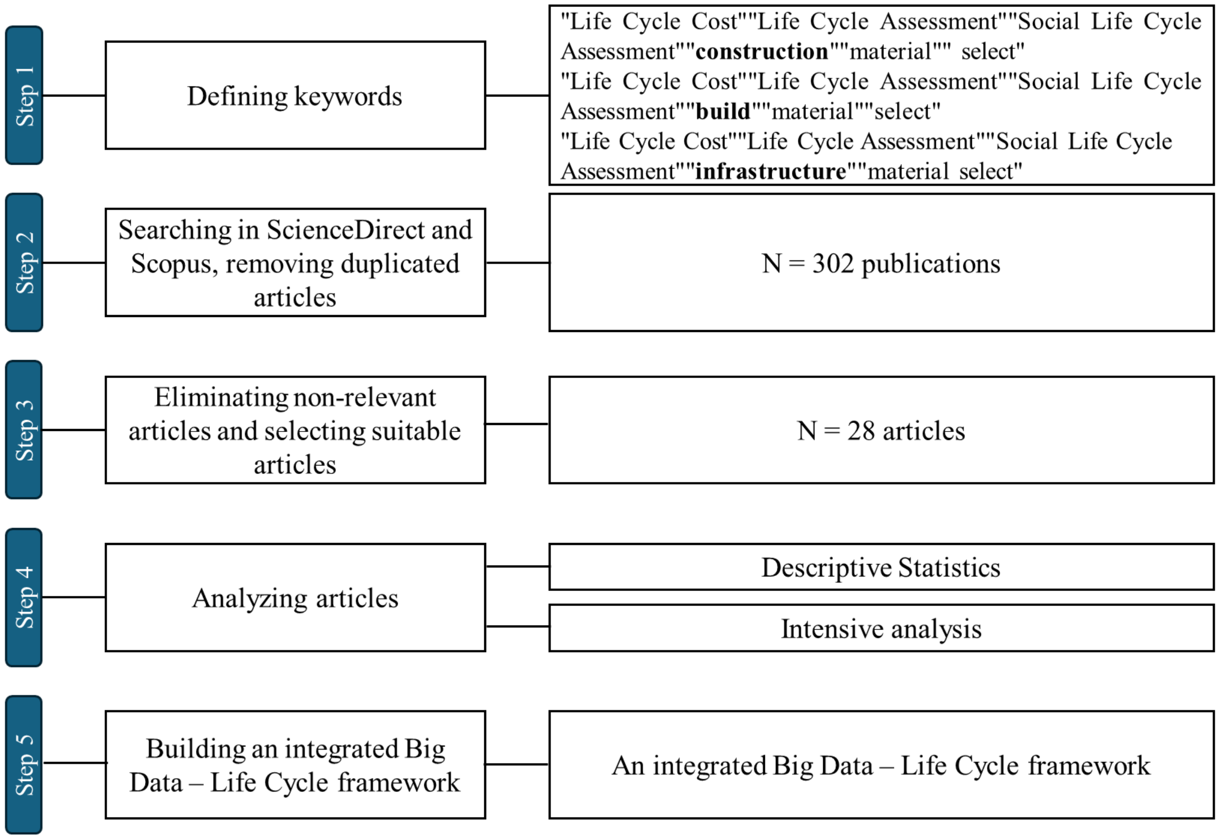

Figure 1 Overview of search strategies and research process.

3. Results

The twenty-two methodology publications will be categorized into six main groups, including title, authors, year, journal name, combining method (Appendix 1), and criteria. The analysis process is conducted through the number of articles by year, the number of articles by the journals, the percentage of main methods used in the articles, the case studies, the percentage of articles mentioned in the preliminary design phase, the percentage of articles using the single score, and the most common criteria in LCC, LCA, and S-LCA analysis.

To understand the academic evolution of integrated sustainability assessments, the distribution of selected studies was analyzed by year. Figure 2 illustrates the publication trends from 2012 to 2025, revealing a notable surge in research activity.

