buildings

Systematic Review

Interrelations of the Factors Influencing the Whole-Life Cost Estimation of Buildings: A Systematic Literature Review

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Abstract: The global GDP has witnessed a significant upswing, majorly due to the growth of the construction industry. Embracing the whole-life costing (WLC) approach, the construction sector strategically manages expenses across a construction project's life cycle. However, despite its widespread adoption, accurate cost forecasting remains a major challenge. The intricate interplay of various influencing factors has not been fully explored, leading to inaccurate cost estimations. A comprehensive understanding of specific factors and their interrelationships is crucial to address this issue. Therefore, it is imperative to conduct further research to identify and explore the subtle nuances of these factors that impact whole-life cost estimation. Our study fills this gap, analysing 51 factors from 84 papers across prominent repositories. We assess interrelationships using a systematic literature review and pairwise comparison as in the analytical hierarchy process. The International Construction Measurement Standards (ICMS) framework structures these relationships and is represented in the causal loop diagrams (CLDs). The pioneering CLDs are a notable contribution, illustrating interrelationships and polarities among the 51 WLC factors. Six reinforcing loops and one balancing loop provide valuable insights into their dynamic nature. Importantly, lower-level factors do not always directly connect with upper-level factors. Instead, they interact within the same level before linking to top-level factors. These findings are significant for professionals, such as cost estimators, quantity surveyors and scholars, offering a comprehensive understanding of the WLC system.

Keywords: whole-life costing; construction; factors; interrelationship; seismicity; adverse weather

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1. Introduction

The construction sector has significantly contributed to the overall construction industry, accounting for 44% of the total construction activities in 2020, which amounted to USD 6800 billion [1]. However, this sector declined steadily from 2021 to 2023 [2,3]. The decline can be attributed to several factors, including the impact of the COVID-19 pandemic on the construction market. This has increased house prices and shifted towards residential renovation and larger living spaces. Moreover, there has been a trend of repurposing redundant space from traditional housing construction sectors [1]. As a result, construction experts are now paying more attention to the whole-life costing (WLC) principle to address the current challenges posed by the shift in the residential market.

Construction cost estimation and control have focused on reducing capital costs as much as possible without considering long-term repercussions. This leads to inappropriate design and specification and poor-quality buildings that perform poorly in the long term. Nevertheless, since the 1990s, the emphasis has shifted to obtaining value for money (VFM), and it is now widely acknowledged that design should consider long-term operation and maintenance expenses. According to Kishk, Al-Hajj [4], practical interest in

WLC in construction dates back to 1950 with the formation of the Building Research Establishment (BRE) Group.

There are various definitions of WLC. WLC can be defined “as a technique for examining and determining all the costs in money terms, direct and indirect, of designing, building and facility management, operating, maintenance, support and replacement of a building throughout its entire service life, including the disposal cost” [5]. As [6] defines it, “The whole-life costs of a facility (often referred to as through-life costs) are the costs of acquiring, operating, maintaining over its whole life through to its disposal—that is, the total ownership costs”. According to [7], “WLC is the methodology for systematic economic consideration of all whole-life costs and benefits throughout analysis, as defined in the agreed scope”. Moreover, WLC can be defined as “a technique used to establish the total cost of acquisition and ownership. It is a structured approach which addresses all the elements of cost and can be used to produce a spend profile of the product over its anticipated lifespan”. WLC is defined in the draft International Standard, ISO 15686 Part 5, as follows: “economic assessment considering all agreed projected significant and relevant cost flows throughout analysis expressed in monetary value. The projected costs are those needed to achieve defined performance levels, including reliability, safety and availability” [8]. After analysis of the above definitions, the definition of WLC can be simplified as follows: “Whole-life cost refers to the total evaluation of all direct and indirect expenses connected with obtaining, possessing, operating, maintaining and disposing of an asset throughout its entire lifespan. It is a systematic approach to understanding the complete cost of ownership, considering all the relevant expenses and benefits expressed in monetary terms”.

WLC offers numerous benefits, including enhancing occupants’ productivity; identifying design inflection points; striking a balance between construction and maintenance costs as well as sustainable procurement [9,10]; recognising the investment purposes [11]; evaluating the environmental impact of a building’s systems and material [12]; and improving efficient use of government funds [13]. It also provides informed and standardised decision making [14–18]. Despite the benefits of WLC, there are many barriers to its application. Whenever a client demands that an L.C.C. be used to compare alternative strategies and is willing to provide additional fees for the service, it would be undertaken by the design team and cost consultant [11]. However, unless it is formalised in contractual terms, the design team will typically not volunteer it [11,19–21]. The capital cost of construction is almost always separated from the operation cost; it is standard practice for clients to accept the cheapest initial price if they are not occupying the building [4]. Also, there is no clear definition of the buyer, seller or their responsibilities towards the operating and maintenance costs [19]. The complexity of analysis [4,10,11,16,17] is another drawback that could be improved in their assessment.

Understanding the relationship between factors that influence whole-life costing (WLC) estimation is crucial. Knowing these relationships is critical for several reasons. Firstly, it helps to evaluate comprehensively the factors that affect WLC, allowing stakeholders to make more informed decisions about resource allocation, budgeting and project management. By clarifying these relationships, it becomes possible to identify potential dependencies, synergies and trade-offs among different factors, thus enabling a more nuanced and accurate estimation of WLC. Moreover, understanding the relationships between influencing factors enhances the predictive capabilities of WLC models and frameworks. By understanding how changes in one factor may impact others, stakeholders can better anticipate and mitigate potential risks and uncertainties associated with cost estimation. This proactive approach can lead to more robust and resilient project planning and execution, ultimately improving project outcomes and minimising cost overruns and delays. Furthermore, clarifying the relationship between influencing factors promotes greater transparency and accountability in the decision-making process. By providing stakeholders with a clear understanding of how various factors interact and influence WLC, it becomes easier to justify investment decisions and garner support from relevant stakeholders. This transparency can help build trust and confidence in the project's financial management and ultimately contribute to its success.

Various factors influence WLC; geographical location plays a significant role due to regional variations. Therefore, it is imperative to consider the geographical characteristics while analysing WLC. For instance, New Zealand is situated on the convergent boundary of the westward-moving Pacific Plate and the northward-moving Australian Plate [22]. Additionally, twelve countries are located in an area of high seismic activity, known as the Ring of Fire, a series of volcanic regions and sites of seismic activity encircling the Pacific Ocean. The Ring of Fire encompasses about 90% of all earthquakes and 75% of all active volcanoes on Earth [23]. However, it is worth noting that not all twelve countries are situated in one seismic zone, and some regions are more prone to severe earthquakes than others [24].

In addition to global seismic activity, unpredictable weather conditions such as snow, heat waves, cyclones, rising sea levels, flooding and wildfires place extra pressure on the construction market. For example, in New Zealand the sun's ultraviolet (UV) rays are incredibly harsh, snow may fall anytime, especially on the South Island, and rain can cause landslides and floods. In addition, wind is significantly more dangerous than rain [25]. The New Zealand Treasury calculated that the 2007–2008 and 2012–2013 droughts collectively decreased New Zealand's GDP by around NZD 4.8 billion. Adverse weather is thought to be responsible for about NZD 800 million of these expenses [26]. The 12 most expensive extreme weather events that produced flooding in New Zealand (NZ) between 2007 and 2018 led to over NZD 140 million in insurance claims [27]. The weather extremes have had a substantial negative impact on society and the economy in the UK. For instance, the cost of the 2007 summer floods to the economy was projected to be over GBP 3.2 billion [28], but the 2010 harsh winter cost the insurance business over GBP 365 million [29]. Therefore, considering seismicity and adverse weather events is essential for whole-life costs.

Current WLC models often fail to provide a comprehensive risk assessment that considers the unique geographical challenges of a region. These models prioritise initial construction costs, overlooking long-term risks associated with seismic events and adverse weather conditions. As a result, construction projects may be vulnerable to unexpected disruptions and expenses. Additionally, these existing WLC models may not be flexible enough to adapt to the diverse regional seismicity and weather pattern variations. Their generic nature can lead to inaccurate cost projections that underestimate the unique challenges faced by specific locations, jeopardising the overall viability of construction projects. Moreover, environmental factors such as harsh UV rays, snowfall, landslides, floods and wind are not always factored into the existing WLC estimations. This oversight can result in insufficient budget allocations for maintenance, repairs and disaster recovery, particularly in regions prone to environmental stressors. Furthermore, the existing WLC models may not adequately address the long-term resilience of structures against seismic and weather-related challenges. Emphasising initial costs can drive compromises in construction materials and methodologies, which ignore the importance of durability and the ability to withstand environmental extremes throughout the project's life cycle.

Acquiring knowledge of the cost throughout the entire lifespan of a building is vital to ensure optimal utilisation of the capital cost incurred in constructing the building and the expenses associated with its operation [30]. Applying WLC in capital works projects within the construction industry can result in the commissioning of entirely different buildings and structures. However, a practical problem arises because, although initial construction costs are relatively straightforward and predictable at the design stage, operational costs are not. The design stage focuses on planning and conceptualising the project's physical aspects, while operational costs relate to maintaining and operating the facility. Operational costs are subject to various dynamic factors, making it challenging to predict their long-term impacts accurately. External factors, such as economic, regulatory and technological changes, can significantly impact operational costs and are often difficult to anticipate during the early design stages. Therefore, costs in use are subject to significant errors in their assessment [9]. To mitigate this error, it is essential to identify the specific factors influencing WLC. However, it is important to note that these factors do not operate in isolation; they interact with one another, influencing the WLC estimation process as a whole. Therefore, it is crucial to focus on the interrelationships between these factors rather than their individual effects. This research aims to highlight the interrelationships of various factors that influence WLC in construction. The objective of the research is to identify the factors and their interrelationships. The research question, "What are the interrelationships of WLC estimation factors in construction?", was formulated following the patient/population, intervention, comparison and outcomes (PICO) framework.

The PICO framework is a structured approach widely used in evidence-based medicine and healthcare research to formulate clinical research questions. The acronym "PICO" represents four key elements:

P—Patient/Population/Problem: This refers to the specific population or patient group under study or the problem being addressed.

I—Intervention: This refers to the intervention, treatment, exposure or factor being studied.

C—Comparison: This refers to the alternative or comparator intervention, treatment or exposure being considered, if applicable.

O—Outcome: This refers to the outcome or endpoint the researcher is interested in measuring or evaluating.

The PICO framework helps researchers to define their research question precisely by identifying the key components of the study: the population being studied, the intervention or exposure being investigated, any relevant comparison and the desired outcome [31]. Concerning construction-related research, the PICO framework can be adapted to formulate research questions about construction methods, materials, safety practices, project management strategies and more. Using the PICO framework in construction-related research can help researchers structure their studies, identify relevant variables and clarify the research question, ultimately leading to more focused and effective research outcomes. The PICO key elements used in this research are as follows:

Product (P) = WLC estimation

Improvement (I) = construction

Comparison (C) = N/A

Outcome (O) = Interrelationships of WLC factors

The following research methods were used to address the research question.

2. Research Methods

A systematic literature review (SLR) was conducted to identify the various factors that impact the estimation of whole-life costs for building construction. Then, A pairwise comparison of factors following the analytical hierarchy process was carried out. A note of caution is that only the pairwise comparison concept was utilised from the analytical hierarchy process. The step-by-step approach for the pairwise comparison adopted from the Analytic Hierarchy Process includes the following steps:

Step 1: Defined the problem and criteria.

Step 2: Defined factors.

Step 3: Established polarity amongst criteria using pairwise comparison.

Step 4: Checked consistency amongst the pairwise comparisons.

Step 5: Evaluated relative factors from the pairwise comparisons.

Step 6: Performed sensitivity analysis using CLD and found interacting loops.

Note: to simplify the interrelationships into four hierarchical levels, the ICMS framework was used, and results are presented in the CLDs.

SLR is the standard strategy used to thoroughly understand the research domain in construction [32]. SLR is a scientific method that starts with a specific question, finds all relevant studies, evaluates their quality and summarises their results using a scientific approach [32]. Articles undertaking systematic literature reviews are considered as unique work since they adhere to strict methodological standards [32]. There are many advantages of SLRs. It employs extracting search strategies to ensure that the maximum extent of relevant research has been considered; original articles are methodologically evaluated and synthesised using strict methods to locate, evaluate and synthesise all research on a topic; and it provides a straightforward methodology that lowers the risk of bias by adhering to a strict and repeatable protocol of procedures [33]. However, while bias reduction is one of the main advantages of SLR, DistillerSR [34] argued that bias can come at any stage because the poor study design and execution and selective outcome report significantly threaten a systematic review.

A SLR was performed using different search strings in Scopus, ScienceDirect, Emerald Insight, SpringerLink and Google Scholar databases. Table 1 shows the search strings and results for all databases used. This study used primary data from books, journals and conference papers.

Table 1. Search strings and results of database search.

Database	Search Strings	Inclusions	Exclusions	Without Filters	Range (2000–2023)
Scopus	"Whole Life Cost" OR "WLC" AND "Construction" AND "Factors"	Subject Area—Engineering Language—English	Review articles	24	24
ScienceDirect	"Whole Life Cost" OR "WLC" AND "Construction" AND "Factors"	Subject Area—Engineering Language—English	Review articles Book review Product review	50	50
Emerald Insight	Abstract: "whole life cost" OR (abstract: "wlc") AND (abstract: "construction") AND (abstract: "factors")	Access—Only content that I have accessed Content Type—Articles	Review articles	105	105
Springer Link	"Construction" AND "factors" AND "Whole life cost"	Discipline—Engineering Subdiscipline—Building Construction and Design	Reference work entry Reference work	42	36
Google Scholar	"Construction" AND "factors" "Whole Life Cost"	Only in title	Review articles	115	115
Other databases		Nil	All other databases are excluded due to article retrieval limitations		
Total				336	330

Apart from preliminary research data, government reports and the guidance notes issued by standard bodies, such as RICS, AIQS, ICMS, NZIOB, BSI and NATO, and the market research reports conducted by AECOM, BRANZ, Turner and Townsend, BDO and Oxford Economist were also used as secondary research data. Secondary data were collected from relevant websites. Only studies in English were selected, with the dates of studies limited from 2000 to 2023. Although most principles of WLC are well developed in theory, it did not receive a wide practical application until the end of the 19th century [35]. However, implementing a new project delivery system of private finance initiative (PFI) in 1992 seems to overcome the practical application obstacle [19]. Therefore, the year 2000 was selected as the cut-off mark of the literature search. The subject area chosen was engineering, excluding review articles to avoid repetition. Once the data searching strategy was established, the PRISMA flow diagram (Figure 1) was followed.

