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A BIBLIOMETRIC ANALYSIS OF RESEARCH TREND ON KNOWLEDGE AND APPLICATION OF THE LIFE CYCLE COSTING

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Abstract:

This study examines the growing trend of applying Life Cycle Costing (LCC) in academic research, a crucial methodology for assessing the long-term economic viability of products, projects, and systems, particularly in the domains of sustainability and construction. Despite the growing relevance of LCC in supporting cost-effective and sustainable decision-making, a comprehensive analysis of how this concept has been adopted and developed within the scholarly literature remains lacking. To address this gap, a bibliometric analysis was conducted using data retrieved from the Scopus database, focusing on documents published up to the early part of 2025. A total of 970 relevant records were identified and analyzed using Scopus Analyzer and VOSviewer software to evaluate publication trends, citation patterns, keyword co-occurrences, and international collaboration networks. The results indicate a steady increase in publications over the past decade, with notable contributions from countries such as the United States, China, the United Kingdom, and Australia. Key research themes include sustainable construction, cost-benefit analysis, circular economy, and decision-making models. Collaboration patterns reveal that countries with higher citation impact tend to have stronger international linkages, suggesting the importance of global cooperation in advancing LCC research. This analysis highlights the growing interest in LCC and the shifting focus toward integrating economic evaluation with environmental and social dimensions. The study concludes that LCC is transitioning from a niche financial tool to a strategic framework for

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sustainable planning and policymaking and recommends increased interdisciplinary and cross-border collaboration to enrich the field further.

Keywords:

Life Cycle Costing (LCC), Bibliometric Analysis, Sustainable Construction, Decision-Making Models, International Research Collaboration

Introduction

The trend of knowledge and application of Life Cycle Costing (LCC) in the construction industry has been evolving, with increasing recognition of its importance in achieving economic sustainability. LCC is a method used to evaluate the total cost of ownership of a building, including initial construction, operation, maintenance, and disposal costs over its entire life span. Despite its potential benefits, the application of LCC in the construction industry remains limited due to several barriers. These include a lack of understanding of the methodology, insufficient reliable data, and the absence of a universal framework for its implementation (Clift, 2003; Dwaikat & Ali, 2018; Gopanagoni & Velpula, 2020; Oduyemi et al., 2014). However, there is a growing awareness of the need to incorporate LCC to optimize the whole-life performance of buildings and infrastructure (Clift, 2003; Mohd Zaki et al., 2019).

One of the significant trends in the application of LCC is its integration with sustainable construction practices. Green construction projects, in particular, benefit from LCC as it helps in evaluating the long-term economic performance and environmental impact of buildings. Studies have shown that energy costs constitute a substantial portion of the total life cycle budget, highlighting the importance of energy-efficient designs (Dwaikat & Ali, 2018; Gopanagoni & Velpula, 2020). However, the implementation of LCC in green construction is still hindered by barriers such as the lack of support from project clients and government policies (Maisham, Adnan, Ismail, Asyikin Mahat, et al., 2022; Maisham, Adnan, Ismail, Mahat, et al., 2022). Efforts are being made to address these challenges through initiatives aimed at promoting the acceptance and understanding of LCC among industry practitioners (Clift, 2003; Maisham, Adnan, Ismail, Mahat, et al., 2022).

The use of advanced technologies such as Building Information Modeling (BIM) is also emerging as a trend to enhance the application of LCC in the construction industry. BIM integration allows for the automation of the LCC process, making it more efficient and accurate (Altaf et al., 2020, 2025; Pučko et al., 2020). This integration facilitates a detailed economic analysis of construction projects, enabling better decision-making and promoting sustainability. For instance, BIM can assist in estimating quantities and costs associated with different building components, providing a comprehensive view of life cycle costs (Altaf et al., 2025; Pučko et al., 2020). As the construction industry continues to evolve, the adoption of LCC, supported by technological advancements, is expected to play a crucial role in achieving sustainable and cost-effective building solutions.

