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Systematic Review

A Systematic Literature Review of the Adoption of Building Information Modelling (BIM) on Life Cycle Cost (LCC)

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Abstract: The need for embedding sustainability in construction development contributed to the introduction of Building information Modelling (BIM) to be adopted into the Life Cycle Cost (LCC) process. Through BIM, project information used during design can be shared to estimate the project's end of life costs. LCC enables to assess the overall cost of an asset (building) through its life cycle via functionalities including the original investment costs, maintenance expenses, operating expenses, and the remaining value of the asset at the end of its life. The objective of this paper is to discuss the merging of BIM into LCC through four prevalent aspects; methodology, design software used, benefits, and challenges. A total of 20 studies were reviewed upon filtering process using PRISMA method. These studies discussed at least one of the aspects mentioned and contributed to the information regarding BIM and LCC. This paper thus aims to expanding studies on BIM adoption on LCC through the collected information sourced from peer-reviewed publications.

Keywords: building information modelling; life cycle cost; BIM; LCC

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1. Introduction

The impact of climate change and the related issues have increasingly become a subject of research amongst a wide range of scientific disciplines [1]. In Engineering, attending the Climate Emergency is therefore at the top of the priorities for present and future generations [2]. According to Obrecht et al. [3], buildings are the major contributor to the climate change generating as much as 40–50% of the world greenhouse gas emissions and 30–40% of the world energy consumption [4]. Although these record will soon be outdated given the speed of progress of buildings development around the world, these depict the level of challenge we all share and understand. This has prompted professionals involved in developing the built environment to devise strategies for mitigating the impact to society. Along those lines, the life cycle cost (LCC) of an asset or component now integrates BS ISO 15686–5 as "cost of an asset or its parts throughout its lifecycle, while fulfils the performance requirements" [5]. The integration of life cycle assessment (LCA) and LCC methodologies expected to create or enhance mechanisms for minimizing the buildings impact towards environment [6]. Furthermore, BIM is now identified as an effective platform to enable the prediction of LCC in various stages of design [5,7–10], one being through the integration of Building Information Modelling (BIM).

BIM facilitates the interaction of two separate systems or software programs [11]. Takim et al. [12] in fact describe BIM as a computer-generated model to stimulate all four aspects of planning, design, construction and operation of a building in a project. These technologies allow users to generate a visual simulation of a design by constructing a digital prototype of a building before construction, as opposed to the previous method of manually exchanging information amongst design consultants, for example through the import/export of data using 3D drawing packages and computer aided design (CAD) programs. For modern urban developers, the information exchange involves civil, mechanical and electrical interphase with subsets, such as mechanical, electrical, and plumbing (MEP) drawing packages operated by the technical specialists. It is noteworthy that different levels of familiarity in these approaches sometimes leads to a complex understanding or misunderstanding of data exchange protocols which might cause delays, site disruptions, disputes etc. in on-going construction projects. Hence, we are currently in the middle of a transition period of education and training.

According to Sun et al. [13], Basbagill et al. [14], and others, BIM increases productivity, overcomes accessibility of classical CAD applications, improves workflow, informs stakeholders as works progress, reduces risks of design error, and most importantly, enhances the communication and coordination among the project team members. Similarly, Altaf et al. [15] highlight that the interactions between BIM and LCC reduces inconsistencies in cost evaluation, whereas the adoption of BIM—Life Cycle Cost Analysis (LCCA) in the planning stage can reduce the Operation and Maintenance cost and energy consumption overall.

The above suggests that the adoption of BIM is likely to expand and speed up the practice of the process of estimating the LCC without mistakes or omissions in project quantities. Additionally, it saves time throughout the computation process and expedites decision-making. Its capabilities would help to minimise effort when completing a LCA while enabling data blocks naturally feeding into LCC [3]. LCC is defined as an objective method for assessing the total cost of assets over entire life cycles [16]. The asset residual value at the end of its life is calculated based on the initial capital costs, maintenance costs, operating costs, and the ongoing maintenance costs of the asset.

It is worth to note that the adoption of LCC methodologies is now recommended by The Royal Institution of Chartered Surveyors (RICS) and other international standards such as ISO 15686–5 [17,18]. Those standard addresses all the issues of LCC implementation including maps for interpreting technical terminology. The standards also differentiate LCC from WLC in what refers to Whole Life Cost. While LCC focuses on the direct economic evaluation of an asset building, WLC is broad, encompassing LCC aspects, externalities such as environmental costs and income factors and non-construction costs. Figure 1 illustrates LCC aspects.

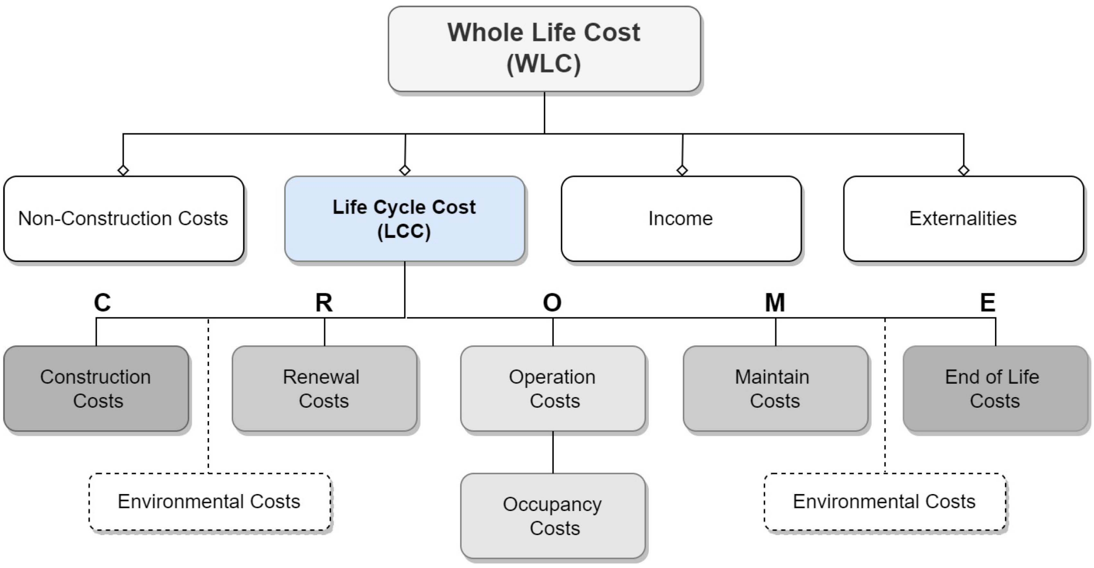


Figure 1. The difference between LCC and WLC [17].

However, WLC is affected by external evaluation factors for example non-construction costs are that acquisition costs, fees, rental costs, and applicable taxes. Furthermore, externalities are costs unrelated to the building's assets, such as the opportunity costs of capital that return from the project's benefits. In addition, income is the future income of the project because of the investment. Also, as the environmental analysis required a long period of analysis, often for the whole life cycle of the building, LCC analysis did not directly address the environmental costs impacts.

In reflection to code recommendations and academic reports, Marzouk et al. [5], Biolek and Hanak [19] and others reinforced the idea that the cost of a building project should be calculated for its entire life cycle. The calculation of the LCC can enhance the decision-making process to lead to appropriate judgements on the performance of the building through its lifecycle. The features of BIM that equips users with visual tools and detailed information of activities and materials can therefore increase accuracy and consistency of LCC results [20].

The present paper provides a systematic review on the current adoption practice on the implementation of the Building Information Modelling (BIM) on Life Cycle Cost (LCC). It focuses on methodologies, software capabilities, benefits and challenges imposed by the adoption of innovative information management technologies.

2. Methodology

Systematic reviews have been conducted using Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) recommended by Page et al. [21]. The following paragraphs describe the data mining process and its key outcomes

2.1. Search Strategy

Electronic databases namely (Web of Science, Google Scholar, Scopus and Science Direct) were utilised for the systematic search of the relevant publications. This study targeted articles that were published between 2012 and 2021, in English.