Initially, 330 articles were identified as primary search data, and 62 documents were removed by the automation tool of the database search engines, followed by the established search strategy. Two hundred and sixty-seven articles were used for document screening. Each abstract was analysed to exclude irrelevant studies. The exclusion criteria were used to remove documents that were not indicated in the "WLC-related factors" section of the abstract. The abstract screening process retained 81 papers. Seventy-five papers could be retrieved and were fully assessed for eligibility after removing duplicates. Articles without authors related to prefabricated/off-site building construction were removed. They were constructed under a controlled nature, procuring bulk of materials, using different technology and special skills required [36]. Therefore, acquisition costs differed from the inflation's effect on acquisition costs, which differs from on-site construction. Sixty-four documents were included from the primary search data, and sixty-nine were selected from secondary search data and carried forward for the eligibility assessment. Forty-seven were excluded as irrelevant, and twenty-two chosen documents were included. The total number of papers included was 84. All the articles selected are listed in Appendix B.

The articles were from 30 countries, as shown in Figure 2 below. This study consisted of almost all the world's regions, and most studies were conducted in the United Kingdom, which constituted to 29.5% overall. A recent interest in the topic can be seen in Nigeria, which is similar to Canada and Australia.

The factors identified from the articles included in this SLR were then placed in a table alongside the authors, country of origin and year of publication, and shown on a visualisation map using the VOSviewer programme 1.6.19. The data were sorted to identify factors influencing whole-life cycle costs and their interrelationships, and the two variables are the factors influencing WLCs and their interrelationships. The outcome of the factors and their interlinks is measured by the number of authors who addressed this topic in the literature. However, we could not assess the risk of biases in the studied literature; hence, it remains a limitation.

The results of this SLR were then analysed in pairs to examine their interaction and gain a more comprehensive understanding of how the two elements relate. To simplify the identified factors and evaluate their polarities, the ICMS framework was integrated into an Analytical Hierarchy Process (AHP) tool. AHP is a structured technique that involves pairwise comparisons, making it a useful tool for decision making in complex, multi-criteria situations [37]. AHP has been widely used in various fields, such as planning, resource allocation, conflict resolution and optimization. Many studies have demonstrated its versatility. Although the AHP process involves six stages, including criteria identification, hierarchical structure, pairwise comparison, scoring, consistency check and aggregation [38], this research only focuses on the pairwise comparison stage.

ICMS is a principles-based international standard that sets out how to classify, define, measure, record, analyse, present and compare construction project life cycle costs and carbon emissions in a structured and logical format. Although life cycle costs include only construction, renewal, operation, maintenance and end-of-life costs, ICMS also makes provision for including acquisition costs, which may significantly impact a project's budget [39]. Figure 3 shows the ICMS framework, which sets out four levels for a framework. At the first level, the primary WLC system is highlighted, further divided into four main factors at level 2: non-construction costs, life-cycle costs (LCCs), income and externalities. The LCC factor is divided into construction, maintenance, operation, renewal and disposal costs (or end-of-life costs) at level 3.

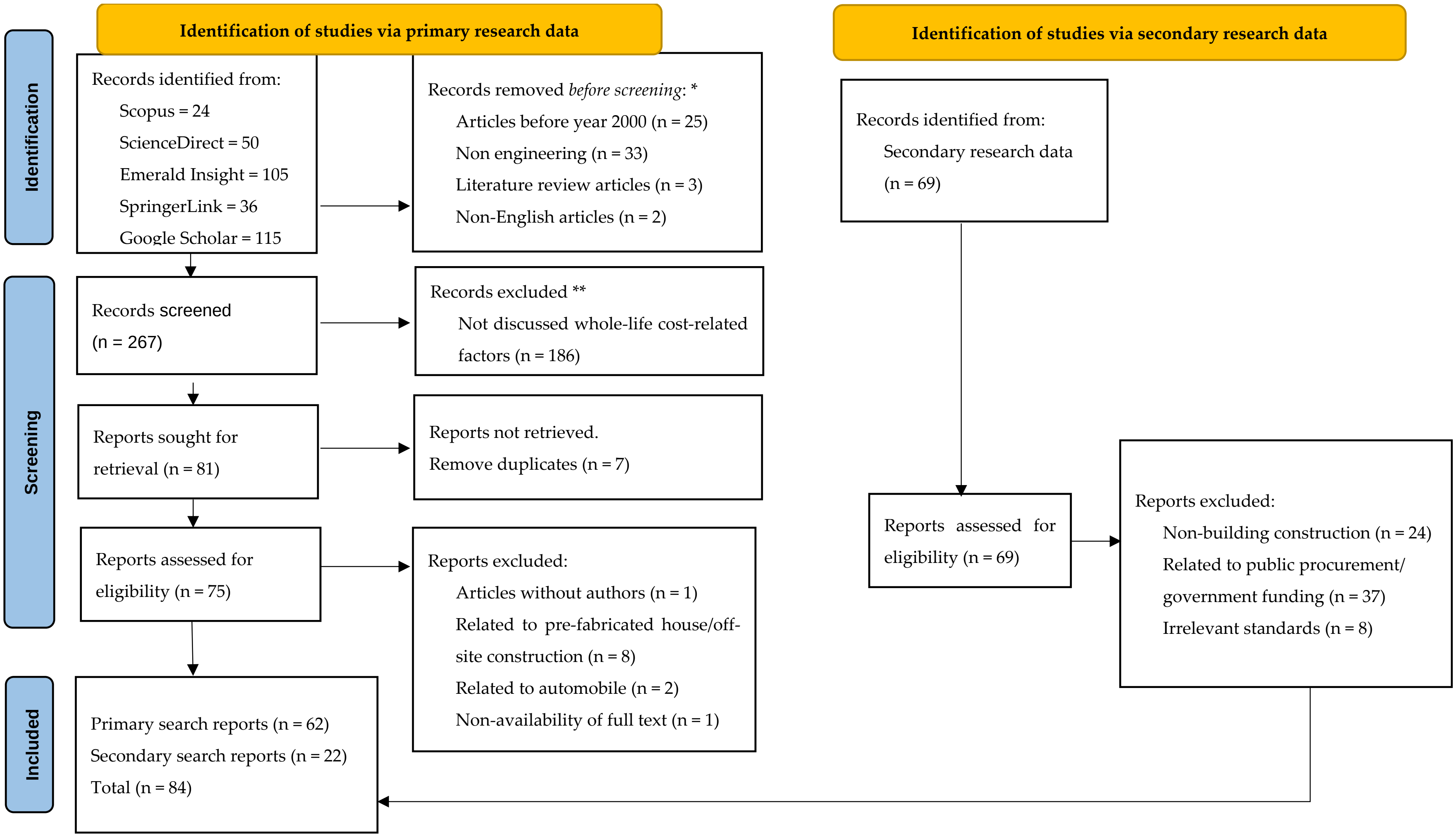

Figure 1. PRISMA flow chart. * Records excluded via automation; ** records excluded via human reviewer.

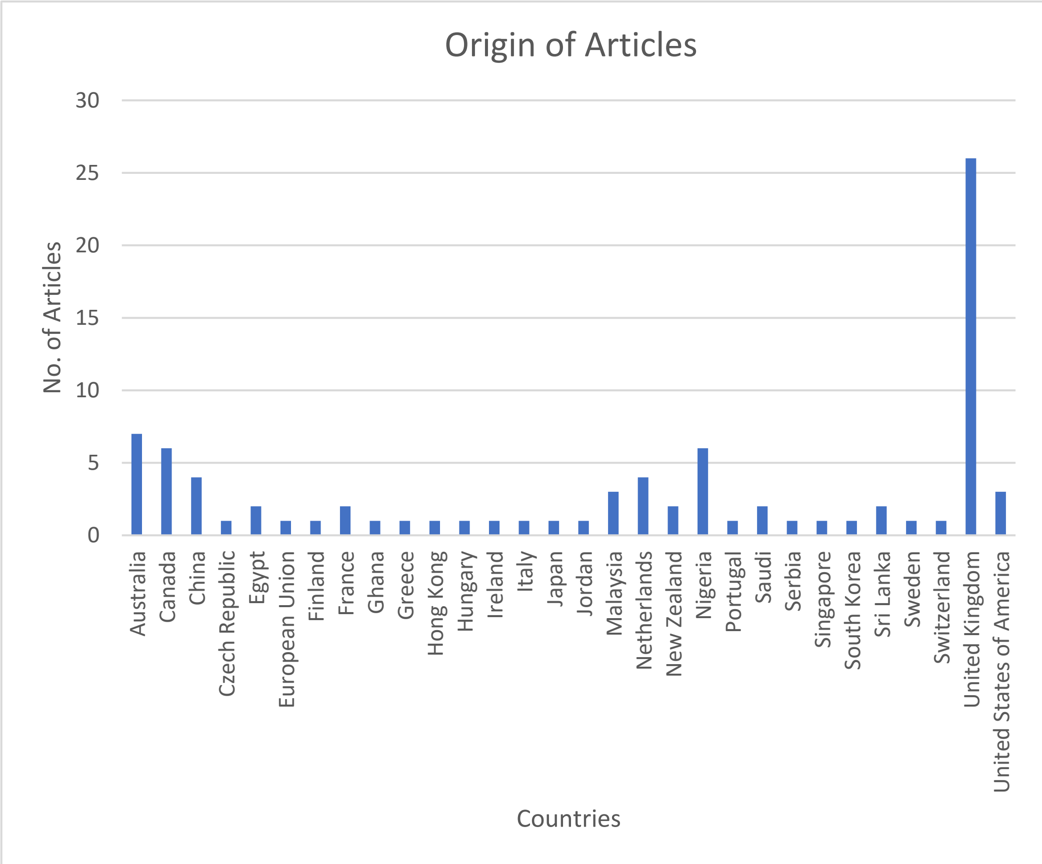

Figure 2. Origin of articles.

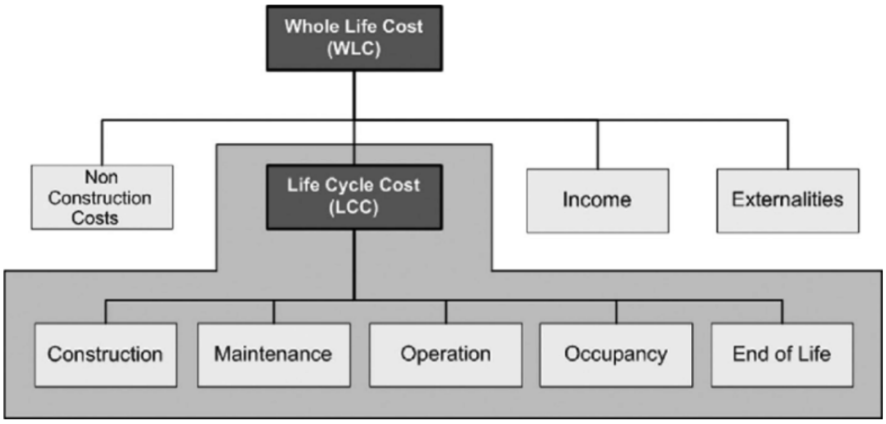

Figure 3. ICMS framework [39].

To start the pairwise comparison, the hierarchy referring to the levels of the ICMS framework was established, as shown in Figure 4. The level 4 factors were then plotted on a table's horizontal and vertical axes for pairwise comparison. The horizontal axis was the fundamental factor that interacted with the secondary factor in the vertical axis. All the positive polarities were displayed in blue, while all the negative polarities were shown in red. By following this methodology, AHP can effectively determine pairwise relations between factors influencing WLC and support decision-making processes. Then, the pairwise comparison results were translated into causal relationships in the causal loop diagram. A causal loop diagram (CLD) is a graphical representation used to visualize the causal relationships between variables in a system. It is a part of system dynamics, a method for understanding the behaviour of complex systems over time. CLDs are particularly useful for modelling dynamic systems where variables interact with each other in feedback loops [40]. The positive and negative polarities identified in the pairwise comparison have been used to determine the causal relationships. Positive relationships indicate that an increase in one variable leads to an increase in another, while negative relationships indicate that an increase in one variable leads to a decrease in another. Add arrows representing causal links between variables, indicating the direction of influence based on the results of pairwise comparisons. Arrows were then labelled with appropriate sign conventions (+ or −) to denote the directionality of the relationships. Three individual CLDs were created for income, LCCs and non-construction costs, and a comprehensive CLD was then produced combining the three individual CLDs. Finally, balancing and reinforcing loops were identified within the SLR articles utilised for this research.

Employing a causal loop diagram (CLD) to represent pairwise comparison results offers a powerful means of visualizing and understanding the complex interdependencies between variables within a system. Causal loop diagrams (CLDs) offer a visual representation of the relationships between different variables. This visual format makes it easier for stakeholders, who may not be familiar with quantitative analysis techniques, to understand and communicate the results of pairwise comparisons. CLDs are part of the system dynamics methodology, which focuses on understanding how variables interact and influence each other over time. The results of pairwise comparisons may reveal important causal relationships between variables, and CLDs help to illustrate these relationships within the broader context of the system. Pairwise comparisons may identify feedback loops where changes in one variable affect another variable, which in turn influences the first variable. CLDs are well-suited for representing these feedback loops, whether they are reinforcing (positive feedback) or balancing (negative feedback) in nature. CLDs capture the dynamic behaviour of systems, showing how variables change.