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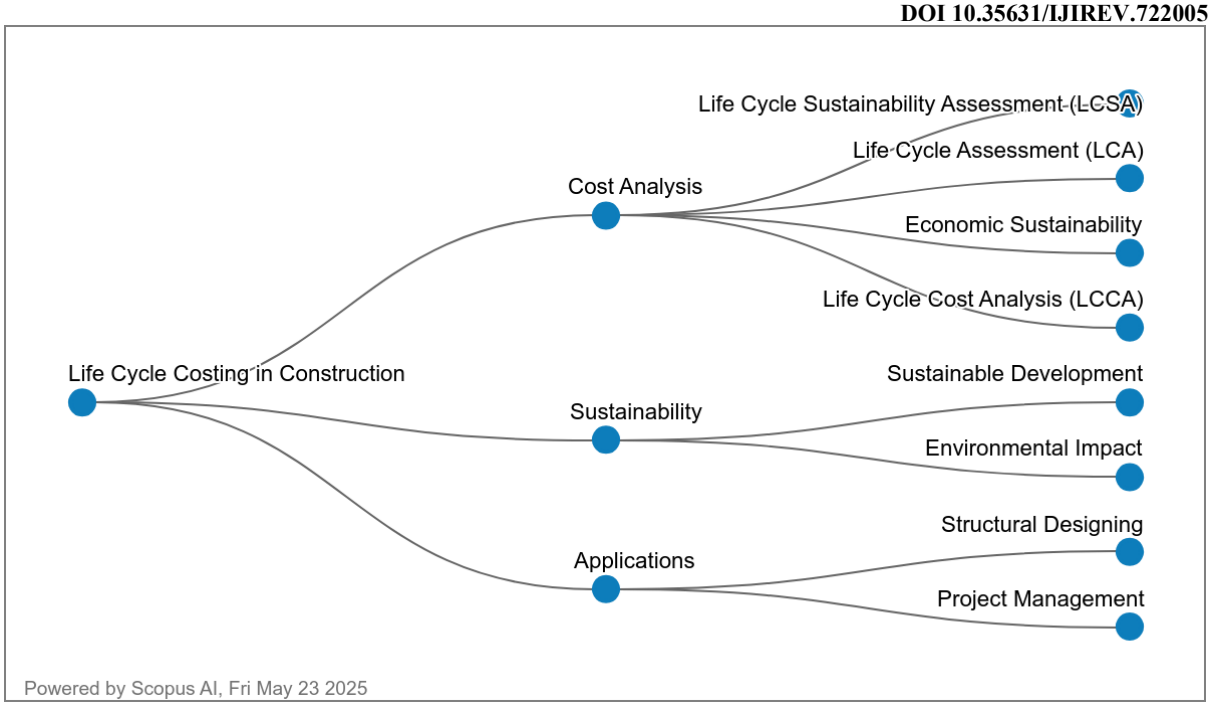

Figure 1: Overview of LCC in Construction

This study seeks to uncover the evolving landscape of online learning research by examining several key bibliometric dimensions. One area of focus involves analyzing how publication trends have evolved, providing insight into the growth and shifting priorities within the field. Attention is also given to identifying the most frequently cited articles, which serve as foundational works that shape the current discourse. Another aspect examines the geographic distribution of research output, highlighting the top ten countries that contribute the most based on publication volume. The study further investigates the most commonly used keywords, aiming to trace how thematic focus has transformed over the past decade. In addition, patterns of international collaboration are assessed through co-authorship networks, which provide a deeper understanding of how scholars from different countries collectively advance the field of online learning.

Methodology

Bibliometrics involves gathering, organizing, and analyzing bibliographic data from scientific publications (Alves et al., 2021; Assyakur & Rosa, 2022; Verbeek et al., 2002). Beyond basic statistics, such as identifying publishing journals, publication years, and leading authors (Wu & Wu, 2017), bibliometrics encompasses more sophisticated techniques, including document co-citation analysis. Conducting a successful literature review requires a careful, iterative process to select suitable keywords, search the literature, and perform an in-depth analysis. This approach facilitates the compilation of a comprehensive bibliography and yields viable results (Fahimnia et al., 2015). With this in mind, the study focused on high-impact publications, as they provide meaningful insights into the theoretical frameworks that shape the research field. To ensure data accuracy, Scopus served as the primary source for data collection (Al-Khoury et al., 2022; di Stefano et al., 2010; Khiste & Paithankar, 2017). Additionally, to maintain quality, the study only considered articles published in peer-reviewed academic journals, deliberately excluding books and lecture notes (Gu et al., 2019). Using Elsevier's Scopus, known for its broad coverage, publications were collected from 2020 through December 2023 for further analysis.

