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Bridging BIM and LCSA to Greening Existing Buildings: From A Literature Review to Development of Conceptual Framework

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Bridging BIM and LCSA to Greening Existing Buildings: From A Literature Review to Development of Conceptual Framework

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Abstract. Instead of looking into new building, this study shifted the focus to existing buildings considering the area has been less explored although the amount of energy released during the phase has significant influence towards sustainability impacts. Deriving from the situation, the purpose of this paper is to explore the potential of bridging BIM and the four-steps approach of Life Cycle Sustainability Assessment (LCSA) as an assisting tool to improve the performances of existing non-green buildings. To achieve aforementioned aim, an extensive literature review to identify the nexus between the two areas is done, as well as possibilities and challenges surfaced pertaining to the idea. Literature review process consists of several approaches including literature searching, classifying, and analysis were conducted. Based on literature review, a research gap is identified, and an initial conceptual framework is developed. The framework entails several areas of research that highlight on integrating LCSA approach, sustainability indicators and BIM functions. Apart from that, several implementation considerations to integrate both areas have been identified too. The conceptual framework presented in this study will serve as a basis to further develop an implementation framework that integrates BIM and LCSA to greening existing buildings. The final implementation framework is expected to assist project stakeholders including project manager (or facility manager), building owner, and consultants in making decision towards improving existing buildings' sustainable performance.

Keywords: Building Information Modelling (BIM), Life Cycle Sustainability Assessment (LCSA), sustainability, greening existing buildings, green BIM

1. Introduction

Nearly 39% of all carbon emissions released in the world has been contributed by buildings and construction sector [1] making it one of the prominent contributors to worldwide carbon (CO_2) emissions and global warming [2-4]. Of this percentage, 28% is from operational emissions and the remaining 11% is from materials and construction [5]. The sector significantly impacted the environment due to

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its long life expectancy and involvement of various kinds of resources (energy and water) and generated waste throughout its life cycle [4, 6]. Researchers have found that existing non-green buildings were considered as part of significant contributors to worldwide CO_2 emission which indirectly is responsible to global warming phenomenon, with approximately 30% in total contribution [7].

Hence, to achieve wider sustainability objectives, several researchers [8, 9] highlight the need to transform the existing buildings by means of retrofitting or refurbishment. The concept was then defined as ‘greening existing buildings’ where the term ‘greening’ is used to explain the perception of integrating sustainability strategies into existing buildings through refurbishment works. These energy reduction strategy are believed to be an effective sustainable tool in tackling large carbon emissions and its climatic changes effect in the future [7]. This is in line with the United Nation’s Global Alliance for Buildings and Constructions (GABC) key priorities roadmap that include strategies to improve existing buildings energy efficiency level through refurbishment.

Considering Life Cycle Assessment (LCA) as the most recognised approach [10-13] to assess building lifecycles environmental impacts, the adoption of the tool to assist project stakeholders in deciding between several sustainability alternatives during refurbishment work has been increasing. However, to ensure the decision-making process comprehensively encompass all triple pillars of sustainability (i.e., environmental, social, and economic), this research incorporates Life Cycle Sustainability Assessment (LCSA) that goes beyond the traditional LCA.

Apart from that, with the emergence of technology and digitalisation as well as recognition of Building Information Modelling (BIM) as a construction digitalisation tool, it shows potential as a tool to support complex decision-making processes through the integration of workflows and information [11]. In this context, BIM has a huge capability to automate LCSA. With growing interest in LCSA as a sustainability approach and BIM as digitalisation tool in construction and building sector, this study aims to explore the potential of bridging these two emerging areas: BIM and LCSA for greening the existing buildings.

2. Methodology

The research began with an extensive literature review following the methods based on [14]. Three major steps involved include (1) literature searching, selection, and classifying, (2) analysis, and (3) discussion on identified gaps. A literature search was conducted from several databases, including Scopus and Web of Science, and through Google search engine. Two types of literature were considered throughout the processes that are peer-reviewed and grey published literature. The search was set to English language and restricted to papers published between 2013 to 2020 to access studies done for the last eight years under these keywords:

> “BIM” or “Building Information Modelling” AND “Life Cycle Sustainability Assessment” or “Life Cycle Sustainability Analysis” or “LCSA”,
>
> Or,
>
> “BIM” or “Building Information Modelling” AND “Life Cycle Assessment” or “LCA”, “Life Cycle Costing” or “LCC”, and “Social Life Cycle Assessment” or “SLCA” or “s-LCA”.