2.2. Key Terms Search

The following keywords, descriptions and their combinations were used placed with Boolean operators of "And" and "Or" to search the relevant articles: "Building Information Modelling", "BIM", "Life Cycle Cost", "LCC", "Building Information Modelling and Life Cycle Cost", "BIM and LCC". Three specific keywords were used: "BIM on LCC", "BIM adoption LCC", and "BIM design on LCC".

2.3. Inclusion and Exclusion Criteria of the Study

The search pre-selected articles strongly related to BIM and LCC in construction or built environment industry. The inclusion criteria were first the articles should have been written by valid scholars and second, they should have been published in indexed journals within the last 10 years i.e., the period 2012–2021. Table 1 shows the inclusion and exclusion consideration of the search criteria.

Table 1. Inclusion and exclusion criteria.

Consideration Factors	Inclusion Criteria	Exclusion Criteria
Types of studies	The empirical studies involving qualitative, quantitative, mixed-method, pilot study, meta-analyses	Editorial letters, government's documents, expert opinions, policy brief, and other non-primary research
Types of topics covered	Any topics that included the BIM and LCC in relevant field of construction and engineering.	Topics of BIM, LCC in other fields.

Table 1. *Cont.*

Consideration Factors	Inclusion Criteria	Exclusion Criteria
Types of publications	Indexed-Journal such as Scopus, Web of Science, Elsevier, Science Direct, and Conference Proceedings in Scopus	Books publications, newspapers, anonymous articles, commercial articles, profitable documents
Types of outcomes	Outcomes related to BIM and LCC generally, benefits, challenges, methodologies, and software analyses during design phase regarding BIM adoption on LCC	Outcomes that are not related to the inclusion criteria

3. Search Outcomes

The search engines, Web of Science, Google Scholar, Scopus and Science Direct, identified 655 relevant titles to the keywords of "BIM on LCC" for the period of 2012–2021. The Web of Science reported 268 articles, Google Scholar did so with 53 articles, Science Direct 56 articles, and Scopus 278 articles by using similar keyword and time-frame. Following, a second search was undertaken with the keywords "BIM adoption LCC". This identified 56 articles in the Web of Science Database, 19 in Google Scholar, 37 in Science Direct, and 57 in Scopus. Lastly, the keyword "BIM design on LCC" was used resulting in 67 articles in Web of Science, 15 in Google Scholar, 19 in Science Direct, and 49 in Scopus. As demonstrated in Figure 2.

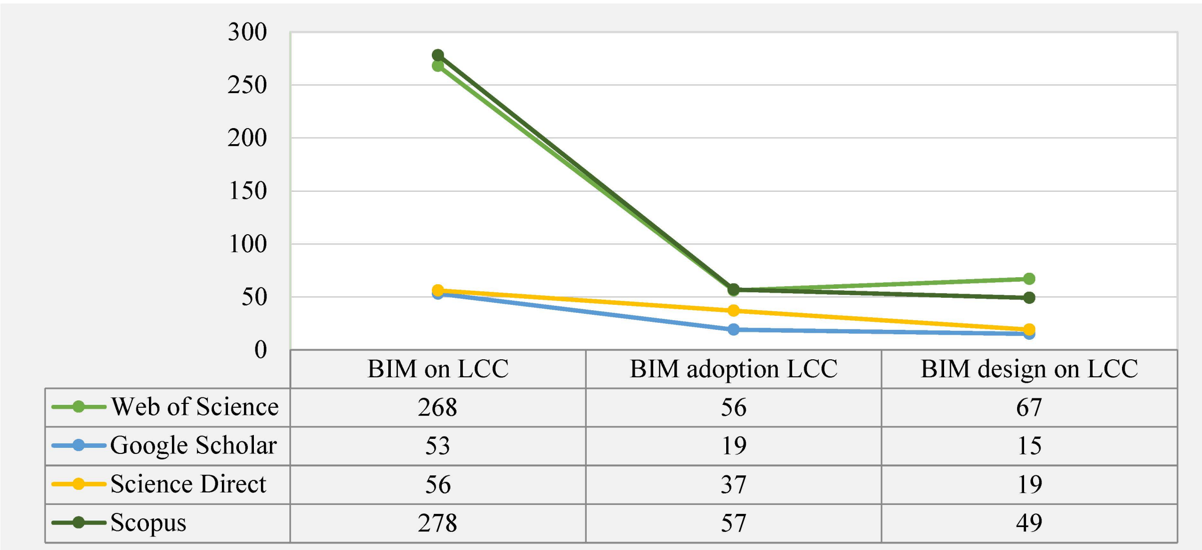


Figure 2. Screening and classification of the articles.

The selection of the articles then went into the inclusion and exclusion filtering criteria. There were 21 articles reviewed for legibility. However, one of them were excluded due to irrelevancy, thus making the number of the final articles for review purpose twenty (20). Figure 3 shows the flowchart of the PRISMA filtering process based on the inclusion and exclusion criteria for this study.

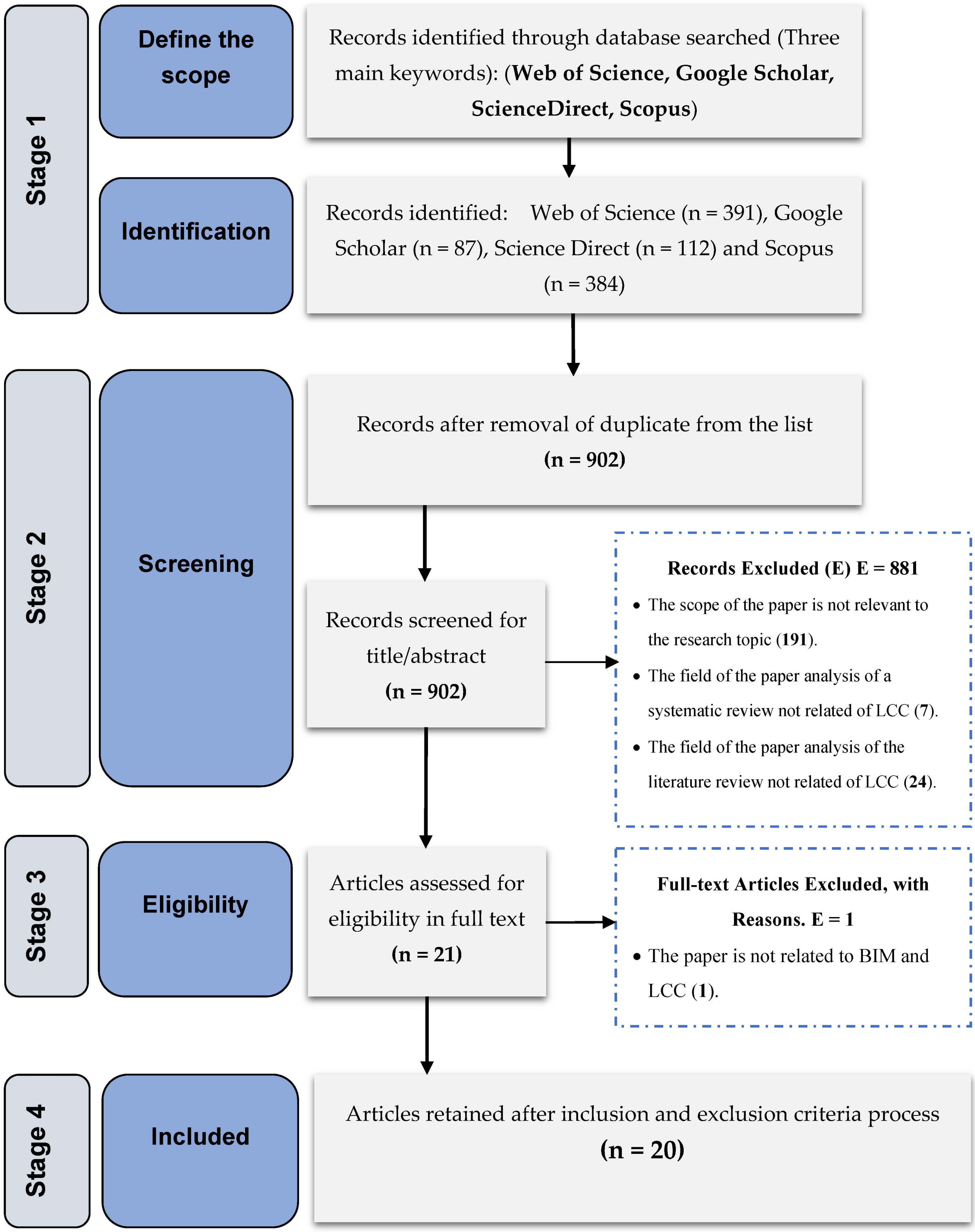


Figure 3. The details of the flow-chart of the systematic review process (PRISMA).