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Data Search Strategy

The study employed a screening sequence to determine the search terms for article retrieval. Afterwards, the query string was revised so that the search terms "LCC" and "CONSTRUCTION" would focus on students as learners. This process yielded 111 results, which were then further scrutinized to include only research articles written in English. Article reviews were also excluded, as noted in Table 2. The final search string refinement included 781 articles, which were used for bibliometric analysis. As of May 2025, all articles from the Scopus database relating to the LCC application were incorporated into the study.

Table 1: The Search String

Scopus	TITLE-ABS-KEY (LCC AND CONSTRUCTION) AND (LIMIT-TO (SUBJAREA , "ENGI") OR LIMIT-TO (SUBJAREA , "ENVI") OR LIMIT-TO (SUBJAREA , "SOCI") OR LIMIT-TO (SUBJAREA , "ENER") OR LIMIT-TO (SUBJAREA , "BUSI"))

Table 2: The Selection Criterion Is Searching

Criterion	Inclusion	Exclusion
Time line	1982 – 2025	None
Literature type	Journal (Article)	Conference, Book, Review
Subject area	Engineering, Environmental Science, Energy, Social Sciences Business, Management and Accounting	Besides Engineering, Environmental Science, Energy, Social Sciences Business, Management and Accounting
Language	English	Non-English

Data Analysis

VOSviewer, developed by Nees Jan van Eck and Ludo Waltman from Leiden University in the Netherlands (van Eck & Waltman, 2010, 2017), stands out as an accessible and powerful tool for conducting bibliometric analyses. Widely adopted in academic research, the software is particularly effective in constructing and visualizing bibliometric networks, including co-authorship, co-citation, and keyword co-occurrence patterns. With its intuitive design and flexible functionality, VOSviewer enables users to generate detailed network maps and density visualizations that capture the intricate structure of scientific domains. Its frequent updates and interactive interface make it especially useful for exploring complex datasets with both precision and ease.

A key strength of VOSviewer lies in its ability to distill complex bibliometric data into interpretable visual forms. It emphasizes network relationships, helping researchers uncover underlying thematic clusters and research trends. The program supports both novice and advanced users in navigating and interpreting large bibliographic datasets. Features such as customizable visualizations and quantitative metric outputs further enhance its analytical depth. Its compatibility with data formats from major sources, such as Scopus and Web of Science, strengthens its utility across a wide range of academic disciplines.

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For this study, bibliographic data were extracted from the Scopus database, covering publications from 2004 through December 2024. These data—formatted in PlainText and comprising information such as publication year, title, author, journal, citations, and keywords—were processed using VOSviewer version 1.6.19. The software's clustering and mapping capabilities enabled the construction of visual networks, offering an insightful alternative to traditional Multidimensional Scaling (MDS) approaches.

While MDS techniques often rely on similarity measures, such as cosine similarity or Jaccard indices, VOSviewer employs a distinct approach centered on the VOS mapping technique. This technique positions items in a low-dimensional space so that the proximity between any two items corresponds directly to their degree of relatedness (van Eck & Waltman, 2010). A fundamental part of this method is the use of Association Strength (AS_{ij}), a metric that normalizes co-occurrence frequencies. It is defined as:

$$AS_{ij} = \frac{C_{ij}}{w_i w_j},$$

where CijC_(ij) Cij is the observed number of co-occurrences between items *i* and *j*, and wiw_iwi, wjw_jwj are their respective total occurrences. This ratio reflects the extent to which items *i* and *j* co-occur more frequently than would be expected by chance, assuming statistical independence (van Eck & Waltman, 2008). By incorporating this measure, VOSviewer offers a more accurate representation of the relational structure within bibliometric data.