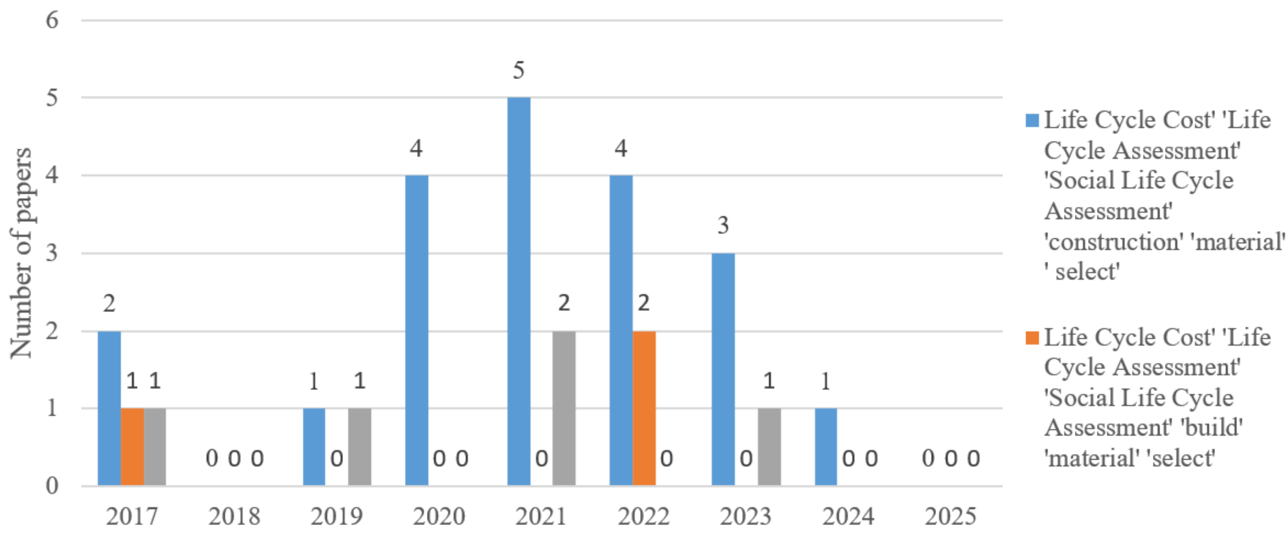

Figure 2 The number of articles by year during the period from 2012 to 2025.

In general, there are several articles on material selection using LCA, LCC, and S-LCA during the period from 2012 to 2025 (see Figure 2). The number of articles is mainly at least two articles per year, peaking at eight articles in 2021. It can be explained by increased knowledge of LCA, LCC, S-LCA, and the sustainability trend in the construction industry. The surge in publications peaking in 2021 reflects a global shift toward mandatory carbon reporting and the maturation of LCSA methodologies.

A critical aspect of this review was to determine the extent to which existing research addresses the earliest stages of project development. Figure 3 presents the percentage of articles that specifically mention or focus on the preliminary design phase.

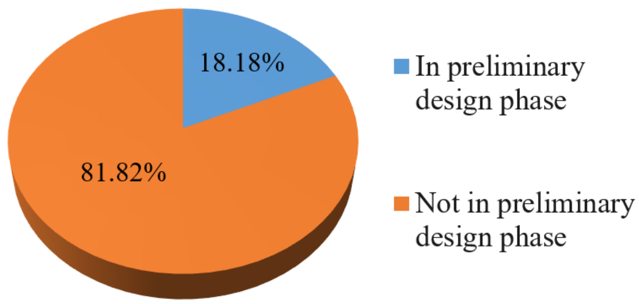

Figure 3 The percentage of articles mentioned in the preliminary design phase.

The preliminary design phase clarifies the requirements of the initiation phase. It involves creating all the necessary documentation for project implementation and management. It also translates ideas and information into basic plans, drawings, and specifications. Additionally, the preliminary design phase defines the main structures, essential materials, and additional facilities. It can be said that a good implementation of the preliminary design stage is the foundation for performing the construction management steps well. From Figure 3, the number of articles relating to the preliminary design phase was 4 out of 22, accounting for 18.18%. This means that there is a small number of papers researching material selection and Life Cycle analysis in the preliminary design phase. This low percentage reveals a “sustainability paradox”: although the earliest design stages have the greatest influence on a project’s life cycle impact, they receive the least analytical attention. This disparity confirms the critical need for a Big Data-driven approach to overcome early-stage data scarcity.