The findings indicate that 2.05% of articles were approved through the database. The main reason for the limited acceptance rate of articles is that search engines aggregate articles based on their keywords. As a result, the search strategy was significant to classify publications according to previously defined approaches and acceptance and rejection criteria. Figure 4 shows the classification of papers accepted and rejected.

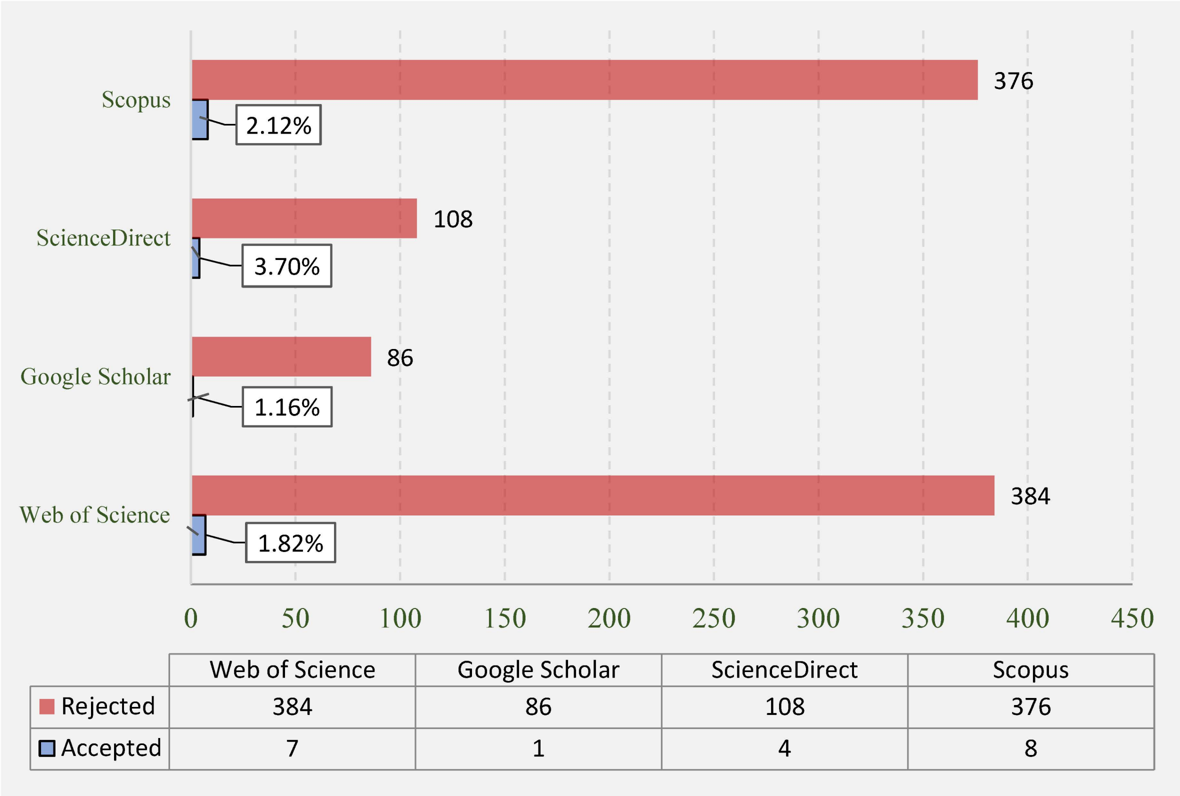


Figure 4. Number of accepted and rejected articles.

Rationale of the Selected Studies

Following the above search approach there were 20 articles extracted. The latter contained the review aspects being the benefits, challenges, methodologies, and software analyses during design phase regarding BIM adoption on LCC. Table 2 presents detailed information contained in the selected articles based on each review aspect (methodology, benefits, challenges, and software designs). Table 3 presents detailed information for each article in line with the content of the review aspects.

Table 2. The selected articles with regard to the review aspects.

No	Keyword Used	Source of Journals	Articles Title	Review Aspects in the Articles
1	BIM on LCC	Journal of Cleaner Production	BIM-based Approach for Optimizing Life Cycle Costs of Sustainable Buildings [5]	Methodology Benefits Software
2	BIM on LCC	Journal of Cleaner Production	Development of a BIM-based Environmental and Economic Life Cycle Assessment tool [6]	Methodology Benefits Software
3	BIM on LCC	Energy and Buildings	Building information modeling based building design optimization for sustainability [22]	Methodology Benefits Challenges Software

Table 2. *Cont.*

No	Keyword Used	Source of Journals	Articles Title	Review Aspects in the Articles
4	BIM adoption LCC	Journal of Information Technology in Construction	Embedding life cycle costing in 5d BIM [23]	Methodology Benefits Challenges Software
5	BIM on LCC	Building and Environment	BIM-based life cycle assessment and life cycle costing of an office building in Western Europe [24]	Methodology Benefits Challenges Software
6	BIM adoption LCC	Innovative Infrastructure Solutions	BIM-based LCA assessment of seismic strengthening solutions for reinforced concrete precast industrial buildings [25]	Methodology Benefits Challenges Software
7	BIM design on LCC	Journal of Asian Architecture and Building	BIM-based preliminary estimation method considering the life cycle cost for decision-making in the early design phase [26]	Methodology Benefits Challenges Software
8	BIM adoption LCC	Engineering Journal	A BIM-Integrated Relational Database Management System for Evaluating Building Life-Cycle Costs [27]	Methodology Benefits Challenges Software
9	BIM adoption LCC	International Journal of Sustainable Development	Integration of Life Cycle Data in a BIM Object Library to Support Green and Digital Public Procurements [28]	Methodology Benefits
10	BIM adoption LCC	Sustainable Cities and Society	An integrated life cycle assessment of different façade systems for a typical residential building in Ghana [29]	Methodology Benefits Software
11	BIM design on LCC	Automation in Construction	BIM-based approach to conduct Life Cycle Cost Analysis of resilient buildings at the conceptual stage [30]	Methodology Benefits Software
12	BIM design on LCC	Automation in Construction	A performance data integrated BIM framework for building life-cycle energy efficiency and environmental optimization design [31]	Methodology Benefits Software
13	BIM adoption LCC	Journal of Cleaner Production	Integration of life cycle assessment and life cycle cost using building information modeling: A critical review [32]	Methodology Benefits Challenges
14	BIM on LCC	Automation in Construction	Integration of LCA and LCC analysis within a BIM-based environment [33]	Methodology Benefits Challenges Software
15	BIM on LCC	Journal of Building Engineering	Simulation-Based Multi-Objective Optimization of institutional building renovation considering energy consumption, Life-Cycle Cost and Life-Cycle Assessment [34]	Methodology Benefits Software
16	BIM adoption LCC	Journal of Building Performance	The Implementation of Life Cycle Costing towards Private Client's Investment: The Case of Malaysian Construction Projects [35]	Methodology Benefits Challenges
17	BIM adoption LCC	Sustainability	BIM-Based Life Cycle Assessment of Buildings—An Investigation of Industry Practice and Needs [36]	Methodology Challenges Software

Table 2. *Cont.*

No	Keyword Used	Source of Journals	Articles Title	Review Aspects in the Articles
18	BIM on LCC	Applied Sciences	BIM-Based Approach to Simulate Building Adaptive Performance and Life Cycle Costs for an Open Building Design [37]	Methodology Benefits Software
19	BIM on LCC	Journal of Information Technology in Construction	Implementing life-cycle costing: Data integration between design models and cost calculations [38]	Methodology Benefits Challenges Software
20	BIM on LCC	Mathematical Problems in Engineering	BIM application to select appropriate design alternative with consideration of LCA and LCCA [39]	Methodology Benefits Challenges Software

Table 3. Details of selected articles.