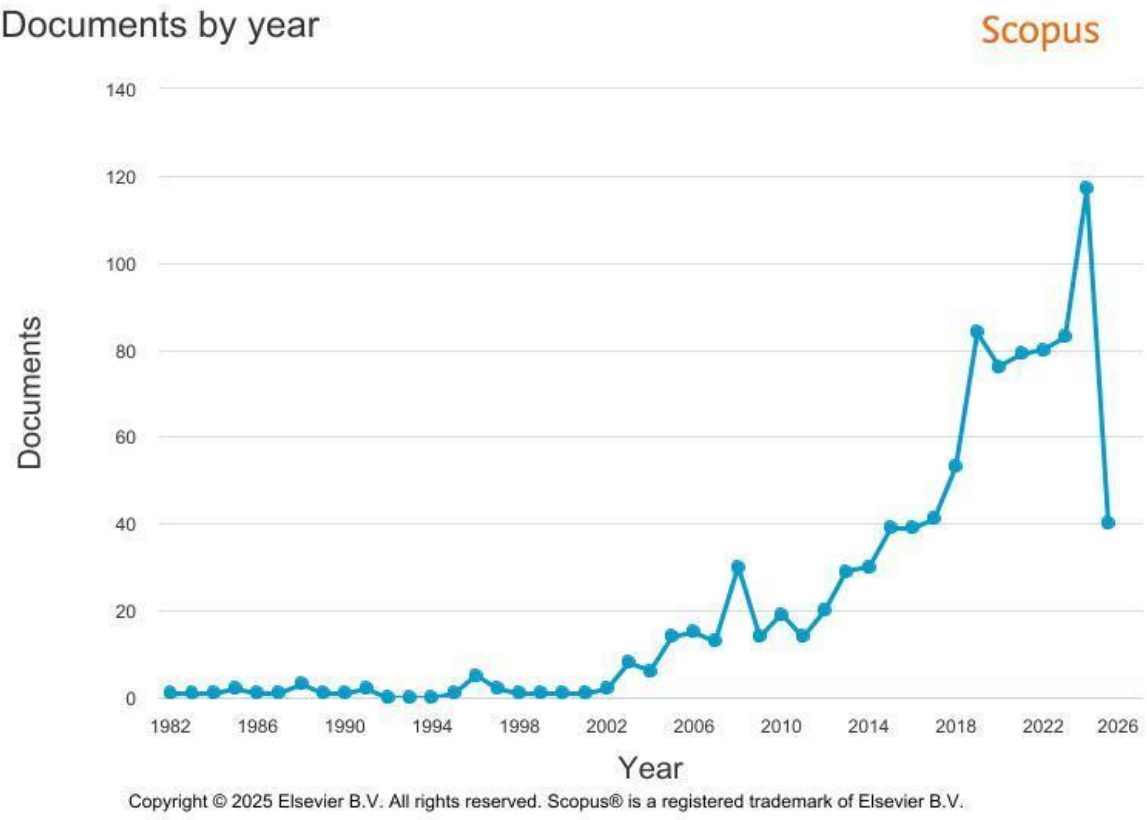

Figure 2: Trend of Research in LCC by Years

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Table 3: Trend of Total Publications Based on Year

Year	Total Publication	Percentage (%)
2025	40	4.12
2024	117	12.05
2023	83	8.55
2022	80	8.24
2021	79	8.14
2020	76	7.83
2019	84	8.65
2018	53	5.46
2017	41	4.22
2016	39	4.02
2015	39	4.02
2014	30	3.09
2013	29	2.99
2012	20	2.06
2011	14	1.44
2010	19	1.96
2009	14	1.44
2008	30	3.09
2007	13	1.34
2006	15	1.54
2005	14	1.44
2004	6	0.62
2003	8	0.82
2002	2	0.21
2001	1	0.10
2000	1	0.10
1999	1	0.10
1998	1	0.10
1997	2	0.21
1996	5	0.51
1995	1	0.10
1991	2	0.21
1990	1	0.10
1989	1	0.10
1988	3	0.31
1987	1	0.10
1986	1	0.10
1985	2	0.21
1984	1	0.10
1983	1	0.10
1982	1	0.10

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The bibliometric analysis of LCC in construction reveals a significant upward trend in scholarly attention over the past few decades. Early publications between 1982 and the late 1990s were scarce, with no more than three publications in any given year and many years recorded only a single contribution. This pattern indicates that LCC was a relatively underexplored topic during this period, likely due to limited awareness and application within the construction industry. The gradual rise in the early 2000s suggests an increasing recognition of the importance of economic sustainability in construction, although the pace remained modest.

A notable increase in publications began in the late 2000s and continued to accelerate through the 2010s. From 2008 onward, annual publications consistently surpassed ten per year, culminating in a marked increase during the 2014–2020 period. The highest single-year output before 2021 was in 2019, with 84 publications (8.65%). This phase likely reflects the growing emphasis on sustainable construction practices and the integration of economic assessment tools, such as LCC, into project planning and policy frameworks. The consistency in publication numbers during this period also suggests that LCC had gained a stable foothold in construction-related research, supported by advancements in data availability and analytical tools.