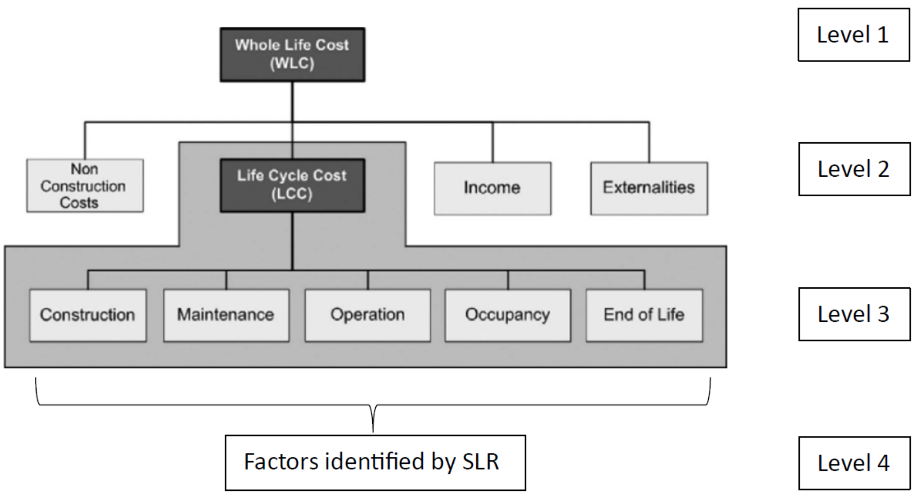

Figure 4. Hierarchical levels.

The overall research methodology process is summarised in Figure 5.

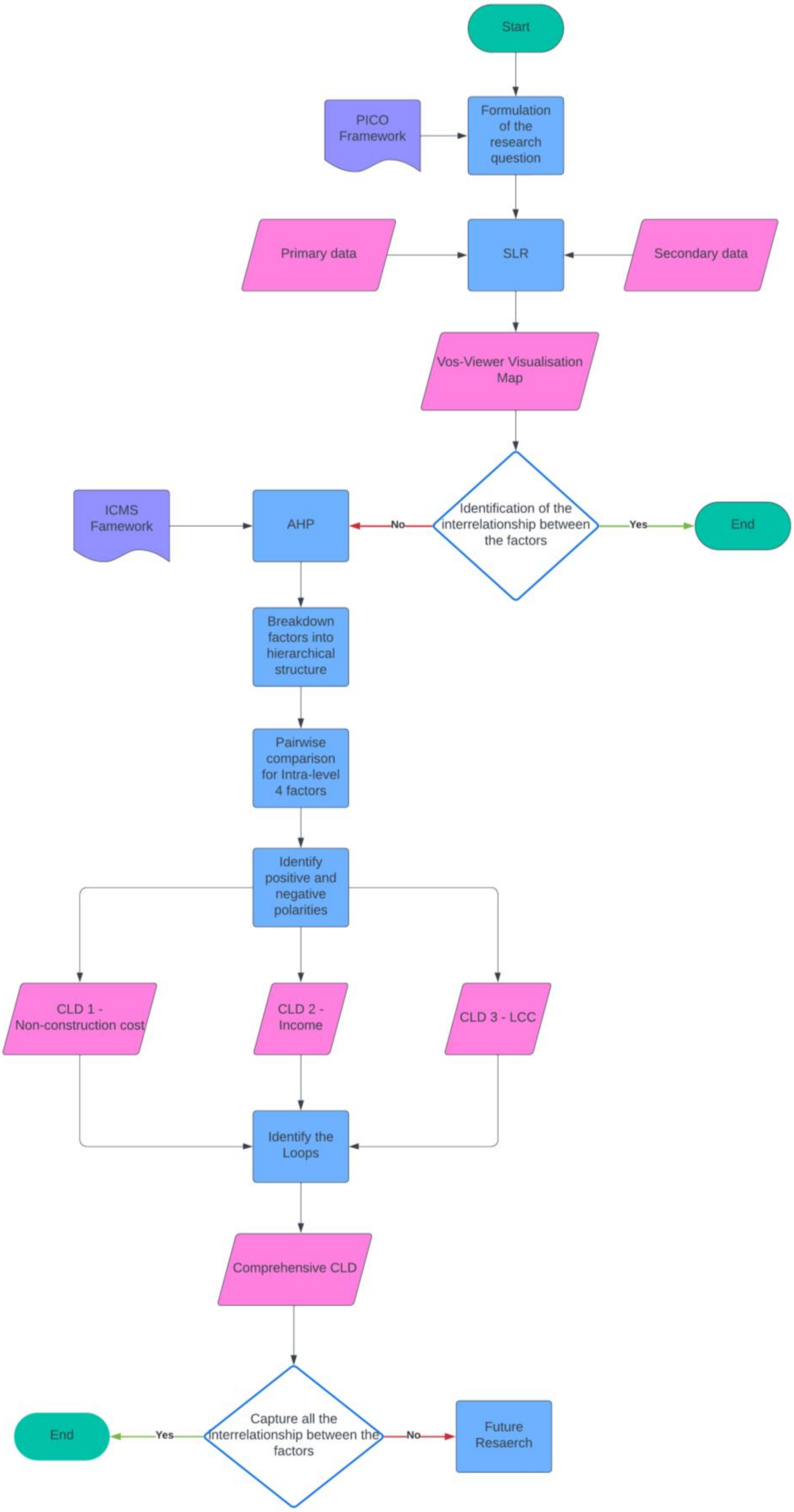

Figure 5. Research process.

In summary, according to Figure 5, the research process began with the formulation of a research question using the PICO framework. Following this, a SLR was conducted using both primary and secondary data sources to gather relevant studies and information on the topic. The findings from the SLR were then visualized using a VOSviewer map, which allowed for the identification of interrelationships of the factors influencing WLC. If there were not clear interrelationships identified between factors influencing WLC, the analysis proceeded to utilize the AHP with the integration of the ICMS framework. This involved breaking down the factors into a hierarchical structure; conducting pairwise comparisons; identifying positive and negative polarities; and creating CLDs for non-construction costs, income and LCCs. These CLDs helped capture the interrelationships between factors and highlighted feedback loops. Finally, a comprehensive CLD was developed by combining the individual CLDs, capturing all interrelationships. If the comprehensive CLD sufficiently captured the interrelationships between factors, the research concluded. Otherwise, areas for future research were identified to further explore and refine the understanding of these interrelationships.

3. Results

Appendix A lists the SLR findings from 84 studies, with 51 distinct factors found. Appendix A shows that more than 70 studies considered maintenance, operating, renewal, disposal and construction costs as the most often mentioned components. Government fees, upfront acquisition costs, residual value, material availability and service life, time value of money, discount rate, income generated from assets, taxation, inflation, building stamina and analysis period were considered in more than 25 studies. In comparison, the least considered factors comprised the estimated annual occupancy hours, environmental factors, real cost, nominal cost, foreign exchange, legislative costs, statutory charges, technology, level of uncertainty, insurance, building type, functionality, size, no. of floors, GFA, location, environment impact, risk allowances and waste management, which appeared in 7 to 21 studies. The least discussed factors include the method of financing, demand and supply of materials, foreign exchange, seismic resistance and fire resistance, which appeared in one to four studies. The SLR-identified factors were ranked by their frequency of comments in Table 2.

Table 2. Ranking of the factors identified via SLR.

Sr. No	Factors	Rank
1	Maintenance cost	77
2	Operation cost/renewal cost	74
3	Disposal/end-of-life cost	72
4	Construction cost	71
5	Residual value	56
6	Time value of money	45
7	Upfront acquisition cost	41
8	Discount rate	41
9	Period of analysis	37
10	Building life	34
11	Government regulations/fees	28
12	Materials availability/service life	25
13	Income generated from the asset	25
14	Building type/functionality	21
15	Taxation	21
16	Inflation	21
17	Gross floor area	17
18	Building element/orientation	16

19	Environmental impact evaluation	16
20	Risk allowances	16
21	Waste management cost	16
22	Maintenance frequency	15
23	No. of floors/height/level above and below ground	14
24	Location	14
25	Replacement frequency	14
26	Construction technology	13
27	Rate of interest	13
28	Design inputs	11
29	Energy saving measures and cost	10
30	Context or purpose determined by stakeholders	10
31	Nominal cost	10
32	Environmental cost	9
33	Real cost	9
34	Carbon sequestration	8
35	Legislative, statutory or economic changes	8
36	Estimated annual occupancy hours	7
37	Shape of facility	6
38	Externalities	4
39	Technology and tools	4
40	Green building certification cost	4
41	Variations in various cost	3
42	Level of uncertainty	3
43	Insurances	3
44	Consideration of design alternatives	2
45	Renewable resources used	2
46	Continuity of supply chain	2
47	Method of financing	1
48	Demand and supply of materials	1
49	Foreign exchange	1
50	Seismic resistance	1
51	Fire resistance	1

The identified factors affecting WLC of buildings were visualised on a VOSviewer map (Figure 6). The process of utilising VOSviewer for visualization mapping with bibliographic data began by gathering pertinent information from diverse sources like research papers, articles, reports and publications focusing on factors affecting whole-life cost analysis. These data underwent thorough analysis and processing to extract essential elements, including keywords, concepts and their interrelations. Subsequently, VOSviewer software was deployed to create a visualization map based on the processed data. By leveraging algorithms, such as VOS mapping and clustering techniques, the software illustrated the connections between different factors or concepts in a visual format, typically presenting them as network or cluster maps. To obtain a better visualisation, the minimum number of occurrences of keywords was set to 2. The resulting visualization offered valuable insights into the interconnectedness and significance of various factors influencing whole-life costs.

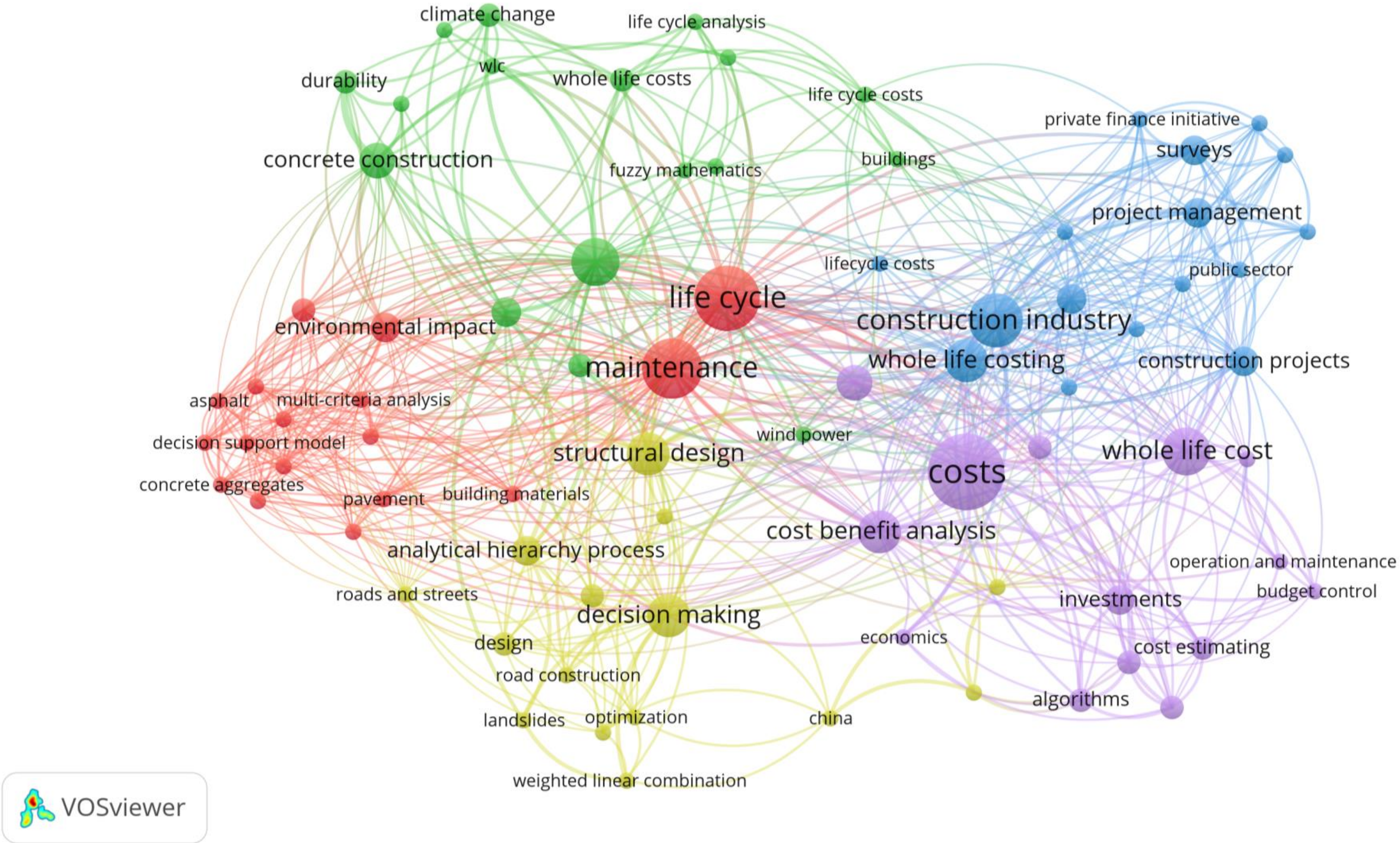

Figure 6. VOSviewer visualisation map for the factors influencing WLC.

Overall, the VOSviewer visualisation map provides valuable insights into the factors that influence WLC, relationships and trends within a dataset, helping to identify important topics, contributors and patterns within the map. It was also used to different clusters of WLC. The nodes with larger sizes or greater centrality in the visualisation map represent items (such as authors, journals or keywords) that are more influential or central within the dataset. The connections between nodes indicate relationships or associations between items. Though the factors are grouped into different clusters and visualised on the map, clusters are confusing. Also, the visualisation map did not capture the expected interrelationships among the factors and their polarities. Lack of contextual understanding, overwhelming complexity and the potential for misleading representation of the factors due to inappropriate visualisation techniques or misinterpretation of data are some of the reasons that confuse the clusters. In addition, static VOSviewer maps may not be interactive, limiting users' ability to explore data dynamically and conduct detailed analyses. Poor design choices and insufficient data quality can further exacerbate these challenges, potentially impeding the map's ability to communicate insights effectively. Therefore, while VOSviewer provides insights, it must be supplemented with comprehensive analysis, expert judgment and stakeholder input to ensure well-informed decision making [41]. To overcome the limitations, the ICMS framework was incorporated within an Analytical Hierarchy Process (AHP) tool to break down the identified factors into hierarchical levels and then conduct pairwise comparisons to assess the polarities of the factors.