Reference No	The Description	
[5]	**Article Title**	BIM-based Approach for Optimizing Life Cycle Costs of Sustainable Buildings **Article Focus:** To propose an integrated BIM framework by using Algorithm optimization and Monte Carlo Simulation that aids in LCC prediction. ***(Case Study)***
	Methodology	Integration of BIM through 2 models: Monte-Carlo simulation and Optimization model. 1. BIM through Revit software allows different material data to be exported into a simulation model, such as masonry concrete, paints, plastering, flooring, etc. 2. The evaluation of LCC is done through the Simulation Model (Monte-Carlo Simulation). 3. Using a simulation model, the function is extracted from the Optimization Model (Utilizing the Genetic Algorithms (GA)). 4. This approach minimises the LCC of construction materials by identifying the optimal scenarios.
	Benefits	The Integration of BIM with Monte-Carlo Simulation and Optimization Modelling helps decision-makers select sustainable material selection from an environmental and economic perspective, thus predicting its LCC and the highest amount of LEED-Credits Scores possible during the evaluation.
	Challenges	NONE
	BIM-Design Software Used	Autodesk Revit [40].
[6]	**Article Title**	Development of a BIM-based Environmental and Economic Life Cycle Assessment tool **Article Focus:** Proposing the BIMEELCA Tool as one of the methodologies to integrate BIM and LCC. ***(Case Study)***
	Methodology	1. BIMEELCA Tool 2. In LCC analysis, the establishment of common measures that relate to an environmental effect category and a purchase cost would be automated. 3. The parameters allow user to visualise a window containing information on the elements and materials inserted in the model as well as useful information to perform the analyses. 4. Choosing the functionality for environmental and economic evaluation of each element. (Streamlined LCA/LCC Analysis)
	Benefits	• The presentation of a functioning BIMEELCA tool that enables users to enter the necessary data into the Bim for the LCC analysis. • The BIMEELCA tool procedure involves integrating spreadsheet data into the model and generating an automated quantity take-off, culminating in an automated Optimized LCC analysis.
	Challenges	NONE
	BIM-Design Software Used	Autodesk Revit [40].

Table 3. *Cont.*

Reference No	The Description	
[22]	**Article Title**	Building information modeling based building design optimization for sustainability **Article Focus:** To build a BIM-based multi-objective optimization framework to aid designers in identifying and selecting the ideal carbon dioxide emissions and cost commutation design plan for their customers. ***(Case Study)***
	Methodology	Stages were taken to integrate BIM modelling, simulation, thermal and lighting performance analysis, and database functions: 1. Adopted a BIM-based building design optimization model. 2. The 3-D models were adopted and developed in the BIM systems. 3. In the database, all critical location, climate, and material information has been collected. 4. The Ecotect software was used in the analysis. For the purposes of optimization, the researchers utilized MOPSO to find the optimal design scheme.
	Benefits	• The BIM model allowed the researchers to incorporate sustainability-related information such as carbon emissions during the first phases of the project. • The BIM enabled the researchers to estimate the maintenance costs during the first phases of the project. • The BIM proved to be a multi-objective model that can help designers design a building that meets multiple sustainability requirements. • Designer can easily check for reasonability and mistakes because the designs are visible visually
	Challenges	The BIM does not have its own database and therefore, the researchers have to rely on inputting new data.
	BIM-Design Software Used	Ecoect software [41].
[23]	**Article Title**	Embedding life cycle costing in 5d BIM **Article Focus:** The purpose of this study is to determine whether LCC can be effectively integrated into a 5D BIM platform. ***(Case Study)***
	Methodology	• An approach to apply LCC calculation structures in 5D BIM technology (CostX) as an extension to the 5D BIM process. • The CostX enables a quick and accurate take off quantities from 2D dwgs and BIMs. • LCC calculations were then embedded into (Workbook of) CostX.
	Benefits	• Highlights the benefits of 5D BIM software, which is able to accommodate variable conditions (such as those in probabilistic LCC analysis) with greater computing power than BIM design software (such as Revit or Archicad). • It is proposed that the proposed process provides an integrated environment that links the cost plans/BOQs of the QS with the LCC calculations.
	Challenges	• Lack of standardization of the proposed LCC structure of calculation • Benefits of LCC cannot be realised due to lack of demand by clients
	BIM-Design Software Used	Autodesk Revit [40].

Table 3. *Cont.*

<table>
<tr><th>Reference No</th><th colspan="2">The Description</th></tr>
<tr><td rowspan="5">[24]</td><td>Article Title</td><td>BIM-based life cycle assessment and life cycle costing of an office building in Western Europe.
Article Focus:
Reviewing the BIM and LCC integration through an office building.
(Case Study)</td></tr>
<tr><td>Methodology</td><td>6 Steps Approaches:
1. Merging all models (architectural and structural) into a single model.
2. Utilize the exported list to analyze BIM model information.
3. Check the exported list to identify duplicates.
4. In order to enable LCC tools to correctly read bills of quantities, the entire project was homogenized.
5. A project that includes information on the environment, economics, and mechanical aspects.
6. Make a list of all the materials and elements in the project (XLS spreadsheet).
7. It is possible to conduct an LCC analysis that is streamlined and comprehensive. (Streamlined LCA/LCC Analysis)</td></tr>
<tr><td>Benefits</td><td>• Incorporating information freely into the LCC calculation is possible.
• The nature of flexibility in the integration of BIM tools with LCC external database.
• Through the selection of sustainable materials and appropriate products in accordance with the remaining service life of the building, the BIM-LCC framework promotes the use of sustainability-related methodologies early in the process.</td></tr>
<tr><td>Challenges</td><td>A complete analysis of a project is carried out with the help of the users, such as designers and LCC experts.</td></tr>
<tr><td>BIM-Design Software Used</td><td>(Athena software [42]—Tally software [43])</td></tr>
<tr><td rowspan="5">[25]</td><td>Article Title</td><td>BIM-based LCA assessment of seismic strengthening solutions for reinforced concrete precast industrial buildings
Article Focus:
Analysing the costs and environmental impacts through adoption of BIM-LCA/LCC calculation
(Case Study)</td></tr>
<tr><td>Methodology</td><td>1. Application of BIM methodology through modeling of the buildings.
2. It is the goal and scope of each case, as well as the inventory and environmental impact assessment, that determine the LCA assessment.
3. A 50-year period was considered for the LCC calculation of constructing the new building and demolishing it, whereas seismic reinforcement and demolition costs associated with demolishing the precast elements of the existing building were considered for a 20-year period.</td></tr>
<tr><td>Benefits</td><td>Based on a Life Cycle Assessment and Life Cycle Costing analysis, renovating the existing building appears to be the most advantageous option, since it has a significantly lower environmental impact and reduces carbon emissions by up to 128.5 times while resulting in a 3.79 times lower cost than a new building.</td></tr>
<tr><td>Challenges</td><td>There was LCC uncertainty between the actual costs of implementing and destroying precast parts and seismic reinforcement. At the same time, there were no estimates for a 50-year service life, so inflation was excluded from the calculations.</td></tr>
<tr><td>BIM-Design Software Used</td><td>Autodesk Revit [40].</td></tr>
</table>