The most dramatic surge occurred in the early to mid-2020s, with 117 publications in 2024 alone (12.05%) and 40 already recorded in 2025, indicating a continuing upward trajectory. This recent spike underscores the expanding role of LCC in aligning construction practices with sustainability goals, regulatory requirements, and stakeholder expectations. It also reflects the impact of global climate commitments and economic resilience strategies post-pandemic, which have prompted researchers and practitioners to prioritize cost-effective and long-term planning tools. Overall, the data confirms that LCC has transitioned from a niche academic topic to a mainstream component of construction research and decision-making.
RQ2: What are the most cited articles?

Table 4: Most Top 10 Cited Authors

Authors	Title	Year	Source Title	Cited by
(Gluch & Baumann, 2004)	The life cycle costing (LCC) approach: A conceptual discussion of its usefulness for environmental decision-making	2004	Building and Environment	414
(Di Maria et al., 2018)	Downcycling versus recycling of construction and demolition waste: Combining LCA and LCC to support sustainable policy making	2018	Waste Management	234
(Santos et al., 2019)	Integration of LCA and LCC analysis within a BIM-based environment	2019	Automation in Construction	232
(Liu et al., 2018)	Energy storage capacity optimization for autonomy microgrid considering CHP and EV scheduling	2018	Applied Energy	220
(Kim et al., 2008)	Simulation of fracture behavior in asphalt concrete using a heterogeneous cohesive zone discrete element model	2008	Journal of Materials in Civil Engineering	211

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(Gautier, 2015)	Slab track: Review of existing systems and optimization potentials including very high speed	2015	Construction and Building Materials	167
(Martin-Ramos et al., 2008)	Power supply for a high-voltage application	2008	IEEE Transactions on Power Electronics	165
(Hasan et al., 2008)	Minimisation of life cycle cost of a detached house using combined simulation and optimisation	2008	Building and Environment	164
(Liu et al., 2015)	Building information modeling-based building design optimization for sustainability	2015	Energy and Buildings	161
(Yu et al., 2020)	Feasibility of using ultrahigh-volume limestone-calcined clay blend to develop sustainable medium-strength Engineered Cementitious Composites (ECC)	2020	Journal of Cleaner Production	148

The analysis of the top 10 most cited authors from the Scopus database highlights the scholarly impact and thematic focus areas within the LCC discourse in construction and related fields. The most cited work is by Gluch and Baumann (2004), with 414 citations, underscoring the foundational nature of their conceptual discussion on the usefulness of LCC for environmental decision-making. This paper, published within the *Building and Environment*, serves as a cornerstone in the literature by establishing the theoretical underpinnings of LCC in sustainable practices. Its high citation count reflects its relevance across disciplines, particularly in sustainability, economics, and environmental policy.

The integration of LCC with other methodologies is a dominant trend among the top-cited works. For instance, Di Maria et al. (2018) and Santos et al. (2019) both emphasise the combination of Life Cycle Assessment (LCA) with LCC to support more comprehensive decision-making. Di Maria et al.'s (2018) paper, cited 234 times and published in *Waste Management*, explored the policy implications of downcycling versus recycling in construction waste. Meanwhile, Santos et al., cited 232 times, explored the integration of LCC and LCA within a BIM environment. These studies demonstrate the growing sophistication of tools and frameworks used in the field, moving beyond siloed approaches to holistic sustainability assessments.

Some of the highly cited studies, such as (S. Liu & Yan, 2018) with 220 citations in *Applied Energy*, and Kim et al. (2008) with 211 citations in *Journal of Materials in Civil Engineering*, reflect the broader application of LCC in areas beyond traditional construction. Liu's study incorporates energy systems and microgrid autonomy, integrating LCC into advanced energy modeling and storage optimization. Similarly, Kim's focus on fracture behavior in asphalt concrete connects material science with life cycle cost implications. These examples demonstrate how LCC is becoming increasingly embedded in diverse technical domains, thereby expanding its relevance and methodological reach.