Figure 7 visually represents the modified ICMS framework, depicting the structured levels and their interconnections. The identified 51 factors are mapped in hierarchical levels 3 and 4, considering the ICMS framework, as illustrated in Figure 4. This visualisation further aids in grasping the intricate relationships and guides a pairwise comparison of the factors to identify their polarities.

The analysis of 84 papers revealed 51 factors that affect WLC. Out of these, 54 papers discussed how different factors are interconnected. The results obtained from Appendix A were subjected to pairwise comparisons. Each level 4 factor is linked to other level 4 factors through the influence of level 3 factors. The pairwise comparison did not reveal any connectivity between level 3 factors. Consequently, pairwise comparisons only revealed level 4 interactions. The pairwise comparison of 51 pre-identified factors is shown in Appendix C. This comparison aimed to provide insights into the interactions between different factors. In this analysis, the vertical axis of the table was designated as the primary factor, while the horizontal axis represented the secondary factor. Instances where a factor was compared to itself (central diagonal) were highlighted in grey.

The selection of the secondary factor was driven by the objective of understanding its impact on the primary factor. If the secondary factor positively influenced the primary factor, the presentation denoted this with a blue colour, accompanied by the author's name (who identified the interrelationship between the factors) and the publication year. Positive polarity was further indicated with a +ve sign. Conversely, negative impacts were represented in red along with the −ve sign, providing a visual cue for better comprehension. For example, using renewable energy sources has varying effects on the financial aspects of building construction and upkeep. Although it brings down operational expenses, it concurrently raises the costs of procuring and maintaining renewable energy sources. Blue conveys the positive correlation between renewable energy and construction and maintenance costs. In contrast, red indicates the inverse relationship between renewable energy and operational expenses and is indicated with a −ve sign.

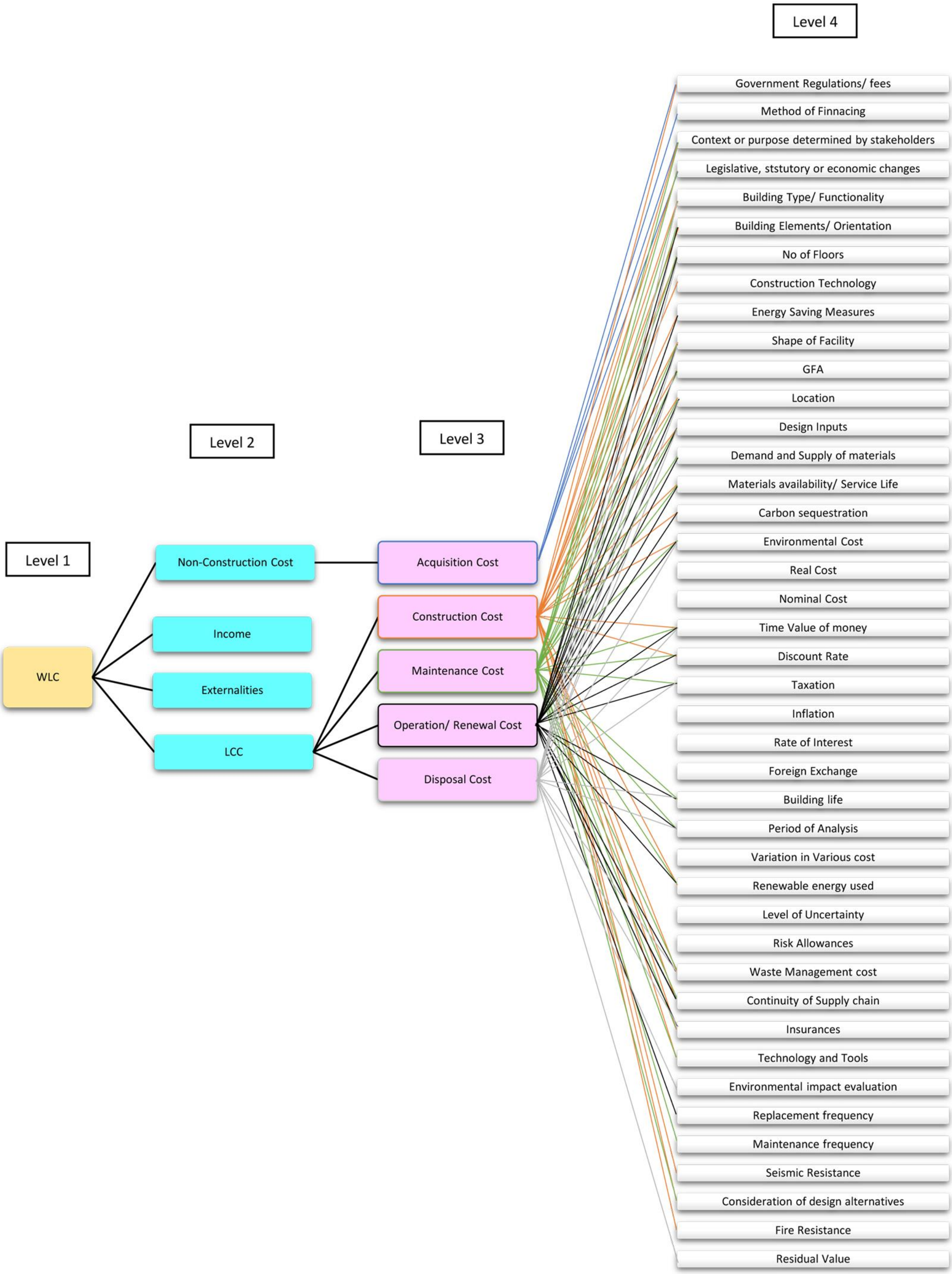

Figure 7. Modified levels of factors using ICMS framework.

Appendix C shows that fifty-four authors mentioned interrelations. Only seven of the interrelations had negative polarities, whereas others had positive polarities. The residual value featured five negative interrelationships (time value of money; building life; the analysis period; legislative, statutory or economic changes; and location), which was the highest. The other two negative interrelations are maintenance costs–energy-saving measures and renewable energy costs–operation and renewal. The most interesting aspect of the table is that [42] regarded the capital cost–taxation relationship as positive polarity, whilst ICMS [39] noted the same as negative polarity. Therefore, the capital cost–taxation relationship was considered neutral.

4. Discussion

WLC is a technique for evaluating the long-term financial impact of design choices. In addition to the capital costs, it considers all expenses associated with usage, including operation, renewal, maintenance and disposal costs. It is crucial to understand the influence of the factors impacting WLC for the WLC process to be as successful as possible. Prior studies have noted factors influencing WLC, but none have considered the interrelation of these factors. To determine the interrelationship and specific factors impacting WLC, this research classified 51 factors into 4 hierarchical levels, utilising the ICMS hierarchical level diagram to provide the flow of factors. However, it does not capture every interrelationship nor their polarities identified through pairwise comparison. To better understand these complex interrelationships, we employed the causal loop diagram. This system thinking tool allowed us to pinpoint the key variables within the system and illustrate the causal relationships between them.

To comprehensively capture the interrelations of factors that impact WLCs and their respective polarities, three individual causal loop diagrams (CLDs) were developed for level 2 factors of the ICMS framework, such as the non-construction costs, income and LCCs. The fourth level 2 factor (refer to Figure 7), "externalities", had no level 3 or level 4 factors and was kept as a stand-alone factor. Figure 8 shows the CLD of non-construction costs.

The causal loop diagram shows that the upfront acquisition costs, a level 3 factor in the ICMS framework, is the only factor affecting non-construction costs. This cost is directly influenced by government regulations; method of financing; context/purpose determined by stakeholders; and legislative, statutory or economic charges. Government regulations play a pivotal role in influencing various aspects of the economy, such as taxation and discount rates. Conversely, inflation significantly impacts the formulation of government regulations [9,43]. Therefore, understanding the interplay between government regulations and inflation is crucial in crafting effective fiscal policies and driving sustainable economic growth for the upfront acquisition cost. The government holds the authority to shape taxation and other obligations, aiming to manage inflation rates through various measures, including establishing interest rates. These actions can significantly impact the business sector, affecting the expenses of acquiring labour and materials and the costs of financing purchases [43]. On the other hand, higher interest is a policy response to rising inflation. However, none of the previous studies identified this connection. There is a reinforcing loop between inflation and discount rates. Government authorities determine discount rates, encouraging banks to lend more money when lowered, allowing them to increase their reserves at a lower cost [44]. This results in additional loans for businesses and consumers, increasing the money supply and spurring economic activity, ultimately leading to inflation.

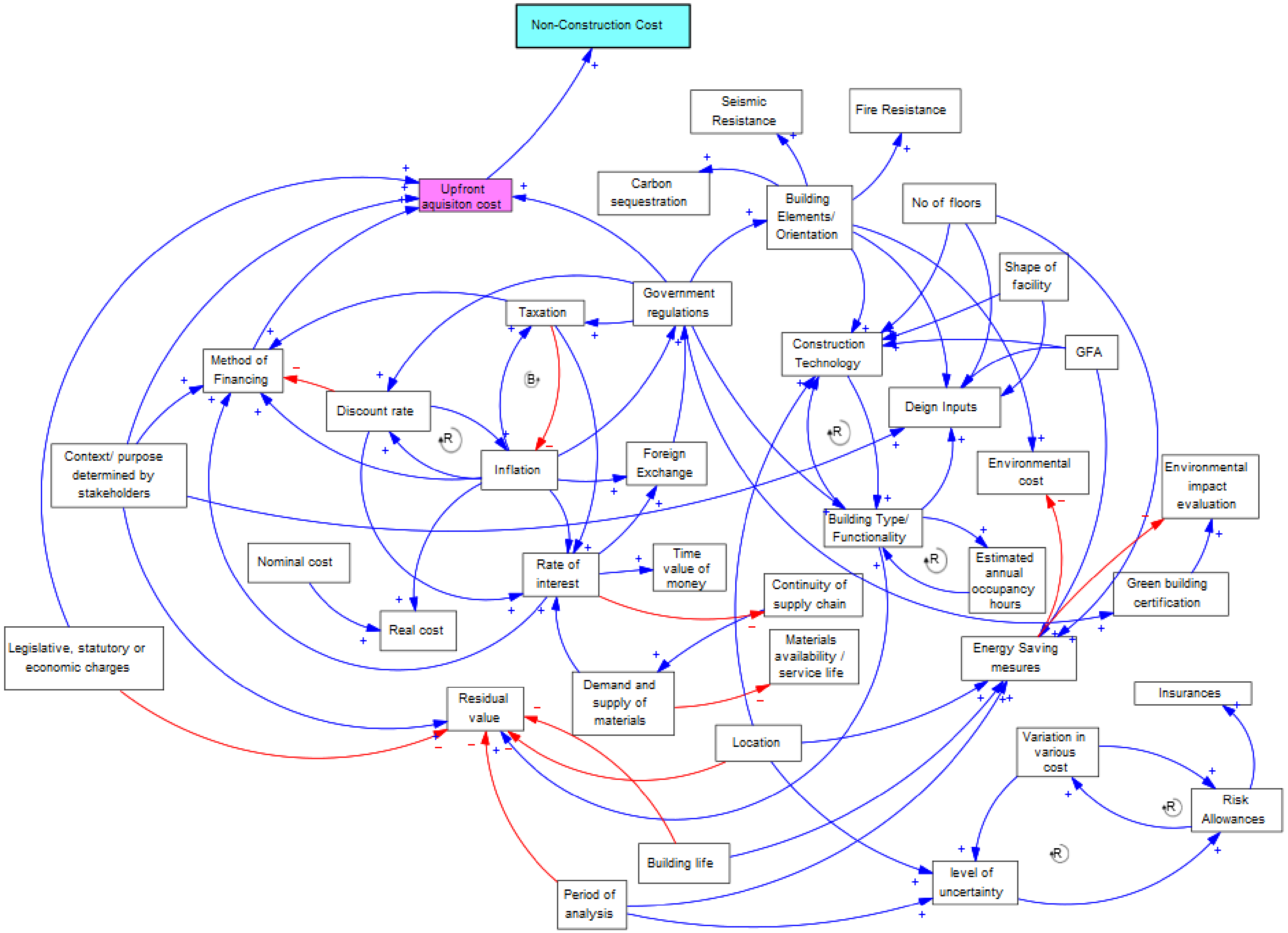

Figure 8. Causal loop diagram for the non-construction costs (created with VENSIM software PLE 9.4.2).

Conversely, as inflation rises, the value of future cash flows decreases, leading to a higher discount rate. Additionally, a balancing loop can be observed between inflation and taxation, wherein the government increases taxes to discourage spending when inflation is high [45]. Raising taxes results in lower inflation. Currency exchange rates can impact the value of imported construction materials and equipment and economic growth, capital flows, inflation and interest rates. However, these interconnections were not captured in previous studies. Availability of materials, demand and supply chain continuity, interest rates, taxation, inflation, discount rates and government regulations are all interconnected. The demand for supply materials, discount rates and taxation affect the interest rate. If the discount rate is high, it can indicate a higher interest rate, inflation or a higher risk associated with receiving future cash flow [43,46]. When the interest rate increases, the supply chain's continuity is reduced, discouraging purchasing power. As a result, demand increases, material availability decreases and construction and maintenance costs increase. There is a reinforcing loop between inflation and the discount rate. Government authorities determine the discount rate, encouraging banks to lend more money when lowered, allowing them to increase their reserves at a lower cost [44]. This results in more loans for businesses and consumers, increasing the money supply and spurring economic activity, which ultimately leads to inflation.

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There are five other reinforcing loops between the following factors:

- Estimated annual occupancy hours and building type/functionality.
- Construction technology and building type/functionality.
- Variations in various costs and risk allowances.
- Variation in various costs, level of uncertainty and risk allowances.
- Government regulations, taxation, rate of interest and foreign exchange.