Table 3. *Cont.*

Reference No	The Description	
[26]	**Article Title**	BIM-based preliminary estimation method considering the life cycle cost for decision-making in the early design phase. **Article Focus:** To propose a BIM integrated method to support decision-making capable to predict LCC. ***(Case Study)***
	Methodology	4 Procedures of Estimating LCC based on BIM 1. Based on the Linking of BIM model information and the preliminary estimate prototype, extract the basic information of the project outline and BIM model. 2. Establishing a database of performance cost and reference data in order to form the preliminary estimation algorithm. 3. The information extracted from the databases is used by system linking to connect the database base information. 4. BIM-based preliminary estimation uses similar cost and standard data in order to provide designers with LCCs based on their design alternatives. (Because tthe estimate is based on the mass model in the early stages of the design proces).
	Benefits	• It is possible to provide LCC using BIM in the early stages of the design process based on accurate preliminary estimations and alternative approaches. • This information can be used by clients and designers to make informed decisions.
	Challenges	• Estimating the cost of a building type that is not included in the constructed database can be challenging. • It is important to keep in mind that in addition to the estimation criteria, the government established its own standard that results in limited classification and scope, which makes estimating LCCs more difficult.
	BIM-Design Software Used	Autodesk Revit [40].
[27]	**Article Title**	A BIM-Integrated Relational Database Management System for Evaluating Building Life-Cycle Costs **Article Focus:** To develop integrated BIM database system capable to utilize LCCA. ***(Case Study)***
	Methodology	The development of BIM-integrated relational database management system (RDBMS) with 2 interrelated modules: • Visualised BIM-Integrated Module and Relational Database Management Module. • The data can be collected, organized, stored, and used in conjunction with either of the two methodologies to construct LCCA.
	Benefits	• In developing a BIM-integrated RDBMS, the components of the database management system, the BIM authoring system, the spreadsheet system, and the visual programming interface are integrated to reduce the calculation time. • To reduce or eliminate data loss as well as inconsistencies due to human error, which will result in more accurate results.
	Challenges	• Current BIM tools are not capable to manage the required data into LCCA process. • Various tools and formats are incompatible with each other because of unstructured data. • It is challenging to segregate standards, calculation methods, and interoperable technologies.
	BIM-Design Software Used	Autodesk Revit [40].

Table 3. *Cont.*

Reference No		The Description
[28]	**Article Title**	Integration of Life Cycle Data in a BIM Object Library to Support Green and Digital Public Procurements **Article Focus:** To review an evaluation system and a workflow in consideration of life cycle of a construction. ***(Review)***
	Methodology	3 Approaches of integration BIM-LCC: 1. Uses of several software such as SimaPro, CostLab, Excel etc to conduct LCC. 2. An LCC database is connected to a quantity generated by a BIM model. 3. The LCC data is directly integrated into the BIM model.
	Benefits	• It is possible to optimize the performance of buildings in terms of both environmental and economic factors. • Transactions have been completed in a shorter amount of time. • Productivity has increased. • A greater level of transparency has been achieved. • Sustainability has been enhanced.
	Challenges	NONE
	BIM-Design Software Used	NONE
[29]	**Article Title**	An integrated life cycle assessment of different façade systems for a typical residential building in Ghana **Article Focus:** To design an integrated framework of BIM, LCA and LCC to perform comparative analysis of 4 different facades systems in Ghana. ***(Case Study)***
	Methodology	This project integrates BIM, LCA and LCC for the purpose of comparing (1) Shotcrete Insulated Composite Façade (Shotcrete ICF), (2) Galvanized Steel Insulated Composite Façade (G. Steel ICF), (3) Stabilized Earth Block Façades (SEBF). As opposed to traditional Concrete Block and Mortar Façade (CBMF) Method: 1. Revit is used to develop a BIM model based on a case study building constructed with CBMF. 2. Three other facades were developed separately using BIM. 3. Each model undergoes a Life Cycle Assessment (LCA) based on ISO 14,000 standards. 4. To predict operational impacts, Microsoft Excel was used to estimate LCC and Integrated Environmental Solutions Virtual Environment (IES-VE) was used to estimate LCC. 5. In addition to comparing different life cycle phases, economic evaluations were carried out on the results.
	Benefits	The usability of the integration of BIM and LCC allows for comparative studies to reduce the environmental impact of selecting sustainable facades.
	Challenges	NONE
	BIM-Design Software Used	Autodesk Revit [40].

Table 3. *Cont.*

Reference No	The Description	
[30]	**Article Title**	BIM-based approach to conduct Life Cycle Cost Analysis of resilient buildings at the conceptual stage **Article Focus:** Tool development of BIM integrated with LCA/LCC ***(Case Study)***
	Methodology	• In Autodesk Revit, a BIM-LCCA plug-in has been developed that provides individual outputs for each section. • An external database can be exported from the BIM tool that contains the information required for LCC estimation.
	Benefits	In the construction industry, the framework provides an opportunity to increase the flexibility of earthquake measurement scenarios during the design process.
	Challenges	NONE
	BIM-Design Software Used	Autodesk Revit [40].
[31]	**Article Title**	A performance data integrated BIM framework for building life-cycle energy efficiency and environmental optimization design **Article Focus:** Designing an integrated BIM (P-BIM) framework that incorporates LCC at the early stage of the design process for optimizing building energy efficiency and environmental performance. ***(Case Study)***
	Methodology	P-BIM Techniques: 1. Three layers of carries — Inner Layer Carrier = Autodesk Revit, Outer Layer Carrier = MySQL, Middle Layer Carrier = Rhino Inside. 2. This tool in Rhino calculates the initial cost of construction by selecting various types of saved construction configuration choices 3. The LCC index provides detailed cost information, including Initial Cost, Operational Cost, Replacement Cost, and System Cost.
	Benefits	• In the early stages of design, LCC assessments may be possible through the extension of the P-BIM framework to include data dimensions regarding costs, acoustics, and visual environments. • By integrating P-BIM into the project life cycle, architects can enhance their awareness and control of the architect's role during the project life cycle. P-BIM can reduce the gap between the expected and actual performance from design separation and procurement.
	Challenges	NONE
	BIM-Design Software Used	Autodesk Revit [40].
[32]	**Article Title**	Integration of life cycle assessment and life cycle cost using building information modeling: A critical review. **Article Focus:** To review relevant peer-reviewed papers in a study on integration of LCA and LCC with BIM. ***(Review)***
	Methodology	Based on reviewed studies, authors found the three (3) major strategies approaches for BIM-integrated LCC and LCA: 1. Data acquisition (bills of quantities, etc.) using existing BIM software. (Widely Used approach—72.2%) 2. Using external platform software to export data from BIM models. 3. Created relevant data within BIM model.
	Benefits	• Integrating BIM-LCC/LCA into the early phases of design assists designers in determining the environmental impact and cost of the project throughout its life cycle. • Five stages of life cycle analysis are incorporated in BIM-integrated LCA and LCC: design, building, operational, maintenance, and destruction.
	Challenges	• The operational information must be provided by a variety of stakeholders. • By integrating LCA and LCC into BIM, there are only three stages of operation, design, and demolition that can be addressed.
	BIM-Design Software Used	NONE