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Finally, papers by Hasan et al. (2008), Liu et al. (2015), and Yu et al. (2020) emphasized the importance of cost-effective building design and material innovation. Hasan's work on minimizing life cycle costs for detached houses (164 citations) and Liu's BIM-based design optimization for sustainability (161 citations), both published in top-tier journals, exemplify the practical applications of LCC in architectural and engineering design. Yu's more recent study on sustainable cementitious composites (148 citations) highlights the role of LCC in evaluating new materials. These works suggest that LCC is a theoretical concept and a critical analytical tool driving innovation as well as sustainability in construction materials, systems, and policies.

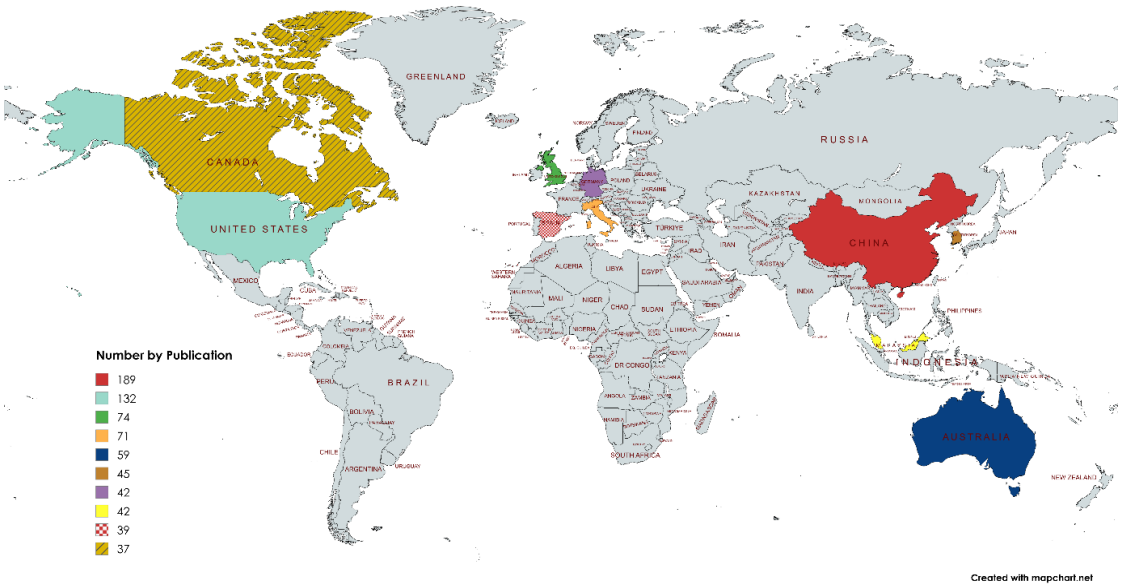

Figure 3: 10 Most Cited Papers by Countries

The bibliometric data on the most cited papers by country reveals China's dominant position in LCC research related to construction, with 189 citations. This reflects China's strong national agenda for sustainability, infrastructure development, and technological integration, including BIM and smart energy systems. Chinese researchers frequently publish in high-impact journals and collaborate across disciplines, resulting in a broad citation footprint. The United States follows with 132 citations, indicative of its established research infrastructure, funding support, and emphasis on innovative technologies and policy-driven sustainability practices. These two countries collectively account for over one-third of the total citations, emphasizing their leadership in shaping the global LCC research agenda.

The United Kingdom (74 citations) and Italy (71 citations) rank next, showing a robust European engagement with LCC, often driven by EU sustainability frameworks and circular economy directives. The United Kingdom, in particular, has made significant contributions in integrating LCC with building regulations and policymaking. At the same time, Italy's research is often associated with the optimization of architectural design and resource efficiency. Australia, with 59 citations, also reflects strong research in environmental assessment and sustainable housing, likely tied to its national policies on low-carbon construction and climate-responsive design.

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Countries such as South Korea, Germany, Malaysia, Spain, and Canada—all with citations ranging from 37 to 45—represent an emerging and influential group in the LCC literature. Germany and South Korea contribute through technology-driven research in materials and energy systems. At the same time, Malaysia's performance is particularly notable, given its developing economy status. Its 42 citations demonstrate active participation in LCC research, particularly in tropical construction practices and green building frameworks. Canada and Spain, with strong research universities and government support for green initiatives, add to the global momentum in applying LCC across diverse climatic and regulatory contexts. Collectively, the geographic spread highlights a growing internationalization of LCC research, with valuable contributions from both developed and developing nations.