Following the searching phase, related literature was selected manually. Any duplicate literature found from different databases were removed from the list. Selected literature was analysed and classified according to research dimensions and sub-topics. Several classifications include BIM group, LCSA group, and BIM-lifecycles integration group. Analysis and discussion of findings from the literature were used to derive and conclude study gaps. Accordingly, a conceptual framework is developed. The framework illustrates the broad idea of the study, emphasising the integration of two areas: BIM and LCSA. Also, the framework introduces supporting variables for the integration that are sustainability indicators and BIM supporting functions. Figure 1 depicts the overall processes and outcomes expected from the literature review conducted for this study.

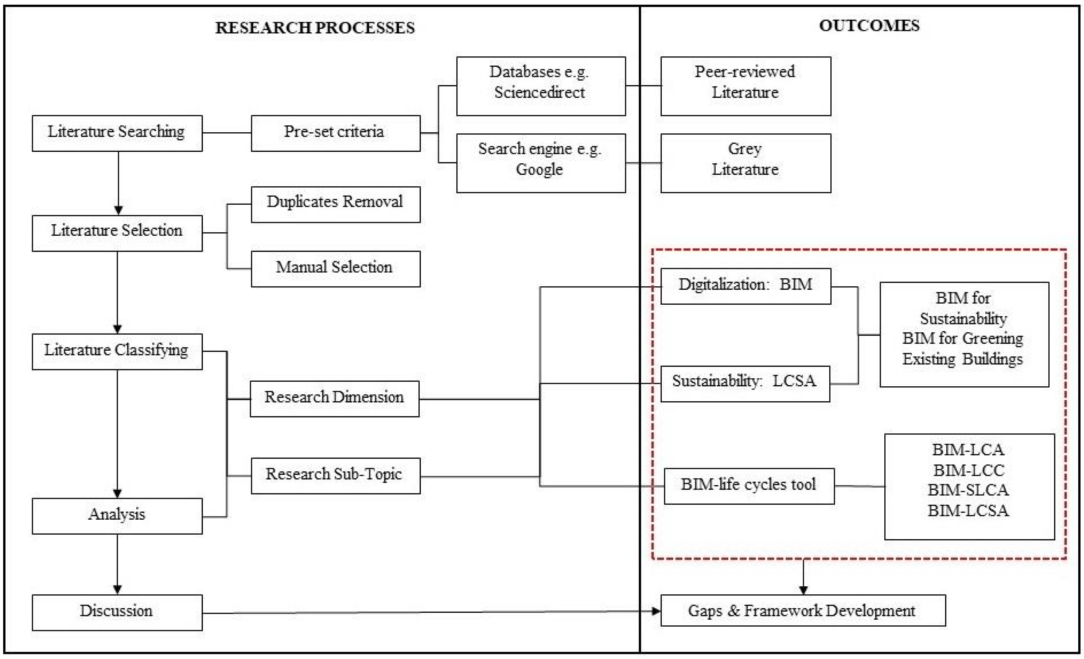


Figure 1. Research processes and outcomes (adapted from [14])

3. Review of Literature

3.1. BIM for Greening Existing Building

Findings from literature have proven that numerous functions of BIM may be used to support various sustainability analysis of building performances [15-22]. Among critical sustainability functions supported include analysing building orientation, massing and envelope analysis during design stage [16-18], energy performance modelling and analysis including renewable energy measures such as solar analysis and prediction [16-20, 22] and sustainable materials selection and performance analysis which will eventually enable LCA to be performed [16, 18-21].