Table 3. *Cont.*

Reference No	The Description	
[33]	**Article Title**	Integration of LCA and LCC analysis within a BIM-based environment **Article Focus:** The purpose of this project is to explore the potential of BIM as a repository for the LCA and LCC information, and how that information can be used to conduct a cost-benefit analysis with respect to the project. ***(Case Study)***
	Methodology	• Using a BIM environment, the researchers identified all the information needed to perform LCA and LCC analyses. • They further developed a BIM-LCA/LCC framework. The IMD/MDV technology was later applied to the developed framework.
	Benefits	• BIM presents an effective model that can help in development of suitable model that can be used in exchange of sustainability-related information using different software. • The BIM is a useful tool for promoting LCA and LCC analysis.
	Challenges	• BIM requires more information than what is contained in the LCA and LCC in conducting an analysis. • Restriction on materials that are used in the current LCA-BIM models present a challenge on the existing BIM based LCA tools. • Inaccurate information may result from a lack of semantic information inside the BIM.
	BIM-Design Software Used	Autodesk Revit [40].
[34]	**Article Title**	Simulation-Based Multi-Objective Optimization of institutional building renovation considering energy consumption, Life-Cycle Cost and Life-Cycle Assessment **Article Focus:** To find the best energy consumption and LCA scenarios for renovating institutional buildings. ***(Case Study)***
	Methodology	• The model has four major phases. The first phase is the model input data collection that aims at defining the model's input data collection methods and developing BIM model. • The second phase is development of database and integration and allocates methods for each strategy. • The third phase id definition of the strategies of renovation. • The last phase involves simulation-based optimization of many objectives.
	Benefits	• The BIM was found to be a useful model that could help in optimizing the building and renovation scenarios and help in minimizing the LCC, TEC and even the environmental impacts of the buildings. • BIM can help in achieving energy savings in the buildings.
	Challenges	NONE
	BIM-Design Software Used	Autodesk Revit [40].
[35]	**Article Title**	The Implementation of Life Cycle Costing towards Private Client's Investment: The Case of Malaysian Construction Projects **Article Focus:** To review the LCC scenario in Malaysia ***(Quantitative Case Study)***
	Methodology	Using the survey methodology to collect data by adopting a quantitative approach and a questionnaire. To measure the level of real estate developers' agreement on: 1. Importance of applying LCC in the construction industry. 2. Determine the benefits of implementing LCC. 3. Identify barriers to implementing LCC.
	Benefits	• Can support the owner to a knowledge of estimated LCC during project design. • Focus on determining the value of projects as a financial evaluation tool for alternatives to the project to contribute to decision-making. • Improving awareness of the total cost of the project.
	Challenges	Difficulty integrating design models with building information modelling (BIM) with LCC adoption.
	BIM-Design Software Used	NONE

Table 3. *Cont.*

Reference No	The Description	
[36]	**Article Title**	BIM-Based Life Cycle Assessment of Buildings—An Investigation of Industry Practice and Needs **Article Focus:** To investigate the needs for integration of BIM and LCA through qualitative interview with experts from companies who performed LCA in their building projects. ***(Qualitative Case Study)***
	Methodology	5 approaches of BIM-LCA integration: 1. Enriched BIM. 2. Quantity Take-Off. 3. Geometry Import. 4. Intermediate Viewer. 5. LCA Plug-In.
	Benefits	NONE
	Challenges	• Inadequate building-model administration for a collaborative process. • Workflow errors and a lack of consistency in the workflow and modeling errors. • Data quality and availability are lacking in models. • Different models have different structures. • Matching model-data with LCA data through the exchange of model-data • A manual workflow is used for large models and workflows.
	BIM-Design Software Used	NONE
[37]	**Article Title**	BIM-Based Approach to Simulate Building Adaptive Performance and Life Cycle Costs for an Open Building Design **Article Focus:** To explore the advantages of an open building design and what it takes to extend a building's life in the future. ***(Case Study)***
	Methodology	• The study adopted three design proposals that targeted three 30, 50 and 100 years of service lives based on the life cycle and the actual cases. • In the 30 years design, a traditional building design was adopted, for the 50 years design a semi-open design was adopted while the 100 years project adopted an open design system. • The BIM was used to conduct simulations related to renovation benefits in the different proposals.
	Benefits	• BIM proved to be an essential tool for simulating the future renovations, usage and maintenance of buildings. • The BIM provides a decision support system that can help in optimizing the benefits and cost of renovation. • The BIM can help in improving the building service life through reasonable estimations of benefits and costs. • Helps in achieving lower LCC compared to traditional systems.
	Challenges	NONE
	BIM-Design Software Used	Autodesk Revit [40].
[38]	**Article Title**	Implementing life-cycle costing: Data integration between design models and cost calculations **Article Focus:** This study seeks to build, test, and summarize the lessons acquired from integrating data amongst autonomous software packages linked to design models, cost calculations, and cost databases in order to provide LCC assessments. ***(Case Study)***
	Methodology	The researchers followed a comprehensive methodology where they started with a literature review followed by interviews. The insights that were obtained from the; literature review and interviews were later used to develop tools that could help in developing link design models and cost databases for the entire building.
	Benefits	• BIM proved to be an effective method that can enhance productivity and collaboration in sustainable building. • BIM presented a unique approach that can help in the collection of data that could help in achieving sustainability of the buildings. • BIM enhances flexibility and innovation that can help in transformation of buildings.
	Challenges	• BIM standards have not been harmonized for models and this is one factor that affects the integration and management of the different stakeholders. • There are several formats of data exchange which affects the standardization.
	BIM-Design Software Used	Autodesk Revit [40].

Table 3. *Cont.*

Reference No	The Description	
[39]	**Article Title**	BIM application to select appropriate design alternative with consideration of LCA and LCCA **Article Focus:** LCCA and LCA can be enhanced through the development of an approach based on 3D parametric BIM. ***(Case Study)***
	Methodology	• The researchers utilized a multistep methodology where they started by conducting a literature review. • In the second step, a data analysis of LCA and LCCA that was collected in the initial set up was conducted. • The third step was the application of the BIM to provide key information related to LCA and LCCA. • In the fourth stage a case study was conducted and the BIM model was applied to a real building.
	Benefits	• The BIM helped in easier calculation of LCA and LCCA. It took less time to conduct the BIM for the three alternatives and therefore BIM proved to be the best method of solving LCA and LCCA related issues. • The BIM is an efficient quality calculator that is compatible with other software. • Relevant information is provided immediately at the initial stages.
	Challenges	• The BIM did not provide information related to fuel consumption. Missing data undermines the reliability and accuracy of the results provided by the BIM • There was no BIM library that could help engineers to gather the required information quickly.
	BIM-Design Software Used	ArchiCAD [44].

4. Outcome

The findings divided into four subcategories namely, the methodology used in BIM and LCC studies, the software design used in BIM adoption, the benefits of BIM on LCC, and the challenges in adopting BIM on LCC.

4.1. Methodology in Studies of BIM and LCC

The methodology proposed or conducted for studying the integration of Building Information Modelling (BIM) and Life Cycle Cost (LCC) varies depending on the objective of the study. Liu et al. [22] developed a BIM-oriented multi-objective optimization model with the integration of the data Ecotect [41], the software that guided the analysis via MOPSO. The multi-objective algorithm enabled an optimal design scheme. Separately, Kehily and Underwood [23] attempted to embed the Life Cycle Costing (LCC) in the 5D BIM environment platform. They present a case study where an extension in 5D BIM process embedded the LCC cost-estimation structure into 5D BIM, which is known as CostX [45]. CostX allows a quick and accurate take off quantities from 2D drawings and BIM models. The LCC calculations feed into CostX through the Workbook. This process enables a link between Quantity Surveying's cost plans or their Bill of Quantities and their LCC calculations in an integrated BIM environment.

In an alternative to CostX application, Marzouk et al. [5] proposed an integrated BIM framework to predict LCC with two model techniques namely, a Genetic Algorithm Optimization and a Monte Carlo Simulation. In that study, the BIM-based Autodesk Revit enabled to export data of materials, e.g., concrete, painting, plastering, flooring, etc into the Monte Carlo simulation model. Then, LCC ran through the model and the Optimization model utilising Genetic Algorithms (GA) i.e., through retrieval of the fitness function from the simulation model. The model finally selects the optimum building materials scenarios that minimise the LCC of building materials.

Santos et al. [24] discussed a case study of BIM-based life cycle assessment and Life Cycle Costing (LCC) of an office building in Western Europe. They adopted a six-step process being the first step the merging of architectural and structural design components into a single BIM master model. In a second phase, the information of the BIM model was analysed through an exported list. The third step was to check the exported list for identifying noise (presence of duplicates). During a fourth step to the whole project homogenises so that the adopted LCC tools can read and manipulate the bill of quantities. The fifth step was to add the environmental, economic, and mechanical information in the projects through the creation of an XLS spreadsheet list that covers all the elements and materials in the project, and the final step was to conduct a Streamlined and Complete LCC analysis of the project.