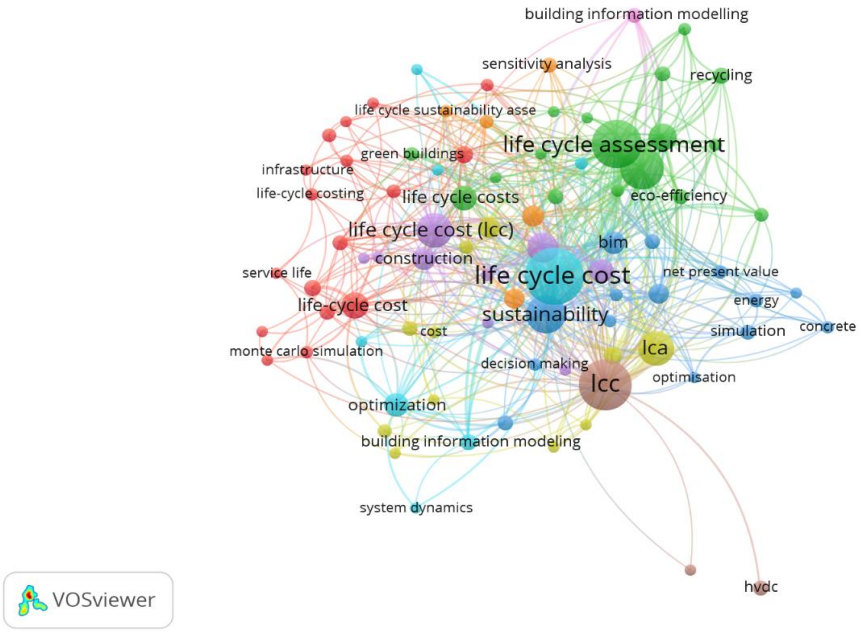

Figure 4: Network Visualization Map of Keywords' Co-Occurrence

The keyword analysis table reveals significant insights into the thematic structure and focus of LCC research in the construction sector. The most dominant keyword is "life cycle cost," with 115 occurrences and a total link strength of 141, indicating its centrality and frequent co-occurrence with other topics. Closely related terms such as "LCC" (93 occurrences, 133 link strength), "life cycle assessment" (85, 143), and "life cycle costing" (65, 97) further emphasize the research community's strong interest in integrating cost and environmental evaluations. The wide variety of term variations—such as "LCCA," "LCC analysis," and "life-cycle cost analysis"—suggests differing methodological or regional terminologies used to describe similar concepts.

Additionally, several other clusters of high-frequency keywords suggest key research directions and cross-disciplinary applications. "Circular economy" (28 occurrences, 57 link strength), "sustainability" (54, 98), and "sustainable construction" (14, 29) underscore the increasing alignment of LCC with broader sustainability objectives. The inclusion of terms like "energy efficiency" (15, 22), "environmental impact" (11, 25), and "eco-efficiency" (8, 13) underscores an emphasis on environmental performance metrics alongside cost considerations.

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The presence of "BIM" (18, 40) and its variants suggests a strong trend toward digitalization and the integration of LCC into BIM platforms for improved life cycle decision-making.

From a methodological perspective, the use of terms such as "multi-objective optimization" (12, 19), "economic analysis" (6, 12), and "sensitivity analysis" (9, 10) reflects a maturing research agenda that combines technical, economic, and environmental modeling approaches. The inclusion of "Monte Carlo simulation," "net present value," and "decision making" highlights efforts to enhance analytical rigor and support robust investment decisions in construction projects. The frequent co-mentioning of these terms with LCC keywords suggests a multidimensional approach to evaluating the long-term viability of projects.

Finally, practical application areas are evident in keywords such as "construction" (18, 26), "building" (16, 32), and "concrete" (6, 9), indicating material- and sector-specific research. Notably, keywords such as "maintenance," "durability," and "embodied energy" reflect concerns over life cycle performance and operational costs, particularly in the infrastructure and residential sectors. The variety and frequency of these keywords reveal the diverse contexts in which LCC is applied, demonstrating a strong trend toward comprehensive, lifecycle-driven decision-making frameworks in the construction industry.