The applicability of Life Cycle methodologies was further categorized based on the type of construction project investigated. Figure 4 compares the focus between building and infrastructure projects within the selected studies.

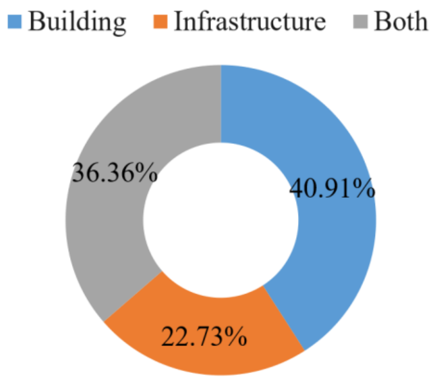

Figure 4 The percentage of case studies used in the articles.

The percentage of infrastructure is only 22.73%, while the figure for building-related ones is about 40.91% (Figure 4). Besides, the number of papers concerning both buildings and infrastructures accounts for 36.36%. It shows that scholars focused on buildings rather than infrastructure. The dominance of building-related studies suggests that sustainability metrics for vertical structures are more established than for horizontal infrastructure. This indicates a significant opportunity to adapt building-based LCSA successes from the infrastructure sector.

To evaluate how researchers simplify complex sustainability data for decision-makers, the use of aggregated metrics was examined. Figure 5 displays the proportion of methodology articles that employ a single score for sustainability comparison.

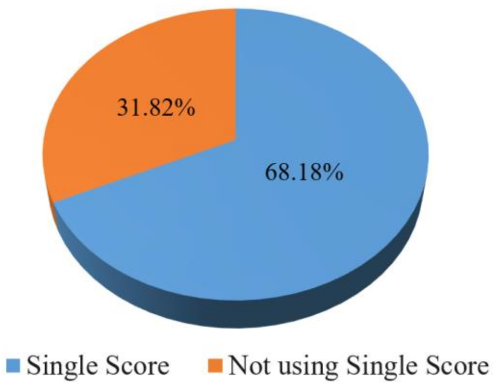

Figure 5 The percentage of articles using a single score.

Using a single score allows experts to compare the sustainability performance of different alternatives straightforwardly. This facilitates the decision-making process since it is immediately clear whether a material's impact is higher than, lower than, or similar to the others. Figure 5 shows that more than half of the articles (15 out of 22 articles) use a single score for the comparison. The preference for single scores demonstrates that decision-makers prioritize actionable intelligence over raw, complex data. This trend supports the inclusion of MCDM methods in the proposed framework to reduce multi-dimensional trade-offs into a comparable metric.

An analysis of the specific indicators used across the three sustainability pillars was conducted to identify industry standards. Figure 6 identifies the most common criteria in LCC, LCA, and S-LCA that appeared in at least four separate publications.

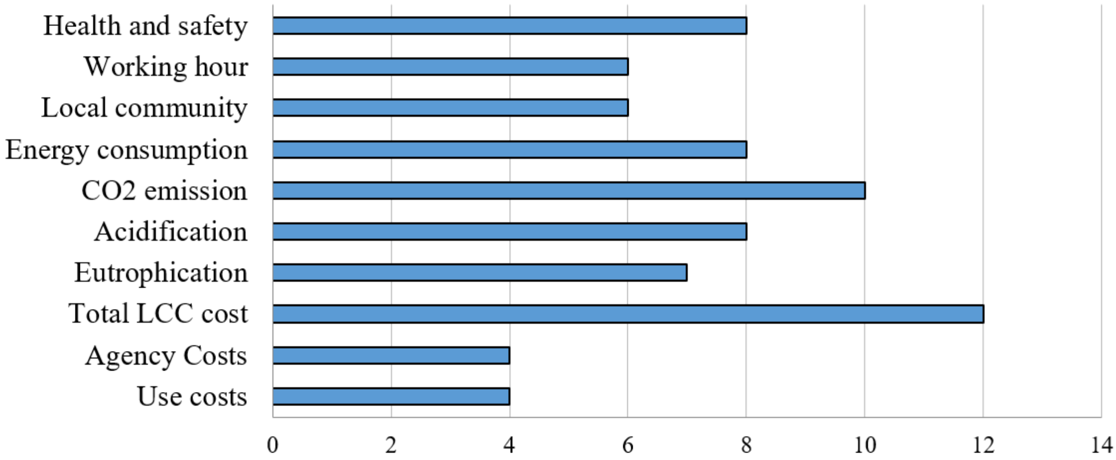

Figure 6 The most common criteria in LCC, LCA, and S-LCA analysis.