In a separate case study, Raposo et al. [25] focused on the analysis the costs and environmental impacts of a reinforced concrete precast industrial building through the adoption of BIM and Life Cycle Analysis (LCA) along with LCC conducting the cost estimation. Their methodology departs from the creation of a BIM prototype, which is then subject of a LCA analysis conducted through pre-defined goal and scope. With this in hand, they proceed to complete the inventory and environmental impact assessment of each construction scenario. As part of its LCC calculation, the study considers the costs of construction and demolition for a new building with a 50-year horizon, assuming seismic reinforcement and demolition of precast elements of the existing building were accounted for a 20-year lifetime.

Following their Western Europe case study, Santos et al. [6] proposed BIMEELCA, known as BIM-based Environmental and Economic Life Cycle Assessment tool, for integrating BIM and LCC. BIMEELCA developed through the automatic creation of shared parameters that correspond to an environmental impact category and acquisition cost that underpins the LCC analysis. The controlling parameters allow users to visualise a dialogue window containing information on materials relevant to the model, where they can select functional units to run the environmental and economic assessment for the whole model or discretised components. This thus therefore allows calculating a complete LCC analysis considering all relevant variables.

A parallel study by Lee et al. [26] proposed a BIM-integrated method oriented to support the decision-making process in the early design phase. They developed four threads of estimating LCC within the BIM environment: Firstly, by linking the BIM model information with the BIM-based project preliminary estimate prototype aiming to extract basic information of the project. Secondly through forming a database to record performance costs and reference data, which defines pre-estimation algorithm. The third pathway uses a System Linkage that connects system environments produced in the previous two stages. The final thread allows building scenarios for which cost and standard data can be estimated. The algorithm thus equips designers BIM-LCC interactions for scrutinising design alternatives and total construction costs.

The same year, Le et al. [27] developed a BIM-Integrated Relational Database Management System for Evaluating Building Life-Cycle Costs (LCC) through two interrelated modules: (1) the Relational Database Management Module, and (2) the Visualised BIM-Integrated Module. They both provide data to build LCC analyses by systematically compiling, organizing, storing, and retrieving them. Barbini et al. [28] observed that this and similar studies manage to integrate BIM and LCC through 3 generic steps: First they use software such as SimaPro [46], CostLab [47], Excel etc to conduct LCC calculations. Second, connect the BIM model to generate the LCC database, and the third one is the direct integration of LCC data into the BIM model.

In a case study for a residential building in Ghana, Ansah et al. [29] designed an akin integrated framework of BIM and LCC/LCA to perform comparative analysis of four different facades systems. Their methodology also departs from the creation of a BIM model in Autodesk Revit [40], which they personalised to a case building constructed in conventional Concrete Block and Mortar Facade (CBMF). Following, separate BIM models were developed for three other facades types (1) Shotcrete Insulated Composite Facade (Shotcrete ICF), (2) Galvanised Steel Insulated Composite Facade (G. Steel ICF) and (3) Stabilised Earth Block Facade (SEBF). A full LCA was then conducted for each model within the framework of the International Standardisation Organisation (ISO) 14000. A user-friendly method to forecast operational implications, consisted on implementing LCC in Microsoft Excel and revert the result into the Integrated Environmental Solutions

Virtual Environment (IES-VE) [48], hence simulating the LCC. The obtained results went through an in-depth comparative analysis of different life cycle phases along with economic evaluations.

Building on previous studies, Rad et al. [30] developed a separate tool to merge BIM with LCC/LCA. here again Autodesk Revit was used to develop a BIM-LCCA plug-in provided with outputs for each section separation. The information required for the LCC estimation thus feeds into the BIM tool but allowing the data to be transferred to an external database. Similarly, but tailored to an early design stage as case for study, Zhuang et al. [31] developed a Performance Integrated BIM (P-BIM) Framework for building energy efficiency and environmental optimization. The P-BIM applies the 3 steps with the corresponding layers of carriers: Autodesk Revit, MySQL [49], and Rhino Inside [50]. Rhino calculates the initial cost for various types of the construction alternatives. Those results facilitate a three-legged LCC index that includes the Initial Cost, the Operation Cost, the Replacement Cost, and the System Cost.

Finally for the present review, Lu et al. [32] analysed a plethora of publications liked to novel interphases between BIM and LCC/LCA. They found that three perspectives for the integration of BIM into LCC and LCA. First is to use the existing BIM software to obtain Bills of Quantities (BoQ) and other data. The second focused on the use external software platforms to import data from and to the BIM model, and the third devoted to build relevant data for LCC/LCA within the BIM model itself.

4.2. Design Software Used in BIM Adoption

As discussed in previous sections Autodesk Revit revealed as the most efficient software to develop BIM interactions. Several consulted publications [5,6,23–27,29–31,33,34,37,38,51–53] adopted Autodesk Revit to work out BIM environments and interconnections with LCC, either internally or through external programmes. The reason appears to be that Revit is capable to combine fundamental disciplines (Architecture, Engineering, and Construction) into one unified modelling environment for enhanced efficient and cost-effective construction projects. For additional information, see Table 4. Past the discussion of BIM-LCC developments presented in previous sections, we now review some identified benefits reported by BIM users.

Table 4. Overview of the software used for the integration of BIM on LCC.

Author	Software of Model	Software of Data		LCC Analysis
[5]	AUTODESK REVIT	**Microsoft Excel**	Excel	**Monte Carlo. The optimization model utilizes Genetic Algorithms (GA).**
[6]	AUTODESK REVIT	**Excel format, Revit GUI**		**BIMEELCA tool. Streamlined LCA/LCC analysis based.**

Table 4. *Cont.*

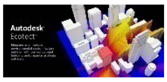
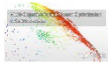
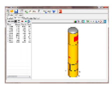
Author	Software of Model	Software of Data		LCC Analysis
[22]		Multiple Objective Particle Swarm Optimization (MOPSO)		Pareto-optimal front.
[23]	AUTODESK REVIT	Exactal CostX with 5D BIM platform		CostX 5D BIM software.
[24]	REVIT tally Athena Impact Estimator for Buildings	LCA database (GaBi), Microsoft Excel	GaBi Software	BIMEELCA tool.
[25]	AUTODESK REVIT	Tally database	tally	Tally LCA Software.
[26]	AUTODESK REVIT	Oracle SQL Developer	Oracle SQL Developer	JAVA-based eclipse JSP. Web-based user interface (UI).
[27]	AUTODESK REVIT	Microsoft Excel	Excel	Relational database management system (RDBMS).
[29]	AUTODESK REVIT	Microsoft Excel	Excel	Integrated Environmental Solutions Virtual Environment (IES-VE).

Table 4. *Cont.*

Author	Software of Model	Software of Data		LCC Analysis
[30]		**RSMeans cost database, Microsoft Access, Microsoft Excel, Platform Revit API**		**Green Building Studio (GBS). The developed BIM-LCCA plug-in.**
[31]		**Platform Revit API, MySQL (V5.7), Rhino.Inside (V0.0.7668).**		**A performance integrated BIM (P-BIM). LadybugTools. EnergyPlus. Octopus tool.**
[33]		**IfcDoc tool, IDM/MVD**		**BIM-LCA/LCC analysis.**
[34]		**Take-Off (MTO) table**		**Simulation-Based Multi-Objective Optimization (SBMO) model. Pareto front.**
[37]		**Microsoft Excel**		**Net Present Value "NPV". The FDS+EVAC tool. Computational Fluid Dynamics (CFD) Simulation of Indoor Wind. The daylight analysis software.**
[38]		**Molio Price Database, MS Excel-based tool**		**Sigma Estimates. 5D BIM cost software. Dynamo model.**
[39]		**Microsoft Excel**		**EcoDesigner software. Excel worksheet-based framework.**

4.3. Benefits from the Application of BIM and LCC

Liu et al. [22] found advantages in using of BIM for the estimation of the maintenance costs at the initial stages of the project, for it can help designers to meets multiple sustainability requirements. Later on, Kehily and Underwood [23] highlighted that 5D BIM software is capable to perform standard BIM functionalities as well as to execute additional tasks through Revit. Today, 5D BIM is identified as a platform that provides all the necessary conditions in the LCC analysis. The utilisation of BIM on LCC was appears on a relatively early report by Marzouk et al. [5]. They stated that the integration of BIM with the Monte Carlo Simulation and the Optimization Modelling could help decision makers in selecting environmentally friendly building materials while fulfilling economic sustainability.