Apart from that, [22] highlighted the ability of BIM to support various facets of green building life cycles too. [23] beforehand, classified various sustainability criteria into several BIM functions. Among major BIM functions identified include scheduling, visualisation, calculation, and clash detection. Similarly, [24] analysed various BIM supporting functions commonly diffused in the construction industry from various past literatures. Aside from similar functions previously mentioned by [23], some additional functions are facility space planning and logistics (simulation), analysis (constructability, energy, and structural), and data management. Data management encompass several functions such as BIM ability to produce shop-drawing, material management, tracking and delivery, stakeholder management, facility management, and project turnover and close-out [24].

This concurs with findings from [25] that indicate BIM has significantly been proven to be impactful and providing benefits towards various stages of construction project lifecycle. Consequently, with rapid development of research on BIM implementation throughout overall project lifecycle, there has been growing interest in the applicability of BIM towards the later stages of project, particularly on the operational (usage) stage. [26] mention that in recent years, research has started to shift their focus from earlier life cycle stages to potentially using BIM during post-occupancy period including building maintenance, refurbishment, deconstruction, and end-of-life [26-29]. According to [22], BIM applications is considered as able to assist decision-maker with various feasible decisions when addressing sustainability issues during refurbishment phase.

Previous studies [30-34] has also revealed that there is a strong relation on the potential of BIM to improve the quality and functionality of existing building [30] towards achieving zero energy building at cost-optimal levels. BIM has been identified as playing a vital role in determining and analysing energy consumption of existing buildings, particularly during energy audit phase [32] which therefore is able to precisely predict buildings' energy performance, creating models, and comparing between alternatives available [31]. Besides, [34] also mention that data acquired from the BIM model may be transferred to cost estimating software to foresee and calculate the cost involved to greening the building. This has led to an opportunity for the integration of BIM as an innovative tool to achieve sustainability objectives of building through improvement on existing structure [31].

3.2. Life Cycle Sustainability Assessment (LCSA) Approach

In attempts to integrate sustainability in the whole life cycles of a building, the concept of life cycle sustainability assessment (LCSA) was introduced by Kloepffer in 2008. It was first brought to attention when UNEP/SETAC Life Cycle Initiatives was discussed to extend the initial scope of LCA (that only focuses on environmental) to include the whole sustainability assessment [35].

LCSA was then further explored by other researchers [36-42] over the past few years and had been recognised as one of the rising approaches that systematically integrate environment, economy, and social dimensions. The approach evaluates the negative impacts as well as benefits of the development throughout its whole life cycle based on the three aforementioned dimensions [36, 40, 41]. To further elaborate LCSA, [43] expressed the concept based on the following equation:

LCSA = LCA [Environment] + LCC [Economic] + S-LCA [Social]

LCSA principally encircle all aformentioned triple techniques [38, 40, 41, 43], one representing different pillars of sustainability [44] throughout the decision-making process. [43] initially proposed two options when conducting LCSA, either (1) to conduct all three life cycle assessments separately, or (2) to perform new LCA that integrates LCC and S-LCA as part of new impact categories during LCIA stage. However, the author further clarifies that the second option actually is not compatible with LCA definition provided by ISO 14044. The standard clearly defines that LCA should address the environmental aspects and not to include economic or social aspects of a product or project. In 2012, UNEP/SETAC released a specific guideline on LCSA and clearly highlighted the framework of conducting LCSA adopted from LCA framework as it is the only tool recognised by ISO 14044 to date [36]. According to the guideline, LCSA should also consist of four steps namely (i) LCSA scope and goal definition, (ii) LCSA inventory assessment, (iii) impact assessment, and (iv) LCSA interpretation [40].

3.3. BIM and LCSA Integration: Previous Studies and Gaps

As shown in Table 1, numerous studies were done on the integration of BIM with lifecycle tools especially LCA. Previously, [45, 46] looked into BIM-LCA integration by suggesting a methodology to connect BIM model with LCA processes using an external database that consists of materials' environmental data. [46] finally proposed two possible approaches for integration. The first approach was 'direct access to the BIM model information to calculate LCA performance' while the later one was 'environmental properties included in the BIM objects' [46, 47]. Meanwhile, [48] reviewed the simplified LCA approach which aims at reducing CO^2 emissions during early design phase. BIM-LCA integration model proposed by [48] eventually follows the essential steps of LCA namely input, analysis, and solution as defined by [49].