Figure 6 illustrates the most common criteria, which appear at least four times in the selected publications. The result shows that the total LCC cost was the most popular criterion used in estimating the economic aspect of construction materials. For environmental burden, there were ten publications on CO_2 emissions, while the health and safety accounted for the largest number of S-LCA papers. The heavy concentration on CO_2 and direct costs shows that environmental and economic assessments are reaching a level of standardization that social metrics (in S-LCA) still lack. The framework addresses this by categorizing these high-frequency criteria as core indicators for early-stage screening.

4. Discussions

This study identified keywords and scientific databases to find papers that discuss the selection of construction materials and Life Cycle analysis. The fixed keywords were "Life Cycle Cost", "Life Cycle Assessment", "Social Life Cycle Assessment", "material", "select", while the changing keywords were "construction", "build", or "infrastructure". Selected 28 articles were classified into two groups: (1) review articles (6 papers) and (2) non-review articles/methodology articles (22 papers).

After reviewing multiple articles, it is clear that construction material selection utilizing Life Cycle Assessment, Life Cycle Costing, and Social Life Cycle Assessment between the years 2012 and 2025 is discussed. The annual article count typically has a maximum of eight articles, with the highest number observed in 2021. The phenomenon can be attributed to the growing understanding of LCC, LCA, S-LCA, and the prevailing sustainability movement in the construction sector. Besides, the study reviews the utilization of a single score, which enables specialists to examine the sustainability performance of various options directly. This simplifies the decision-making process by clarifying whether a construction material's influence is equal to, greater than, or less than that of others.

Furthermore, the findings indicate that the LCC was the predominant criterion employed to assess the economic dimension of construction materials. Regarding the environmental impacts, there were ten publications specifically addressing CO_2 emissions. At the same time, the highest number of papers in the field of Social Life Cycle Assessment focused on health and safety was eight.

A good implementation of the preliminary design phase is the foundation for effective construction management. In Figure 3, only 4 of 22 articles related to the preliminary design phase, accounting for 18.18%. This means that there is a small number of papers researching material selection and Life Cycle analysis in the preliminary design phase. The majority of design decisions, such as the selection of key materials that significantly affect sustainability, are made in the early stages of design [28]. Although some research has confirmed that material selection in the preliminary design phase is vital for reducing environmental impacts and enhancing economic and social aspects [5, 12, 28], only four papers have addressed material selection and Life Cycle Analysis for sustainability in this phase. Dinh and Dinh [5] looked at sustainability in the preliminary design phase and the importance of choosing suitable materials for sustainability. The paper established a conceptual framework that includes sub-aspects of sustainability (economic, environmental, and social) to help select the most sustainable materials. However, there is a shortage of specific methods for evaluating each sub-criterion. Besides, Soust-Verdaguer et al. [29] pointed out the gap in data gathering and analysis between the preliminary design phase and the detailed design phase. Accordingly, they proposed the integration of LCSA and Building Information Modeling (BIM) to assess the sustainability of buildings and materials in the preliminary design phase. However, a detailed case study has not been conducted, and it is only suitable for developed countries that are able to apply BIM in the construction industry, similar to Llatas [30].

There are six papers that review current studies on the combination of LCC, LCA, and S-LCA in material selection. They mostly agree that the LCSA was introduced as an efficient tool to combine the LCC, LCA, and S-LCA [31-33]. In the research by Babashami et al. [34], a framework was proposed to measure pavement structures in terms of sustainability. Similarly, future research should head towards setting up a reliable framework for LCSA with respect to all three pillars of sustainability, according to [31, 32, 35]. Based on Kumar and Mani [36], the framework is presented in a general form and lacks specific evaluation methodologies. Janjua et al. [37, 38] also proposed considering different locations while evaluating all three aspects of sustainability. Besides, the main shortcoming of this research is the lack of maintenance and close-out phases in the estimation [39].