According to Figure 8, insurance is only influenced by risk allowances. However, the construction insurance was also influenced by the building type/functionality, building elements/orientation, number of floors, GFA, facility shape, location, building life, context/purpose determined by stakeholders and location. Unfortunately, the previous studies failed to capture these interconnections. Within the ICMS framework, income is the second crucial element that can be affected by multiple factors such as residual value, building lifespan and the intended use determined by stakeholders. These income interconnections are illustrated in Figure 9.

Residual value plays a significant role in determining income. It is defined as the monetary value assigned to an asset at the end of the analysis period. Residual value is the only factor that has more negative polarities than positives from other factors, as shown in Figure 9. Building life; period of analysis; location; and legislative, statutory or economic changes interact negatively with residual value, implying that an increase in any of these elements will reduce residual value [9,43,47–49]. On the contrary, context/purpose determined by stakeholders, design inputs and energy-saving measures interact favourably [17,50,51], meaning these features increase residual value. Notably, residual value only influences the income, as shown in Figure 9.

An asset's generated income, including rent and residual value, is dependent on how effectively it serves its intended purpose, which is established by stakeholders [43]. Additionally, stakeholders indirectly impact income through the building's predetermined lifespan. However, the income generated from the asset is also influenced by inflation and discount rates. Inflation is a rise in the general price level reflecting a decline in the purchasing power of money. As a result, the cost of use will rise, and the target income will be reduced. However, the previous studies do not highlight the negative polarity of inflation and discount rate regarding income.

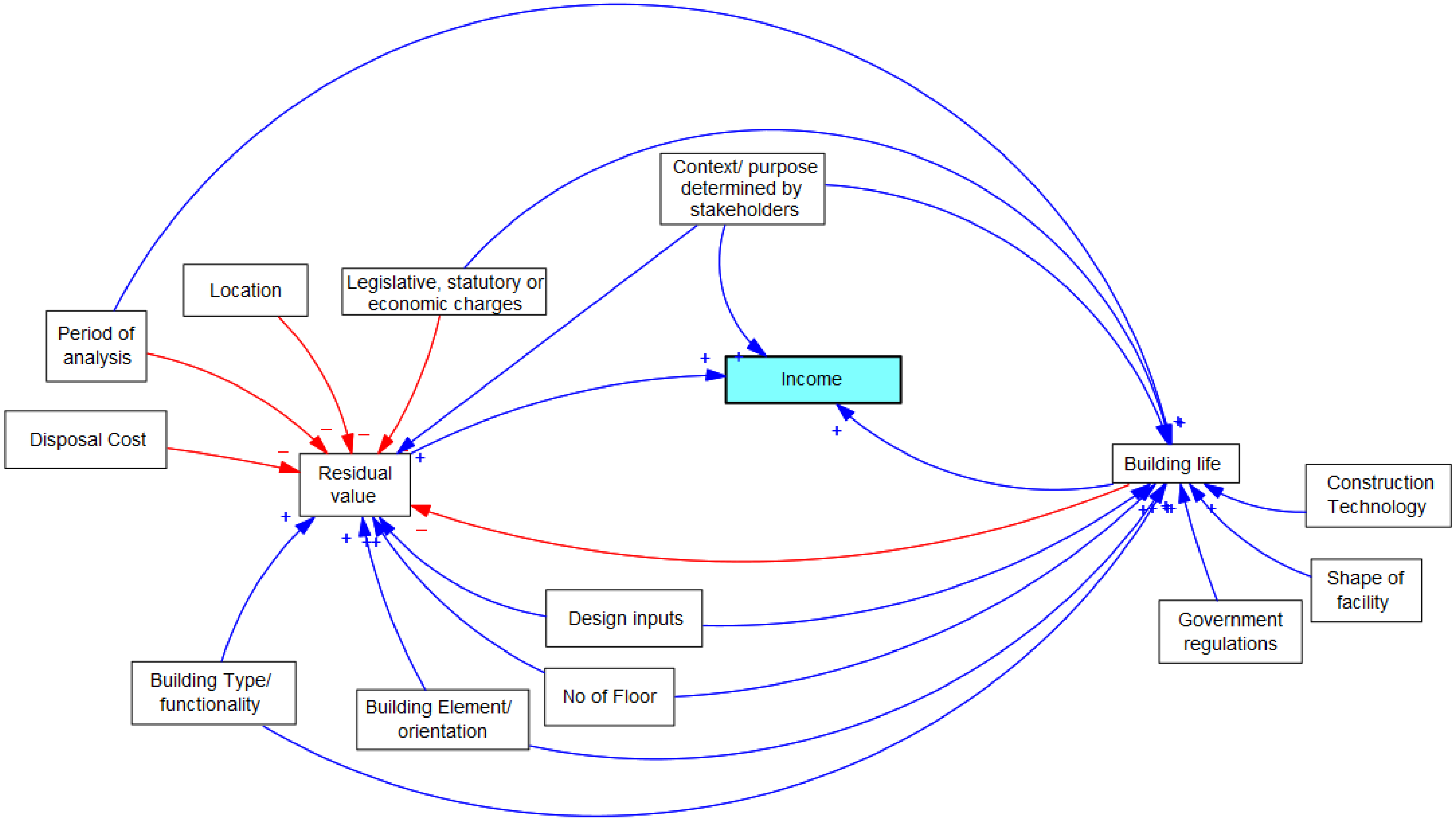

Figure 9. Causal loop diagram for income (created with VENSIM software PLE 9.4.2).

The life of a building can significantly affect its rental income potential. A prolonged lifespan typically translates to a higher rental yield, yet it may also diminish the salvage value of the property upon the conclusion of its life cycle. Hence, the lifetime of a building can have a dual impact on income, which can be both advantageous and disadvantageous. However, only the positive polarity was captured in a previous study.

LCC is the 3rd level 2 factor of the ICMS framework, and it is mainly positively interconnected with the construction, maintenance, operation/renewal and disposal costs, as shown in Figure 10. Construction costs are inclusive of site costs or opportunity costs, finance charges, professional fees, construction and infrastructure costs, tax allowances, statutory charges, development grants, planning gain and third-party costs (such as rights of light, oversailing charges, wayleaves and easements) [43].

Maintenance Costs: The total costs of labour, material and other related costs to retain a constructed asset or its parts so that it can perform its required functions [52] Maintenance costs exclude renewal costs. However, they consist of all related management, cleaning services, repainting, repairing or replacing parts necessary for the constructed asset to be used for its intended purpose [11]. Building consumers are typically motivated by the concerns relating to the costs of ownership. They can be ready to pay a higher capital cost, provided they have some assurance that cheaper maintenance costs would be more than compensated. They may choose for themselves what each option is worth. Maintenance costs are positively influenced by building parameters, such as building type/functionality; building elements/orientation; number of floors; shape of facility; GFA; location; context/purpose determined by stakeholders; environmental factors; maintenance frequency; demand and supply of materials; material availability; continuity of supply chain; discount rate; taxation, insurance; building life; period of analysis; environmental impact evaluation; technology and tools; design and technology; government regulations; legislative, statutory or economic changes; maintenance frequency; and waste management. For example, if building parameters increase, the amount required for maintenance will also increase. The analysis period influences the maintenance cost directly and indirectly through the maintenance frequency.

Operation Costs: Costs incurred in running and managing a constructed asset during its occupation, including administrative support services, rent, insurance and energy and other environmental factors/regulations [39]. Renewal Costs: The costs of replacing a constructed asset and significant components once they reach the end of their life, which will be included in the capital rather than the revenue budget, depending on the client's decision [39]. All the factors that affect maintenance costs favourably impact operation/renewal costs as well, although the usage of renewal energy and energy-saving techniques have the opposite polarity. In addition, replacement frequency and estimated annual occupancy hours have positive polarities. However, none of the authors discussed the impact of income generated from an asset on its operation/renewal costs. Rental income has a negative polarity with operation and renewal costs. The analysis period influences operation/renewal costs directly and indirectly through the replacement frequency.

Disposal/end-of-life costs are factors that directly interconnect with LCCs. While RICS [43] and ICMS [39] classified disposal costs as a component of end-of-life costs, BS ISO 15686-5 [53] recognised disposal and end-of-life costs as two distinct things. ICMS has provided a broad definition for end-of-life costs as "the net costs or fees for disposing of an asset at the end of its service life after deducting the salvage value and other income due to disposal, including costs resulting from disposal inspection, decommissioning and decontamination, demolition and reclamation, reinstatement, asset transfer obligations, recycling, recovery, disposal of components and materials, and transport and regulatory costs" [39]. Accordingly, disposal/end-of-life costs also interact with maintenance and operation/renewal costs, except for maintenance frequency, replacement frequency, consideration of design alternatives, supply chain continuity and insurance.

The interconnections related to LCCs are shown in Figure 10. According to Figure 10, legislative, statutory or economic charges; location; and the context/purpose determined by stakeholders are common influencers for all those factors.

Constructing a building is a multifaceted process that requires collaboration from all parties involved to ensure success. Throughout a building's life cycle, various stakeholders influence its requirements based on their needs and preferences. To accurately calculate WLC, the process must reflect the inputs from these stakeholders over time. The client/developer must clearly understand the costs of land, professional fees, design-related costs and expected future incomes. Financial institutions must contribute through loan/credit facilities and establish interest rates that can be used in WLC calculations. Contractors, subcontractors and suppliers must provide precise cost estimations for initial capital and subsequent adaptation costs. In contrast, maintenance and operation costs of the building after completion can be gathered from facility managers and project quantity surveyors. Finally, all these measurable costs and benefits must be expressed in present-day values. It is evident that project stakeholders hold critical knowledge and play key roles in improving WLC for adaptable buildings and contributing towards the supply of information, which controls the accuracy of the WLC outcome [54].

Buildings start to deteriorate and become obsolete as soon as they are constructed. Physical deterioration can be controlled by choosing suitable materials and components during the design phase. Still, obsolescence is much harder to manage because it involves predicting uncertain events like changes in appearance, technological advancement and innovation [9]. Although obsolescence is influenced by the context/purpose determined by the stakeholders, their influence on it has not been thoroughly explored in prior studies. Rather, obsolescence has been linked to the lifespan of a building in resources such as the RICS guidance note on life cycle costs [43] and cost studies of buildings [9]. Technological life, functional life, economic life, social life, legal life and aesthetic life are the several types of obsolescence. It is recommended that the analysis period should be less than any of the periods described along with these types of obsolescence [43]. In this way, the construction of a building can also be influenced by the context and purpose determined by stakeholders.

The location of a construction project plays a crucial role in determining the overall cost of the project [49]. The cost of building in a remote area can be significantly higher than in an urban area due to several factors. Firstly, remote areas often lack the necessary infrastructure required for construction, such as roads, electricity and water supply. This means the construction company may have to invest in building these facilities, which can add to the project's overall cost. Secondly, remote areas may have limited access to materials required for construction. This means that the construction company may have to transport the materials from a distant location, which can be expensive. Additionally, transporting materials to remote areas may be challenging due to poor road conditions, which can further increase the project's cost.

On the other hand, building in an urban area may be less expensive due to the availability of infrastructure and materials. Urban areas often have well-developed transportation networks, making transporting materials to the construction site easier. Additionally, urban areas have a higher concentration of construction companies, which means more competition and lower prices. Therefore, the location has negative and positive polarities to the construction, maintenance, operation/renewal and disposal costs.

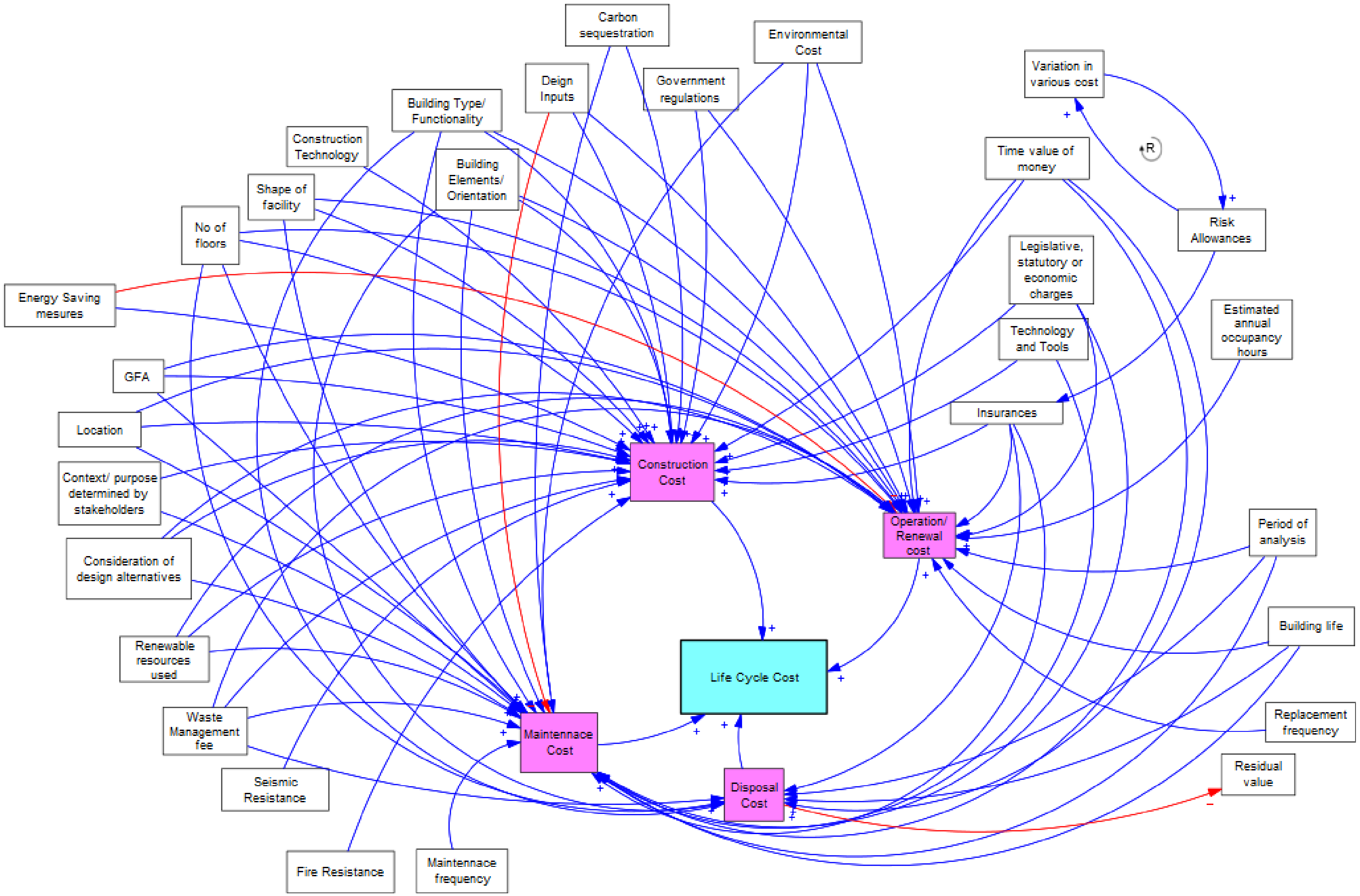

Figure 10. Causal loop diagram for LCCs (created with VENSIM software PLE 9.4.2).