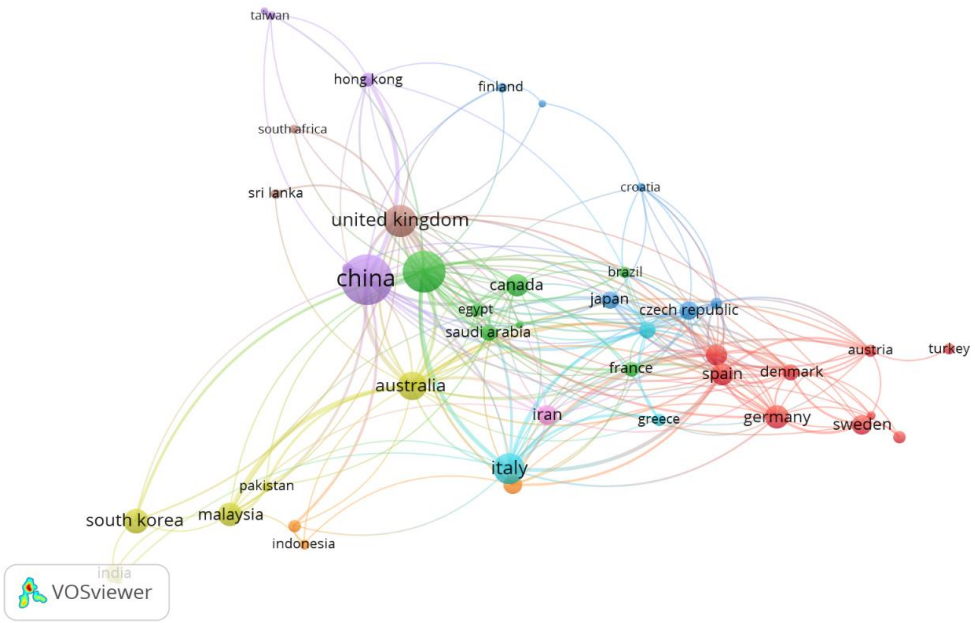

Figure 5: Co-Authorship by Countries

The "Total Link Strength" column reflects the level of international research collaboration among countries. Countries like the United States (77), Australia (72), China (69), Italy (57), and the United Kingdom (48) lead with the highest link strengths, indicating their central roles in global research networks. These countries also tend to have high publication and citation counts, suggesting that strong international collaboration often correlates with greater research impact and visibility.

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A second tier of countries—including Malaysia (27), Japan (24), Belgium (23), and Canada (23)—shows moderate levels of collaboration. While they are active participants in the global research landscape, their collaborative intensity is not as high as that of the top-tier nations. Nonetheless, they have significant opportunities to enhance their research influence by forming strategic international partnerships.

On the other hand, countries such as Poland (0), Turkey (1), and the Russian Federation (2) exhibit low link strengths, suggesting limited collaboration with international research communities. Despite some countries having respectable publication or citation counts, they would greatly benefit from increased cross-border research efforts. Strengthening international ties could not only improve their global scientific standing but also elevate the quality and reach of their research outputs.

Conclusion

This study aimed to examine the trends and development of LCC research, particularly in its application to the construction sector. Using bibliometric analysis tools such as Scopus Analyzer and VOSviewer, the investigation focused on identifying publication patterns, influential contributors, thematic evolution, and international collaboration within a dataset of 970 scholarly records. The analysis aimed to address several key questions, including the annual growth of publications, the most cited works and authors, the leading contributing countries, and the most frequently occurring keywords relevant to LCC research.

The findings revealed a significant upward trajectory in LCC-related publications, especially over the past decade, with a peak in 2024. Countries such as China, the United States, and the United Kingdom emerged as the most productive. They often collaborate extensively across borders. Thematic analysis revealed a growing integration of LCC with sustainability principles, circular economy frameworks, and digital technologies, such as BIM. Commonly recurring keywords indicate a multidimensional focus on cost, energy, and environmental impact, reflecting the evolving role of LCC from a financial evaluation tool to a comprehensive decision-making framework in sustainable construction practices.

By synthesizing global research trends, this study contributes to a clearer understanding of the academic landscape surrounding LCC. It provides evidence of how scholarly interest has shifted from foundational economic analysis to more integrative models that support policy and practical implementation. While the study presents a valuable overview, limitations include reliance on a single database and exclusion of non-English publications. Future studies could expand the scope by incorporating multiple data sources, analyzing sector-specific applications, and examining the actual impact of LCC on project outcomes. Ultimately, this analysis underscores the utility of bibliometric methods in capturing the dynamic progression of research fields and encourages continued exploration of LCC's role in advancing sustainable development goals.

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