According to the methodology articles (Appendix 1), the MCDM methods promise a great potential for determining the importance weightings of LCC, LCA, and S-LCA results, then integrating the weightings into the LCSA result. Dinh et al. [40] examined the integration of sustainability criteria and LCSA into the selection of construction materials in developing countries. They pointed out that sustainability is studied extensively in developed countries; however, research integration in developing countries has been underexplored due to significant data limitations. Zheng et al. also proposed an uncertainty-based LCSA framework for selecting pavement alternatives considering the uncertainties associated with economic, environmental, and social pillars [41]. However, it was developed based on uncertainties that are difficult to fully identify across different alternatives. Besides, Figueiredo et al. [42] also offered a decision-making framework that integrates LCSA, MCDM, and BIM to select appropriate building materials. The framework was developed based on the four main steps illustrated in the ISO [43]. However, only one equation for a specific social impact category was developed in this research. Tran et al. [44] developed an integrated framework for assessing building sustainability in terms of environmental, economic, and social aspects based on Life Cycle thinking. The framework was presented in detail, but it should be validated by a case study.

Several studies have emphasized the importance of material selection during the preliminary design phase to minimize costs and environmental impacts and maximize social benefits. However, there is a lack of research papers that specifically address the relationship between material selection, the Life Cycle approach, and sustainability. Besides, the lack of data in the preliminary design phase remains a significant drawback [29]. In the next section, an integrated Big Data - Life Cycle framework is developed for selecting construction materials towards sustainability in the preliminary design phase.

5. An Integrated Big Data - Life Cycle Framework for Selecting Construction Material Towards Sustainability in the Preliminary Design Phase

Some research has shown that material selection in the preliminary design phase is essential for reducing environmental impacts and enhancing economic and social benefits [5, 12, 28]. There were a few papers addressing the material selection and Life Cycle analysis towards sustainability. The gap in data collection and analysis between the preliminary and detailed design phases remains a significant disadvantage. Big Data can be applied to solve this problem. The paper proposes an integrated framework of material selection in the preliminary design phase based on a Big Data approach from BIM and the Life Cycle approach (see Figure 7). The framework begins with defining project goals and requirements. Technical performance requirements are then identified with crucial characteristics such as strength, durability, and density. After that, the screening analysis is conducted to determine which materials meet the technical requirements. If there is no material meeting the demands, the technical performance requirements need to be adjusted. The pre-selected materials are listed to assess the sustainability performance. Following this, sustainability criteria are established, including the economic, environmental, and social criteria. Next, the sustainability performance evaluation assesses the sustainability of the pre-selected alternatives. Due to the lack of information during the preliminary design phase, analogous estimating and parametric estimating methods are used to estimate the LCI inputs and outputs. The BIM-based database gathered from BIM data of previous projects provides data (Big Data) for evaluating LCI results by applying analogous and parametric estimating methods. After that, the LCIA step evaluates the economic, environmental, and social performance of material alternatives according to the estimated LCI inputs and outputs. Lastly, the LCSA model and MCDM method can be applied to compare the alternatives and make decisions.