Figure 10 illustrates that construction, maintenance and disposal costs have only positive polarities, while operation/renewal costs have a mix of positive and negative polarities. Using renewable energy sources has varying effects on the financial aspects of building construction and upkeep [55]. Although it brings down operational expenses, it concurrently raises the costs of procuring and maintaining renewable energy sources.

The three causal loop diagrams of non-construction costs, income and LCCs were combined to produce a comprehensive causal loop diagram for WLCs, as shown in Figure 11. The CLDs in Figures 8–10 revealed a few loops that were mentioned in the literature, revealing that much research needs to be done to enhance the knowledge regarding connections and loops.

Figure 11 reveals one balancing loop and six reinforcement loops, which are the same as in Figures 8–10. This indicates that no additional loops are identified in Figure 11.

Figure 11 also shows that level 4 factors, such as discount rate, taxation, inflation, foreign exchange, green building certification, variation in various costs, risk allowance, real cost, nominal cost, material availability/service life, rate of interest, demand and supply of materials and level of uncertainty, are not directly linked to level 3 factors. Instead, they are interconnected with other level 4 factors. For instance, the level of uncertainty is not directly related to any of the level 3 factors. It is connected to the risk allowances, which are connected to insurance, and insurance is only linked to construction, maintenance, operation/renewal and disposal costs. Additionally, Figure 11 shows that context/purpose determined by stakeholders, residual value and building life are directly interconnected with the level 2 income factors and interlinked with LCC and non-construction cost factors through level 3 factors.

Moreover, Figure 11 shows that minor attention has been given to the time value of money and real and nominal costs, as they have few interconnections. Real Costs: The costs expressed as a value at the common date, including estimated changes in price due to forecast changes in efficiency and technology, but excluding general price inflation or deflation. Nominal Costs: The expected price that will be paid when a cost is due to be paid, including estimated changes in price due to, for example, forecast changes in efficiency, inflation or deflation and technology [53]. The time value of money refers to investment and price movements over time [43]. Net present value (NPV) and annual equivalent value (AEV) are the two methods of evaluating the time cost factor [42]. The present value represents the amount of investment today required for the capital cost plus all future operating (revenue) costs. NPV is the sum to be invested, and is less than the total of all the costs because some will occur in the future [56]. The loss incurred by investing money in a building instead of a bank is known as AEV [42]. Collectively, the figure shows 51 factors that are interlinked with 6 reinforcing loops and 1 balancing loop. However, the authors of this SLR have not identified geographical and weather factors, such as seismicity and flood resistance, which were not reflected in the ICMS framework or the causal loop diagram.

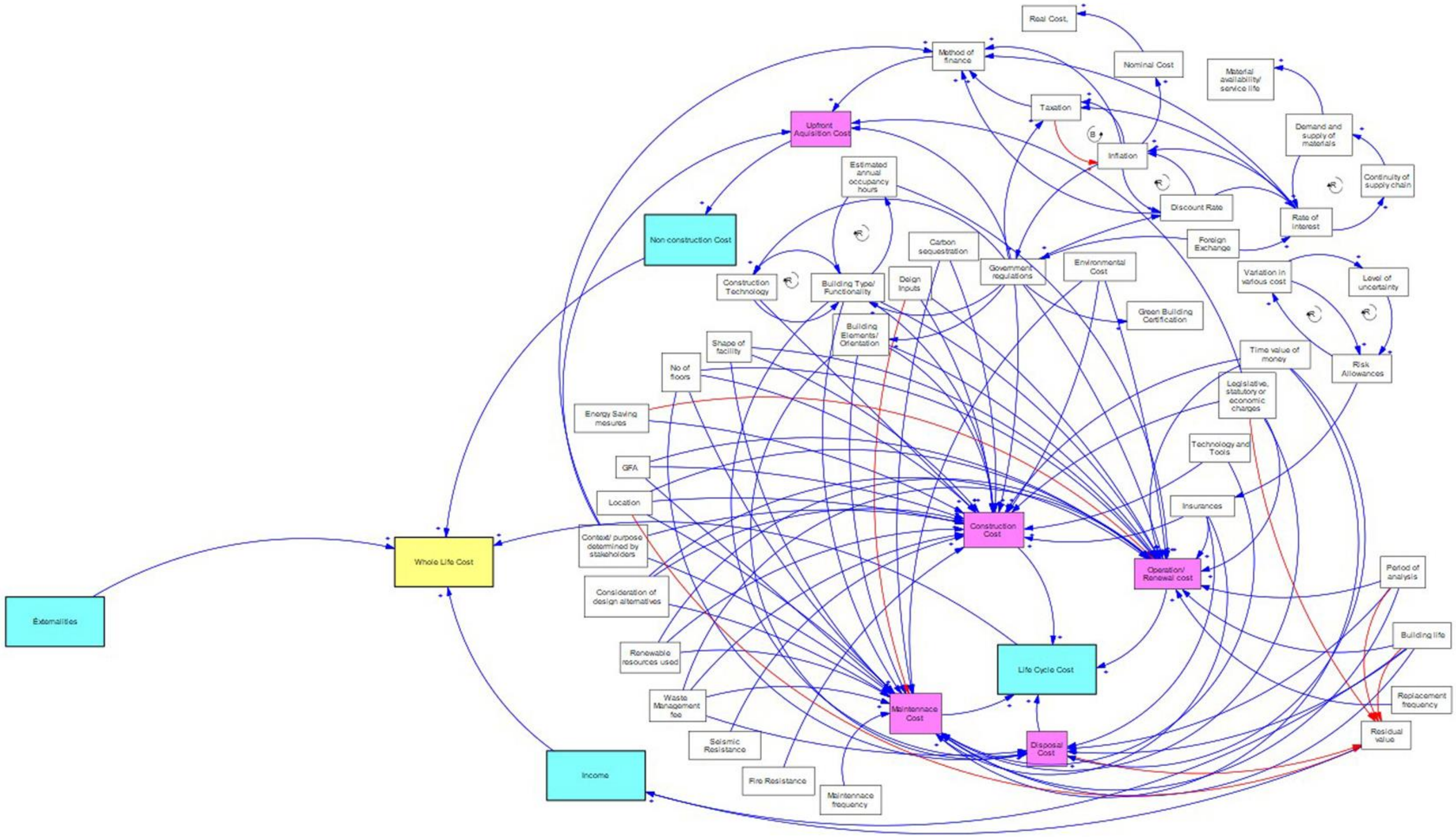

Figure 11. Comprehensive causal loop diagram for WLC (created with VENSIM software PLE 9.4.2).

5. Conclusions

While WLC is recognised for its advantages by construction professionals, it is not widely employed in the industry due to apprehensions about its estimation accuracy. Enhancing the precision of WLC necessitates discerning the factors that affect it. Nevertheless, these factors are not independent but are interrelated and function together. Therefore, comprehending the interconnections between these factors impacting the life cost is essential.

A systematic literature review was conducted to determine the factors affecting the estimation of WLC of building construction. This study found 51 variables from 84 research publications visualised on a map using VOSviewer. Their search results categorised the factors into a hierarchy in the ICMS framework. However, the map and framework did not capture the expected interrelationships among the factors, as each factor belonged to only one cluster. A pairwise comparison method was employed to analyse the relationships between the different factors and their polarities. This method obtained an understanding of how these factors are interrelated.

This study revealed a sole balancing loop that links the discount rate and inflation. Furthermore, six reinforced loops exist that interconnect inflation and discount rate, building type/functionality and estimated annual occupancy hours; building type/functionality and construction technology; variations in various costs and risk allowances; and variations of various costs; risk allowances; and level of uncertainty. Additionally, government regulations, taxation, rates of interest and foreign exchange loops are shared among the specific CLDs depicted in Figures 8–10. However, the researchers in this SLR did not explore the relationship between government regulations, energy-saving measures and waste management.

This paper emphasised the importance of considering geographical and weather factors such as seismicity and flood resistance for WLC estimation, but none of this SLR's articles addressed it. According to the ICMS framework, the identified interrelationships and polarities were divided into four hierarchical levels. It was found that not all level 4 factors are directly connected to level 3 factors. Instead, they interact with factors at the same level before connecting with level 3 factors.

The theoretical and practical applications include enhanced knowledge of cost estimators, quantity surveyors and academics who can thoroughly understand the entire WLC system with the interrelationships of the factors identified in this research. The building construction industry can gain insights into the interrelationships and could potentially include the relevant cost factors that would provide a more accurate WLC. By highlighting the interactions of factors, this paper added knowledge to the construction industry's current understanding of whole-life costing (WLC). The knowledge gained from this research will be helpful for construction professionals and stakeholders to estimate the costs involved in the whole life cycle of construction projects. Moreover, it will encourage academics to research the different elements and their interactions with WLC in future.

It is important to note that this study has a few potential limitations. This systematic literature review's sample bias is a significant constraint. While this SLR's methodology is simple to implement, the selective outcome relied on a relatively small number of databases to identify potentially eligible studies. The authors could not determine the biases that were prevalent for each of the searched literature. Hence, the risk of biases in the studied literature could not be assessed and remains a limitation.

Additionally, the websites used to display the data employed artificial intelligence and not the authors, which remains a limitation for systematic literature reviews worldwide. Although WLC is not a common term, it was included to capture relevant articles and information for this study, but irrelevant papers were manually eliminated. Moreover, even though construction as a search string resulted in many irrelevant non-building construction articles, the term "construction" was used independently to broaden the search area. Furthermore, the location-specific results of Google Scholar remained a limitation as the authors carried out searches from New Zealand.

Limiting this study to a thorough systematic literature review and establishing pairwise relations based on the SLR-produced CLDs constituted to a failure of manifesting all the relevant causal relationships. Therefore, future research should prioritise identifying the system dynamic of the interrelationships between the factors that influence WLCs. Future research should also consider the geographical characteristics of WLCs, as there is a lack of research exploring the correlation between geographical characteristics and WLCs.

Author Contributions: The authors confirm their contributions to this paper as follows: H.M.S.N.S.: corresponding author, conceptualisation, methodology, formal analysis, investigation, visualisation and writing—original and revised draft preparation; M.B.P.: supervision, methodology, visualisation and writing—review and editing; F.E.R.: supervision, methodology, visualisation and writing—review and editing. All authors have read and agreed to the published version of the manuscript.

Data Availability Statement: No new data were created or analysed in this study. Data sharing does not apply to this article.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A. Factors Influencing WLC

Item	Author	Origin	Year	Building Type/Functionality	Building Element/Orientation	No. of Floors/Height/Level above and below Ground	Construction Technology	Energy Saving Measures and Cost	Shape of Facility	Estimated Annual Occupancy Hours	Gross Floor Area	Location	Context or Purpose Determined by Stakeholders	Design Inputs	Method of Financing	Carbon sequestration	Government Regulations/Fees	Environmental Cost	Externalities	Upfront Acquisition Cost	Construction Cost	Residual Value	Maintenance Cost	Operation Cost/Renewal Cost	Disposal/End-of-Life Cost	Demand and Supply of Materials	Materials Availability/Service Life	Real Cost	Nominal Cost	Time Value of Money	Discount Rate	Income Generated from the Asset	Taxation	Inflation	Rate of Interest	Foreign Exchange	Building Life	Period of Analysis	Legislative, Statutory or Economic Changes	Technology and Tools	Environmental Impact Evaluation	Green Building Certification Cost	Variations in Various Cost	Replacement Frequency	Maintenance Frequency	Consideration of Design Alternatives	Renewable Resources Used	Level of Uncertainty	Risk Allowances	Waste Management Cost	Continuity of Supply Chain	Seismic Resistance	Fire Resistance	Insurances
1	[57]	Egypt	2019	✓	✓						✓										✓		✓	✓	✓		✓			✓	✓	✓		✓			✓	✓			✓			✓	✓				✓	✓				
2	[58]	Nigeria	2013																	✓	✓	✓	✓	✓	✓												✓	✓						✓	✓									
3	[59]	Nigeria	2022								✓	✓		✓		✓					✓	✓	✓	✓	✓					✓	✓								✓	✓	✓									✓				
4	[60]	USA	2022													✓	✓	✓		✓	✓	✓	✓	✓	✓		✓			✓	✓		✓	✓			✓	✓			✓	✓												
5	[9]	UK	2015	✓	✓							✓					✓			✓	✓	✓	✓	✓	✓		✓		✓	✓	✓	✓	✓	✓	✓		✓	✓	✓		✓			✓	✓				✓					
6	[61]	Malaysia	2012		✓															✓	✓	✓	✓	✓	✓					✓	✓	✓																						
7	[62]	Nigeria	2018																		✓	✓	✓	✓	✓																									✓				
8	[42]	Australia	2021			✓					✓		✓	✓									✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓				✓	✓	✓	✓			✓						✓					
9	[63]	UK	2008														✓				✓	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓	✓			✓	✓	✓											✓				✓
10	[47]	UK	2012	✓	✓	✓	✓				✓			✓			✓			✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓			✓	✓						✓	✓				✓					
11	[46]	Greece	2015					✓												✓	✓	✓	✓	✓	✓					✓	✓	✓																						
12	[64]	France	2013																																																			
13	[65]	UK	2008	✓		✓	✓	✓	✓	✓	✓	✓											✓	✓						✓	✓	✓	✓	✓	✓		✓												✓					
14	[55]	NZ	2016	✓			✓					✓						✓			✓	✓	✓	✓	✓												✓	✓																
15	[66]	Canada	2016																		✓	✓	✓	✓	✓					✓																								
16	[67]	Hong Kong	2007																								✓														✓													
17	[68]	Serbia	2014														✓	✓	✓	✓	✓	✓	✓	✓	✓					✓	✓	✓					✓	✓						✓	✓									
18	[69]	France	2020																		✓		✓	✓	✓					✓			✓								✓									✓				
19	[70]	Ghana	2021									✓			✓					✓	✓	✓	✓	✓	✓					✓	✓	✓	✓	✓	✓		✓	✓																