Santos et al. [33] discussed the benefits of developing BIM-LCC interactions while allowing integrating LCC external database, for cost-analysis completion within the BIM platform. They reiterated that coupling BIM-LCC helps to promote sustainability-related methodologies to be executed in the early stage of a project, hence takin on-board green materials and products that could guarantee the remaining service life of the building. In a separate study, Santos et al. [6] developed BIMEELCA, a tool that allows users to insert information within a BIM model to run an LCC analysis. This tool also enables the import and export of information from external spreadsheets, thus leading up to the automatic Streamlined LCC analysis.

Lee et al. [26] highlighted that implementing BIM in the construction flow of project provides decision-makers with accurate preliminary cost estimation over design alternatives. In this way, project cost can be reduced and its value can be increased. A similar point was stressed by Sharif and Hammad [34], who identify BIM as the optimum platform for leading building renovation and structural interventions to then reduce cradle-to-grave environmental impacts. that the consulted materials also verified that the computing timescales associated to LCC also reduced through the integration of BIM [27].

In a separate report Barbini et al. [28] highlight the integration of BIM-LCC as a mean to optimise environmental and economic performance of buildings, reduce transaction time, increase productivity, transparency, and enhance sustainability. Similarly, Ansah et al. [29] found the BIM-LCC integration useful for quantifying benefit of using façade systems that lower environmental impacts. Those statements were later reinforced by Zhuang et al. [31], Lu et al. [32], amongst others, who mentioned benefits aligned with current sustainability trends and policies through the integration of P-BIM that links local supply chains and early- or mid-stage projects for the enhancement of architectural (designer's) control of the project Life Cycle.

4.4. Challenges in the Study of BIM and LCC

Researchers underlined various challenges when implementing BIM-LCC integrations. Kehily and Underwood [23] pointed out the lack of standardisation of LCC cost estimation methods, which could explain clients' reluctance to integrating LCC into formal projects. The lack of uniformity could derive that each project requires different input data in terms of materials, processed, and timelines, to run a LCC, hence a generic database does not actually exist [24]. This point was stresses by Lee et al. [26] when stating that full characterisation of a building type is difficult achieve from a semi-empirical database. Cost criteria aligned with government's standards often lead to limited scope for classification, which induces difficulties in competing a LCC estimation.

Le et al. [27] highlighted further challenges when implementing BIM in a LCC analysis. They cited issues with unstructured and uncommon data format, lack of interoperability among different tools, segregation of standards, calculation methods, and interoperable technologies. Zakaria et al. [35] supported the notion by reporting similar complexities when trying to integrate design models into BIM with full adoption of LCC.

More recently, Zimmermann et al. [36] identified seven constraints facing industrialists when implementing BIM into LCC. These are: inadequate building-model administration for a collaborative process, workflow errors and a lack of consistency in the workflow and modeling errors, Data quality and availability lacking in model control tools for supervising models, errors in the modelling process as a result, ways to quantify variations in models structure over time, problems with data exchange and matching model data with LCA data, and lastly, the need to undertake manual workflow that derive in extended time-scales. The complication in the process of project workflow was stressed by Lu et al. [32]. They identified challenges in managing BIM-LCC related information that result from data collection involving various stakeholders. Those interactions have a knock effect on every stakeholder's workflow. All the above currently imposes challenges that limit the full integration of BIM and LCC, that prevent a fast efficient simulation of design, operation, and demolition stages.

5. Discussion and Final Remarks

The current frameworks for merging BIM and LCC require dynamic interactions between internal and external databases. [25–27,29,33], amongst others, have reported the creation of an interphase between a BIM database in which LCC integrates. Similar works have been reported by [5,23,32], who also managed to bring into BIM external data. The development of Autodesk Revit revealed a turning point in this process, given its ample capabilities to feed physical properties and measurements into an user-friendly BIM design environment. This tool has since been adopted by industrialists and researchers, see for example [5,6,23–27,29–32,34,37,38]. They all report studies on BIM, LCC, and the use of Revit.

Amongst the benefits of creating BIM-LCC interactions is the scope created for decision makers to select building materials that are sustainable [23,24,28,29]. This identifies changing trends to fixed design process in which material selection based on limited information constrained the potential for the sustainable design [31]. Other benefits of BIM-LCC extend across project costs and values as highlighted by [26,27]. For example, environmental and economic performance of buildings can be optimized, transaction time can be reduced, whereas productivity and transparency can be enhanced through the adopting of BIM-LCC frameworks [28]. BIM-LCC also enables urban developers to quantify environmental impact and partial cost early in the design stage thus enabling higher control over the project [31,32]. Noting that decisions made in the early design stage do establish directives for the entire project period [26].

The most notable challenges cited by authors who studied BIM and LCC integration come down to unsuitable or limited data in a project database which hinders BIM and LCC modelling [23,24,26,36]. There are also concern on the capabilities of the BIM application to effectively perform LCC analysis [27,35]. Lu et al. [32] also highlighted a major challenge when trying to integrate and standardise information collected from various stakeholders, as each of these uses and applies their own tools and workflow.

The above highlights BIM-LCC integration benefits and challenges that define future research avenues for optimising methodologies and further developing digital tools.

6. Conclusions

Sustainability is an important indicator for construction projects as it promotes the development of the built environment without damaging environment and with minimum contribution to the greenhouse phenomenon. Through BIM-LCC integration, decision makers in construction project are able to determine the type of building materials that are sustainable. This is important in promoting sustainability of the constructed buildings or facilities or infrastructure. However, the Most prevalent challenge is the data integration between BIM and LCC in project database. In addition, a BIM and LCC integration is essential for understanding estimated building costs. There have been significant research contributions to the integration of LCC into BIM. Despite this, BIM occasionally finds problems with data integration and the presentation of various data types. In order to integrate the applications, it is necessary to develop software that links BIM models with LCC analysis models and creates one database from numerous simulation tools that can be implemented into simulation software. To this end, the present paper could be considered as a contribution towards a systematic review on the BIM adoption to LCC. Four several review aspects have been considered as follows: Methodology, Design-Software, Benefits, and Challenges. Thus, this paper aims to contribute to the review perspective of the current trends related to the BIM adoption on LCC.

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Abbreviations

Abbreviations	The Description	Abbreviations	The Description
BS ISO	British Standards and International Organization for Standards	CAD	Computer-Aided Design
PRISMA	The Preferred Reporting Items for Systematic reviews and Meta-Analyses	3D	Three Dimensional
GA	Genetic Algorithms	BIM	Building Information Modelling
BIMEELCA	a BIM-based Environmental and Economic Life Cycle Assessment	WLC	Whole-Life Cost
LEED	Leadership in Energy and Environmental Design	LCC	Life Cycle Cost
MEP	Mechanical, Electrical, and Plumbing	LCA	Life Cycle Assessment
RICS	The Royal Institution of Chartered Surveyors	LCCA	Life Cycle Cost Analysis
RDBMS	The relational database management system	QS	Quantity Surveying
CBMF	Concrete Block and Mortar Facade	BOQ	Bill of quantities
Shotcrete ICF	Shotcrete Insulated Composite Facade	IDM	Information Delivery Manual
G. Steel ICF	Galvanized Steel Insulated Composite Facade	MVD	Model View Definition
SEBF	Stabilized Earth Block Facade	TEC	Total Energy Consumption

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