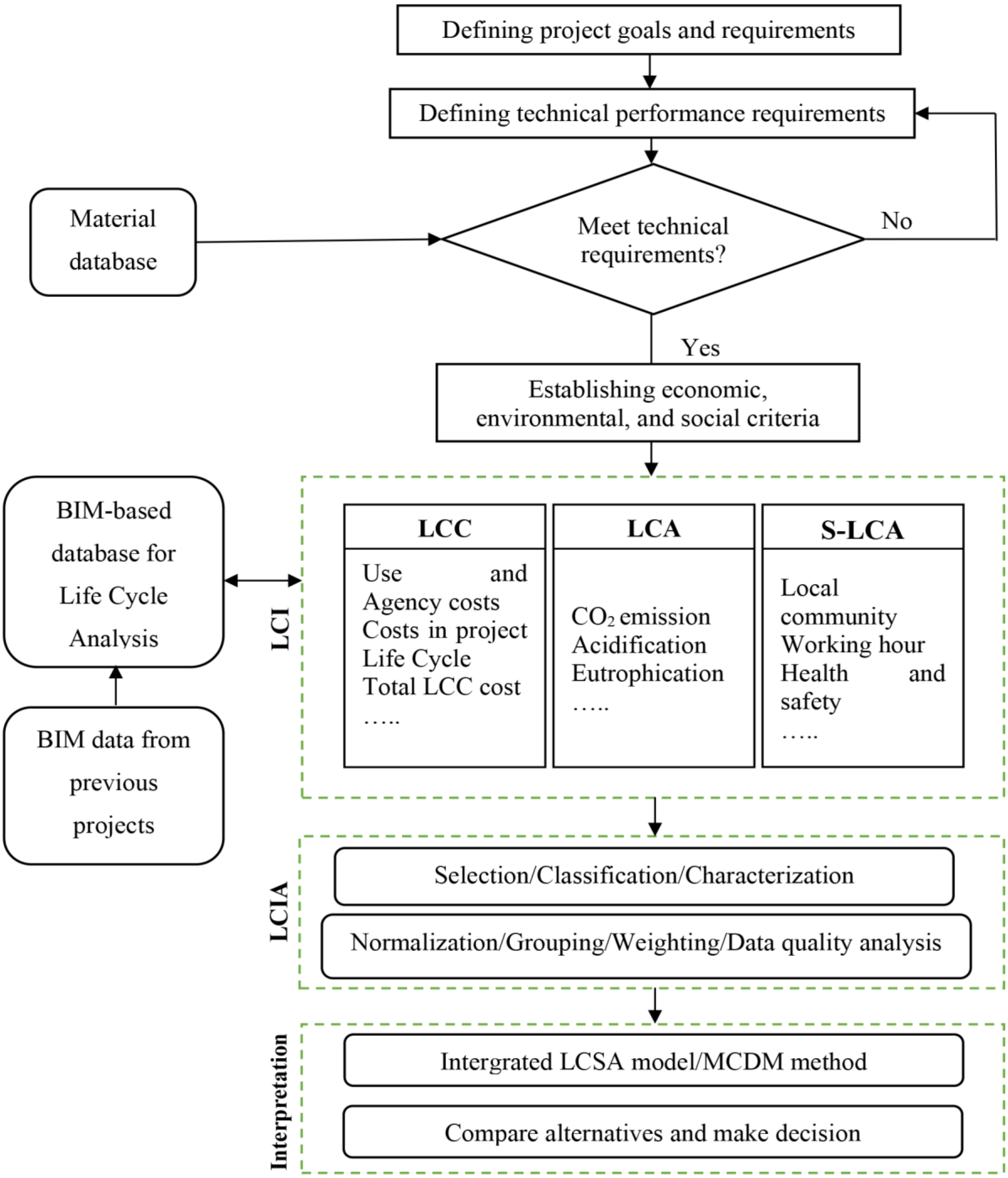

Figure 7 The integrated Big Data - Life Cycle framework of material selection in the preliminary design phase.

To bridge the identified data gap in early-stage material selection, this study proposes a novel methodological approach. Figure 7 details the integrated Big Data and Life Cycle framework, which leverages BIM-based databases to facilitate sustainability assessments during the preliminary design phase.

The BIM-based database is created by collecting BIM data from previous projects to build Big Data. The data focuses on sustainability criteria in construction activities, such as costs, CO_2 emissions, and working hours. For example, the costs of construction activities (such as building walls with specific dimensions) from some projects are stored in BIM data, along with CO_2 emissions and labor working hours. Accordingly, the average costs, CO_2 emissions, and working hours of building the walls will be applied to the next projects in the preliminary design phase. It required extending the BIM specifications and parameters, aiming for sustainability. The connection between the BIM-based database and LCI estimation is not merely a data transfer but a predictive mapping process. By utilizing analogous estimating, the framework leverages Big Data approach from completed BIM models to provide reliable LCI proxies, such as average CO_2 emissions per material volume, for the preliminary design phase, where specific vendor data is typically unavailable. Unlike traditional linear models, this framework creates a continuous feedback loop using Big Data from previous projects to fill the information void in the preliminary phase. It transforms BIM from a mere modeling tool into a predictive sustainability engine, allowing for analogous and parametric estimates when specific material data is not yet available.