20	[71]	The Netherlands	2014	✓							✓									✓	✓	✓	✓	✓	✓		✓										✓							✓	✓								
21	[72]	China	2023									|✓|																											|✓|												
22	[73]	Australia	2005	✓		✓	✓	✓		✓	✓			✓							✓		✓	✓	✓					✓	✓							✓								✓	✓						
23	[50]	Malaysia	2014													✓	✓	✓			✓	✓	✓	✓	✓		✓					✓																		✓			
24	[48]	Egypt	2022	✓	✓						✓	✓	✓					✓			✓		✓	✓	✓												✓	✓						✓	✓					✓			
25	[5]	UK	2002																	✓	✓	✓	✓	✓	✓		✓			✓	✓	✓	✓	✓	✓														✓			
26	[74]	UK	2015																		✓	✓	✓	✓	✓																						✓				
27	[75]	EU	2018		✓			✓									✓			✓	✓	✓	✓	✓	✓		✓			✓	✓		✓	✓			✓		✓		✓									✓			
28	[76]	UK	2004										✓				✓				✓	✓	✓	✓	✓		✓																										
29	[77]	UK	2023														✓				✓	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓	✓			✓	✓													✓		
30	[78]	Australia	2021							✓			✓	✓		✓	✓			✓		✓	✓	✓	✓																												
31	[79]	Singapore	2016	✓						✓										✓	✓	✓	✓	✓	✓												✓	✓						✓	✓								
32	[80]	Australia	2021																	✓	✓		✓	✓	✓					✓	✓	✓																					
33	[81]	Canada	2012																	✓	✓		✓	✓	✓					✓				✓		✓		✓										✓					
34	[82]	UK	2012	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓		✓	✓	✓	✓	✓	✓		✓																										✓				
35	[12]	Canada	2015	✓	✓								✓							✓	✓		✓	✓	✓																✓						✓					✓	✓
36	[83]	UK	2005	✓								✓									✓		✓	✓							✓	✓					✓	✓															
37	[39]	UK	2021	✓	✓	✓	✓				✓			✓			✓			✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓			✓	✓						✓	✓				✓				
38	[84]	Saudi Arabia	2021																	✓	✓	✓	✓	✓	✓					✓																							
39	[85]	Nigeria	2018	✓	✓	✓	✓	✓	✓	✓	✓												✓																						✓								
40	[86]	Australia	2019	✓																																		✓															
41	[87]	The Netherlands	2022																		✓	✓	✓	✓	✓		✓			✓	✓						✓	✓												✓			
42	[88]	UK	2001	✓	✓	✓	✓				✓										✓		✓	✓	✓		✓	✓																						✓			
43	[89]	Switzerland	2022																														✓	✓	✓																		
44	[15]	Australia	2017																								✓														✓		✓										
45	[4]	UK	2003														✓			✓	✓	✓	✓	✓	✓		✓			✓	✓	✓	✓	✓	✓		✓	✓										✓	✓				
46	[54]	UK	2009										✓								✓		✓	✓	✓					✓	✓	✓					✓	✓						✓	✓								
47	[90]	The Netherlands	2009				✓														✓		✓	✓	✓															✓	✓									✓			

48	[91]	UK	2013																		✓	✓	✓	✓	✓												✓	✓																
49	[92]	China	2014										✓	✓			✓				✓	✓	✓	✓	✓																									✓	✓			
50	[49]	Canada	2017														✓				✓	✓	✓	✓	✓					✓	✓							✓			✓													
51	[93]	Japan	2005	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓			✓			✓	✓	✓	✓	✓	✓		✓																											
52	[94]	Nigeria	2021																	✓	✓	✓	✓	✓	✓					✓	✓	✓	✓	✓	✓		✓	✓						✓	✓				✓					
53	[95]	Jordan	2021																																						✓												
54	[96]	Hungary	2022																✓	✓	✓	✓	✓	✓	✓		✓			✓	✓																							
55	[6]	UK	2007	✓		✓					✓	✓					✓			✓	✓	✓	✓	✓	✓		✓			✓	✓	✓																	✓					✓
56	[97]	Nigeria	2006																		✓	✓	✓	✓	✓												✓	✓																
57	[98]	Italy	2020																	✓	✓	✓	✓	✓	✓										✓						✓													
58	[99]	Sri Lanka	2019									✓									✓		✓	✓	✓																													
59	[100]	Republic of Korea	2009	✓	✓	✓	✓				✓	✓					✓				✓	✓	✓	✓	✓													✓										✓	✓					
60	[21]	Canada	2009																	✓	✓	✓	✓	✓	✓						✓			✓				✓	✓				✓											
61	[101]	UK	2007					✓													✓		✓																															
62	[102]	Saudi Arabia	2017																	✓	✓	✓	✓	✓	✓					✓			✓																					
63	[103]	Australia	2016																		✓	✓	✓	✓	✓			✓	✓		✓																							
64	[51]	Malaysia	2016	✓	✓	✓	✓	✓	✓	✓	✓						✓	✓	✓	✓	✓	✓	✓	✓	✓																													
65	[43]	UK	2016														✓				✓	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓	✓			✓	✓	✓											✓				✓
66	[104]	UK	2021	✓	✓	✓					✓	✓		✓						✓	✓	✓	✓	✓	✓		✓			✓	✓	✓	✓	✓	✓		✓	✓	✓					✓	✓	✓			✓	✓				
67	[17]	Finland	2013			✓		✓	✓			✓		✓						✓	✓	✓	✓	✓	✓					✓	✓																							
68	[105]	Czech Republic	2018																	✓	✓		✓	✓	✓																													
69	[7]	UK	2011														✓				✓	✓	✓	✓	✓			✓	✓	✓	✓																							
70	[106]	Ireland	2022																	✓	✓	✓	✓	✓	✓				✓	✓	✓				✓		✓	✓																
71	[107]	UK	2021													✓	✓	✓		✓	✓	✓	✓	✓	✓		✓			✓	✓	✓	✓	✓	✓		✓	✓			✓	✓						✓	✓					
72	[108]	UK	2003																		✓		✓	✓	✓		✓										✓	✓						✓	✓									
73	[109]	USA	2010																	✓	✓	✓	✓	✓	✓					✓	✓																		✓					
74	[110]	Portugal	2013															✓		✓	✓	✓	✓	✓	✓					✓		✓									✓													
75	[111]	UK	2002																	✓	✓	✓	✓	✓	✓																													
76	[112]	Sweden	2000																											✓	✓																							
77	[113]	Canada	2018		✓											✓	✓				✓		✓	✓	✓					✓							✓	✓																

78	[114]	NZ	2015																	✓	✓	✓	✓	✓	✓					✓	✓						✓	✓																
79	[52]	USA	2023													✓	✓	✓		✓	✓	✓	✓	✓	✓		✓			✓	✓		✓	✓			✓	✓			✓	✓												
80	[13]	China	2016																	✓		✓	✓	✓	✓					✓	✓																							
81	[115]	China	2018														✓			✓	✓	✓	✓	✓	✓																													
82	[116]	Sri Lanka	2019																		✓	✓	✓	✓	✓		✓			✓	✓						✓	✓																
83	[117]	UK	2013				✓						✓				✓				✓	✓	✓	✓	✓		✓													✓														
84	[118]	UK	2019																	✓	✓	✓	✓	✓	✓					✓	✓	✓	✓	✓	✓		✓	✓						✓	✓				✓					
	Totals			21	16	14	13	10	6	7	17	14	10	11	1	8	28	9	4	41	71	56	77	74	72	1	25	9	10	45	41	25	21	21	13	1	34	37	8	4	16	4	3	14	15	2	2	3	16	16	2	1	1	3

Appendix B. Retrieved Articles

Item	Author	Title	Origin	Year
1	(AbouHamad & Abu-Hamd, 2019) [57]	Framework for construction system selection based on life cycle cost and sustainability assessment.	Egypt	2019
2	(Ade-Ojo & Fasuyi, 2013) [58]	Cost-In-Use: A panacea for sustainable building development in Nigeria.	Nigeria	2013
3	(Aderogba et al., 2022) [59]	Mass Residential Housing Projects and Sustainable Construction Practices.	Nigeria	2022
4	(Ashtiani & Muench, 2022) [60]	Using construction data and whole life cycle assessment to establish sustainable roadway performance benchmarks.	USA	2022
5	(Ashworth & Perera, 2015) [9]	Cost Studies of Buildings.	UK	2015
6	(Aziz, 2012) [61]	Comparing Conventional to Industrialized Building System Construction Costing: A Case Study of School Building Projects.	Malaysia	2012
7	(BAKARE, 2018) [62]	AN INVESTIGATION ON COMPARATIVE USE OF LIGHT GAUGE STEEL CONSTRUCTION OVER CONCRETE WORKS DEPARTMENT OF CIVIL ENGINEERING.	Nigeria	2018
8	(Ballesty, 2021) [42]	Life Cycle Cost Analysis Information Paper.	Australia	2021
9	(BCIS, 2008) [63]	Standardised Method of Life Cycle Costing for Construction Procurement.	UK	2008
10	(BCIS, 2012) [47]	Elemental Standard Form of Cost Analysis.	UK	2012
11	(Bekas et al., 2015) [46]	Life Cycle Analysis and Optimisation of a Steel Building.	Greece	2015
12	(Bernard et al., 2013) [64]	Product Lifecycle Management for Society.	France	2013
13	(Boussabaine & Kirkham, 2008) [65]	Whole lifecycle costing: risk and risk responses.	UK	2008
14	(BRANZ, 2016) [55]	Study Report SR350 New Zealand whole-building whole-of-life framework: Development of reference office buildings for use in early design.	New Zealand	2016

15	(CACQS, 2016) [66]	Cost Managemnt Best Practice Guide. T. C. A. o. C. Q. Surveyors.	Canada	2016
16	(Chau et al., 2007) [67]	Environmental impacts of building materials and building services components for commercial buildings in Hong Kong.	Hong Kong	2007
17	(Ćirović et al., 2014) [68]	FINANCIAL VALUATION OF CONSTRUCTION INVESTMENT IN SERBIA.	Serbia	2014
18	(Colli et al., 2020) [69]	Investigating eco-efficiency procedure to compare refurbishment scenarios with different insulating materials.	France	2020
19	(Dafeamekpor et al., 2021) [70]	Theoretical framework for assessing self-help housing projects affordability. Sustainable Education and Development.	Ghana	2021
20	(de Jong & Arkesteijn, 2014) [71]	Life cycle costs of Dutch school buildings.	The Netherlands	2014
21	(Dong et al., 2023) [72]	Life Cycle Sustainability Assessment of Building Construction: A Case Study in China.	China	2023
22	(dsr.wa.gov.au, 2005) [73]	A guide for sport and recreation facilities owners and managers.	Australia	2005
23	(Ebrahimi et al., 2014) [50]	Lifecycle framework for sustainable residential buildings in Malaysia.	Malaysia	2014
24	(El Hadidi et al., 2022) [48]	EVALUATION OF A BUILDING LIFE CYCLE COST (LCC) CRITERIA IN EGYPT USING THE ANALYTIC HIERARCHY PROCESS (AHP).	Egypt	2022
25	(El-Haram et al., 2002) [5]	Development of a generic framework for collecting whole-life cost data for the building industry.	UK	2002
26	(Estébanez et al., 2015) [74]	An Integrated Aerospace Requirement Setting and Risk Analysis Tool for Life Cycle Cost Reduction and System Design Improvement.	UK	2015
27	(Estevan et al., 2018) [75]	Life Cycle Costing State of the art report.	EU	2018
28	(Fairey et al., 2004) [76]	Financial analysis and investment appraisal.	UK	2004
29	(FIFE) [77]	whole life costing (+ CO2) user guide.	UK	2023
30	(Figueiredo et al., 2021) [78]	Sustainable material choice for construction projects: A Life Cycle Sustainability Assessment framework based on BIM and Fuzzy-AHP.	Australia	2021
31	(Goh, 2016) [79]	Designing a whole-life building cost index in Singapore.	Singapore	2016
32	(Gov.au, 2021) [80]	Whole-of-Life Costing Guideline.	Australia	2021
33	(Gov.ca, 2012) [81]	Next Generation Fighter Capability: Life Cycle Cost Framework.	Canada	2012
34	(Henjewele et al., 2012) [82]	Analysis of factors affecting value for money in UK PFI projects.	UK	2012
35	(Hossaini et al., 2015) [12]	AHP-based life cycle sustainability assessment (LCSA) framework: a case study of six-storey wood frame and concrete frame buildings in Vancouver.	Canada	2015
36	(Hunter et al., 2005) [83]	A whole life costing input tool for surveyors in UK local government.	UK	2005
37	(ICMS, 2021) [39]	ICMS: Global Consistency in Presenting Construction Life Cycle Costs and Carbon Emissions.	UK	2021
38	(ISBD, 2021) [84]	Guidance Note for the use of Lifecycle Costing (LCC) in Procurement of Goods and Works Contract for IsDB-financed Projects.	Saudi Arabia	2021

39	(Izobo-Martins et al., 2018) [85]	Architects' View on Design Consideration that Can Reduce Maintenance Cost.	Nigeria	2018
40	(Janjua et al., 2019) [86]	Sustainability assessment of a residential building using a life cycle assessment approach.	Australia	2019
41	(Jansen et al., 2020) [87]	A circular economy life cycle costing model (CE-LCC) for building components.	The Netherlands	2022
42	(Johansson, 2001) [88]	A MODULARISATION APPROACH TO HOUSING.	UK	2001
43	(Junior et al., 2022) [89]	Product Lifecycle Management. Green and Blue Technologies to Support Smart and Sustainable Organizations.	Switzerland	2022
44	(Khatri & Moore, 2017) [15]	Achieving Low Life Cycle Cost.	Australia	2017
45	(Kishk et al., 2003) [4]	Whole life costing in construction: a state of the art review.	UK	2003
46	(Manewa et al., 2009) [54,90]	The paradigm shift towards whole life analysis in adaptable buildings.	UK	2009
47	(Manewa, 2009) [90]	Towards economic sustainability through adaptable buildings.	The Netherlands	2009
48	(Meng & Harshaw, 2013) [91]	The application of whole-life costing in PFI/PPP projects.	UK	2013
49	(Mills, 2014) [92]	Smart and Sustainable Built Environment.	China	2014
50	(Moges et al., 2017) [49]	Review and recommendations for Canadian LCCA guidelines.	Canada	2017
51	(Motooka et al., 2005) [93]	Small House Projects in Japan Housing Experiments for Open-Building Concept.	Japan	2005
52	(Nalaya, 2021) [94]	WHOLE LIFE COSTING PRACTICES EMPLOYED BY DESIGN TEAMS OF BUILDING CONSTRUCTION PROJECTS IN ABUJA, NIGERIA.	Nigeria	2021
53	(Nasereddin & Price, 2021) [95]	Addressing the capital cost barrier to sustainable construction.	Jordan	2021
54	(OECD, 2022) [96]	Life-Cycle Costing in Public Procurement in Hungary.	Hungary	2022
55	(OGC, 2007) [6]	Whole-life costing and cost management (Achieving Excellence in Construction Procurement Guide).	UK	2007
56	(Onukwube, 2006) [97]	Whole–Life Costing and Cost Management Framework for Construction Projects in Nigeria.	Nigeria	2006
57	(Paganin et al., 2020) [98]	An integrated decision support system for the sustainable evaluation of pavement technologies.	Italy	2020
58	(Parameswaran et al., 2019) [99]	Analysing the Impact of Location Factors on Building Construction Cost in Sri Lanka.	Sri Lanka	2019
59	(Park, 2009) [100]	Whole life performance assessment: Critical success factors.	Republic of Korea	2009
60	(Perera et al., 2009) [21]	Life cycle costing in sustainable public procurement: A question of value.	Canada	2009
61	(Phillips et al., 2007) [101]	The development of a tender analysis support tool for use in social housing best value procurement.	UK	2007

62	(QABAJA, 2017) [102]	APPLICATION LIFE CYCLE COST ANALYSIS IN THE BUILDING SECTOR IN SAUDI ARABIA.	Saudi Arabia	2017
63	(QTC, 2016) [103]	Whole-Of-Life Costing: A quick guide for elected officials and staff.	Australia	2016
64	(Rahim et al., 2016) [51]	Implementation of life cycle costing in enhancing value for money of projects.	Malaysia	2016
65	(RICS, 2016) [43]	Life Cycle Costing.	UK	2016
66	(RICS, 2021) [104]	NRM3: Order of cost estimating and cost planning for building maintenance works.	UK	2021
67	(Ristimäki et al., 2013) [17]	Combining life cycle costing and life cycle assessment for an analysis of a new residential district energy system design.	Finland	2013
68	(Schneiderova-Heralova, 2018) [105]	Life Cycle Cost Optimisation Within Decision Making on Alternative Designs of Public Buildings.	Czech Republic	2018
69	(SCI-Network, 2011) [7]	Whole Life Costing.	UK	2011
70	(SCSI, 2022) [106]	Guide to Life Cycle Costing.	Ireland	2022
71	(SFT, 2016) [107]	Whole Life Appraisal Tool for the Built Environment.	UK	2021
72	(Shabha, 2003) [108]	A low-cost maintenance approach to high-rise flats.	UK	2003
73	(Shankar Kshirsagar et al., 2010) [109]	Suitability of life cycle cost analysis (LCCA) as asset management tools for institutional buildings.	USA	2010
74	(Silvestre et al., 2013) [110]	From the new European Standards to an environmental, energy and economic assessment of building assemblies from cradle to cradle.	Portugal	2013
75	(Sohlenius & Johansson, 2002) [111]	A framework for decision-making in construction–based on Axiomatic Design.	UK	2002
76	(Sterner, 2000) [11]	Lifecycle costing and its use in the Swedish building sector.	Sweden	2000
77	(Teshnizi et al., 2018) [113]	Lessons learned from life cycle assessment and life cycle costing of two residential towers at the University of British Columbia.	Canada	2018
78	(treasury.govt.nz, 2015) [114]	The whole of Life Costs Guidance	New Zealand	2015
79	(Vasishta et al., 2023) [52]	Comparative life cycle assessment (LCA) and life cycle cost analysis (LCCA) of precast and cast–in–place buildings in the United States.	USA	2023
80	(Wang, 2016) [13]	The application of the life cycle cost concept in government procurement.	China	2016
81	(Wang, 2018) [115]	Life Cycle Cost Management of Fixed Assets in Chinese Power Grid Enterprises.	China	2018
82	(Withanage et al., 2019) [116]	Financial viability of using green roofing in residential buildings.	Sri Lanka	2019
83	(Zahirah et al., 2013) [117]	Soft cost elements that affect developers' decision to build green.	UK	2013
84	(Zanni et al., 2019) [118]	Standardisation of whole-life cost estimation for early design decision-making utilising BIM.	UK	2019

Appendix C. Pairwise Comparison

Pairwise Comparison for Polarity	Building Type/Functionality	Building Element/Orientation	No. of Floors/Height/Level above and below Ground	Construction Technology	Energy Saving Measures and Cost	Shape of Facility	Estimated Annual Occupancy Hours	Gross Floor Area (GFA)	Location	Context or Purpose Determined by Stakeholders	Design Inputs	Method of Financing	Carbon Sequestration	Government Regulations	Environmental Cost	Externalities	Residual Value	Demand and Supply of Materials	Materials Availability/Service Life	Real Cost	Nominal Cost	Time Value of Money	Discount Rate	Income Generates from the Asset	Taxation	Inflation	Rate of interest	Foreign Exchange	Building Life	Period of Analysis	Legislative, Statutory or Economic Changes	Technology and Tools	Environmental Impact Evaluation	Green Building Certification Cost	Variation in Various Cost	Replacement Frequency	Maintenance Frequency	Consideration of Design Alternatives	Renewable Resources Used	Level of Uncertainty	Risk Allowances	Waste Management Cost	Continuity of Supply Chain	Seismic Resistance	Fire Resistance	Insurances
Building type/functionality							Figueiredo, 21 +ve			Shankar, 10 +ve	Figueiredo, 21 +ve Shankar, 10 +ve		Figueiredo, 21 +ve	Figueiredo, 21 +ve																																
Building element/orientation														Teshnizi, 18 +ve Vasishta, 23 +ve																																
No. of floors/height/level above and below ground/size																																														
Construction technology	Motooka, 05 +ve	Motooka, 05 +ve	Motooka, 05 +ve			Motooka, 05 +ve		Motooka, 05 +ve	Motooka, 05 +ve																																					

Energy saving measures and cost			Ristimäki, 13 +ve					Ristimäki, 13 +ve	Ristimäki, 13 +ve													Ristimäki, 13 +ve	Ristimäki, 13 +ve						Ristimäki, 13 +ve	Ristimäki, 13 +ve																
Shape of facility																																														
Estimated annual occupancy hours																																														
GFA																																														
Location																														moges, 17 +ve																
Context or purpose determined by stakeholders																																														
Design inputs	Motooka, 05 +ve	Motooka, 05 +ve	Motooka, 05 +ve			Motooka, 05 +ve		Motooka, 05 +ve	Motooka, 05 +ve	Manewa, 09 +ve																																				
Method of financing										Ćirović, 14 +ve Ashworth, 15 +ve Ashworth, 15 +ve RICS, 16 +ve RICS, 21 +ve Boussabaine, 08 +ve													Ashworth, 15 +ve RICS, 16 +ve RICS, 21 +ve BCIS, 12 +ve		Ashworth, 15 +ve RICS, 16 +ve RICS, 21 +ve BCIS, 12 +ve	Ashworth, 15 +ve RICS, 16 +ve RICS, 21 +ve BCIS, 12 +ve	Ashworth, 15 +ve RICS, 16 +ve RICS, 21 +ve BCIS, 12 +ve																			

Carbon sequestration		Teshnizi, 18 +ve Vasishta, 23 +ve																													
Government regulations/ fees																									Ashworth, 15 +ve RICS, 16 +ve RICS, 21 +ve BCIS, 12 +ve						
Environmental cost		Vasishta, 23 +ve			Silvestre, 13 −ve																										
Externalities																															
Residual value	Figueiredo, 21 +ve Ashworth, 15 +ve RICS, 16 +ve RICS, 21 +ve BCIS, 12 +ve	Bekas, 15 +ve			Ristimäki, 13 +ve				Moges, 17 −ve	Ashworth, 15 +ve RICS, 16 +ve RICS, 21 +ve	Ebrahimi, 14 +ve Rahim, 16 +ve										Peganin, 20 −ve Ashworth, 15 −ve RICS, 16 −ve RICS, 21 −ve BCIS, 12 −ve							Gov, 21 −ve El Hadidi, 22 −ve	Gov, 21 −ve El Hadidi, 22 −ve	QTC, 16 −ve DSR, 05 −ve Gov, 21 −ve

Demand and supply of materials						Gov, 21 +ve	Gov, 21 +ve Ashworth, 15 +ve RICS, 16 +ve	Janjua, 19 +ve	Gov, 21 +ve		
Materials availability/service life	Chua, 07 +ve							Janjua, 19 +ve		Colli, 20 +ve Chua, 07 +ve	Chua, 07 +ve
Real cost							Ashworth, 15 +ve RICS, 16 +ve RICS, 21 +ve				
Nominal cost							Ashworth, 15 +ve RICS, 16 +ve RICS, 21 +ve				

Time value of money			Ballesty, 21 +ve Gov, 21 +ve SCSI, 22 +ve Ashworth, 15 +ve RICS, 16 +ve RICS, 21 +ve Boussabaine, 08 +ve BCIS, 12 +ve Kishk, 03 +ve		SCSI, 22 +ve	Peganin, 20 +ve	SCSI, 22 +ve	SCSI, 22 +ve Gov.ca, 18 +ve ICMS, 21 +ve
Discount rate					Hunter, 05 +ve			Ballesty, 21 +ve Moges, 17 +ve Kishk, 03 +ve
Income generates from the asset	BCIS, 08 +ve						Hunter, 05 +ve	

Taxation	RICS, 16 +ve Ashworth, 15 +ve RICS, 16 +ve RICS, 21 +ve BCIS, 12 +ve					Ashworth, 15 +ve RICS, 16 +ve					Ashworth, 15 +ve RICS, 16 +ve RICS, 21 +ve BCIS, 12 +ve
Inflation										Gov.ca, 18 +ve Ashworth, 15 +ve RICS, 16 +ve RICS, 21 +ve BCIS, 12 +ve	Ashworth, 15 +ve RICS, 16 +ve RICS, 21 +ve BCIS, 12 +ve
Rate of interest		Kishk, 03 +ve	Hunter, 05 +ve		Ashworth, 15 +ve RICS, 16 +ve RICS, 21 +ve	Ashworth, 15 +ve RICS, 16 +ve RICS, 21 +ve			Manewa, 09 +ve	Manewa, 09 +ve	
Foreign exchange										Gov.ca, 18 +ve	

Building life	Janjua, 19 +ve AbouHamad, 19 +ve Goh, 16 +ve	Janjua, 19 +ve Teshnizi, 18 +ve	Janjua, 19 +ve	Ashworth, 15 +ve		Janjua, 19 +ve				Manewa, 09 +ve	Ashworth, 15 +ve RICS, 16 +ve RICS, 21 +ve			Ashworth, 15 +ve RICS, 16 +ve RICS, 21 +ve	Janjua, 19 +ve															Janjua, 19 +ve Ballesty, 21 +ve	Ashworth, 15 +ve RICS, 16 +ve RICS, 21 +ve BCIS, 12 +ve															
Period of analysis															Janjua, 19 +ve																															
Legislative, statutory or economic changes																																														
Technology and tools																			Ćirović, 14 +ve																											
Environmental impact evaluation					Hossaini, 15 −ve																													Naseredin, 21 +ve												
Green building certification cost														Naseredin, 21 +ve																																
Variation in various cost																																														

Replacement frequency																													Ashworth, 15 +ve RICS, 16 +ve RICS, 21 +ve BCIS, 12 +ve																
Maintenance frequency																													Ashworth, 15 +ve RICS, 16 +ve RICS, 21 +ve BCIS, 12 +ve																
Consideration of design alternatives	AbuHamad, 19 +ve	AbuHamad, 19 +ve	AbuHamad, 19 +ve				Schneiderova, 18 +ve	Schneiderova, 18 +ve			Schneiderova, 18 +ve															Ashworth, 15 +ve RICS, 16 +ve RICS, 21 +ve BCIS, 12 +ve													Schneiderova, 18 +ve		Schneiderova, 18 +ve	Rahim, 16 +ve				

Renewable resources used	BRANZ, 16 +ve	BRANZ, 16 +ve	BRANZ, 16 +ve Ristimäki, 13 +ve					BRANZ, 16 +ve	BRANZ, 16 +ve					BRANZ, 16 +ve																																
Level of uncertainty									moges, 17 +ve																					Gov.ca, 18 +ve Ashworth, 15 +ve RICS, 16 +ve RICS, 21 +ve BCIS, 12 +ve					Ashworth, 15 +ve RICS, 16 +ve RICS, 21 +ve BCIS, 12 +ve											
Risk allowances																																			Ashworth, 15 +ve RICS, 16 +ve RICS, 21 +ve BCIS, 12 +ve					Ashworth, 15 +ve RICS, 16 +ve RICS, 21 +ve BCIS, 12 +ve						
Waste management cost											Rahim, 16 +ve																							Ebrahimi, 14 +ve													
Continuity of supply chain																																														

Seismic resistance	Hossaini, 15 +ve	
Fire resistance	Hossaini, 15 +ve	
Insurances		

Positive polarities are represented in blue and negative in red.

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