The framework is designed as a modular system where specific legal requirements or regional sustainability indicators can be integrated into the LCI and LCIA steps without altering the core methodology.

6. Conclusions and Future Works

Much effort has been made in previous studies, with a specific focus on sustainable construction projects. However, there is still no standardized framework for measuring progress towards sustainability by integrating the LCC, LCA, and S-LCA into material selection. The use of LCA and LCC could be interpreted as widespread, while the S-LCA has just started to be applied.

The Life Cycle-oriented application will improve the delivery of sustainable development goals more holistically, and it is necessary to balance all sustainability dimensions throughout the project Life Cycle. The LCC, LCA, and S-LCA results can be integrated by the LCSA to estimate trade-offs among economic, environmental, and social aspects and to produce a single comparable score. It is also noted that LCSA studies should consider all phases of a construction product's life cycle, and the LCSA framework should be flexible enough to handle variation in region-specific impact indicators. A critical comparative analysis of the 28 selected studies reveals a significant methodological divergence in how sustainability dimensions are prioritized and integrated. While several authors agree that Life Cycle Sustainability Assessment is the most effective tool for Triple Bottom Line evaluation, there is a clear inconsistency in the weighting of social versus environmental indicators. For instance, studies by Dinh et al. [5] and Zheng et al. [41] emphasize the role of Multi-Criteria Decision Making to balance these pillars. Yet, their approaches differ: the former focuses on qualitative stakeholder impacts in developing regions, whereas the latter prioritizes quantitative uncertainty modeling in pavement alternatives.

Besides, the omission of material-dependent costs and sustainability performance in the close-out phase should be considered. In the preliminary design phase, the integration of LCC, LCA, and S-LCA should be conducted to increase the sustainable development of construction projects. However, there are too few studies concerning the combination. The gap in available data between the preliminary design phase and the detailed design phase was pointed out by Soust-Verdaguer et al. [29]. Although the LCSA is designed to be integrated with the preliminary and detailed design phases [28], data management remains a crucial limitation. Accordingly, some studies have proposed the integration of LCSA, MCDM, and BIM to assess the sustainability of buildings and materials in the preliminary design phase [5, 29, 30]. In addition, the development of design-oriented software that enables designers to pre-select materials and elements early, along with the

BIM model, can become a highly relevant aspect of LCSA implementation in the preliminary design phase.

While previous studies have established foundational concepts of sustainable construction, this research addresses a critical methodological gap by introducing a standardized framework that integrates the Triple Bottom Line for the preliminary design phase. The primary originality of this study lies in the development of a Big Data-driven bridging mechanism that resolves the persistent information scarcity in early-stage project development. By leveraging historical BIM-based databases, the proposed framework facilitates the transition from reactive assessments to proactive material selection through analogous and parametric estimating techniques. Consequently, this study advances current practice by transforming Building Information Modeling (BIM) from a static 3D visualization tool into a predictive sustainability engine, enabling designers to synthesize complex environmental and social data into actionable single-score metrics for more transparent decision-making. Besides, the study proposed an integrated Big Data-Life Cycle framework for material selection in the preliminary design phase.

However, detailed case studies and several other databases were not included (such as PubMed and Web of Science), and developing countries should widely apply BIM and Big Data in the construction industry. Future research can focus on establishing a reliable framework for LCSA and MCDM, especially in the preliminary design phase, across all three pillars of sustainability.

List of Abbreviations

BIM	Building Information Modeling
LCA	Life Cycle Assessment
LCC	Life Cycle Cost
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LCSA	Life Cycle Sustainability Assessment
MCDM	Multi-Criteria Decision Making
SLR	Systematic Literature Review
S-LCA	Social Life Cycle Assessment

Author Contributions

Trong Hung Dinh: Conceptualization, Methodology, Formal analysis, Writing – Original Draft, Supervision, Project administration. Trung Hieu Dinh: Validation, Investigation, Resources, Data Curation, Writing – Review & Editing.

Competing Interests

The authors have declared that no competing interests exist.

AI-Assisted Technologies Statement

During the preparation of this work, the authors used Grammarly to improve the English language and correct grammatical errors. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the final content of the publication.

Additional Materials

The following additional materials are uploaded at the page of this paper.

1. Appendix 1: Methodology articles for literature reviews.

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