On the other hand, [50] indicated how BIM might reduce the effort in carrying out LCA. The authors [50] developed an integrated BIM-LCA approach for the whole building process using an established four-step workflow. The study relied on environmental indicators derived from existing Swiss LCA databases and cost-planning structures for cost estimation purposes. The developed methodology enables decision-making assistance at both building and element levels for every building phase including their related Levels of Development (LOD). [51] then explored the potential of integrating

BIM and LCA, using specific pre-identified sustainability criteria derived from a Building Sustainability Assessment (BSA) method namely SBTool. The integration between BIM, LCA and BSA eventually enhanced the decision-making procedure by providing better results evaluation and interpretation.

As for BIM integration with LCC or economic sustainability assessment, [52] highlighted the lack of available existing literature regarding the matters. Few authors [53-56] previously published a framework on BIM related to economic assessment. For instance, [56] proposed a framework that integrates BIM and rating system (LEED) to select sustainable building materials based on LCC calculations. Meanwhile, [53] presented a framework to effectively assist decision-makers in designing a sustainable building at early stage through integration of BIM functionality and LCC. In a different study, [55] developed a BIM-based framework to search for the best sustainable building design improvement based on a trade-off between LCC and life cycle carbon emissions. Similarly, [54] developed a framework to identify the most optimal design with minimum LCC during the design stage. BIM was used as a simulation tool to model the selection design and analyse total energy consumption.

For the moment, for social assessment integration with BIM, there has been little discussion available. [57] presented BIM model integrated with only LCA and LCC putting aside social assessment. According to [58], there is a lack of tools available in the literature emphasising on cultural and social aspects of sustainability. [59] pointed out that most of the tools presented were centred on environmental and economic, leaving out social dimension. Deriving from the gaps, the authors [59] presented a framework that integrates BIM with sets of indicators for residential buildings' social assessment.

Apart from looking individually at the three dimensions of sustainability, research to date has tended to focus on all three at once, adopting the concept of LCSA approach. However, Table 1 shows the scarce existence of it. Previously, [60] developed a framework that integrates BIM and LCSA to efficiently design the external envelope of existing buildings. The framework consists of several iterative steps including designing BIM variables, identifying LCSA criteria and defining efficiency index through the quantitative method. Optimisation techniques were adopted to calculate the life cycle efficiency index (LCEI) which was defined by values and costs. The authors highlight the ability of their framework to support the decision making and design process by selecting the best scenario based on identifying various life cycle values and costs.

Similarly, [13] presented a methodological framework on BIM-LCSA integration. The authors proposed three steps workflow to link both LCSA and BIM. The process begins with the development of BIM model (step 1) to enable project stakeholders to simulate the design with different alternatives and scenarios, followed by LCSA calculation (step 2) and finally, communication of results (step 3). Throughout LCSA calculation phase, a unit process approach is proposed with the Triple Bottom Line (TBL) sustainability database, where data related to environmental, social and economic impacts were collected. LCSA part, as recommended by the authors [13], eventually follows four common steps as outlined by UNEP/SETAC.

Table 1. Previous studies on BIM – life cycles integration

Ref.	Tools	Sustainability Dimension	Purposes
[45]	LCA	Environment	Framework to connect BIM model with LCA processes using external database of material's environmental data
[61]	LCA	Environment	Application of LCA into BIM model to assist decision on environmental impacts of building materials during design stage
[56]	LCC	Economic	Integrate BIM with LEED rating system to select sustainable materials based on LCC calculation
[46]	LCA	Environment	Integrate LCA and BIM to develop sustainable design of building
[53]	LCC	Economic	Integration of BIM functions and LCC to design sustainable building during early stage

[55]	LCC & Carbon Emissions	Economic Environment	BIM based framework for best sustainable design improvement based on trade-off between LCC and LCCE
[54]	LCC	Economic	Framework to identify most optimal design with minimum LCC during early design stage
[59]	S-LCA	Social	Development of social sustainability framework and its responsiveness as BIM plug-in applications
[48]	LCA	Environment	Analyse how BIM may contribute in LCA to reduce CO2 emissions during early design phase
[11]	LCA	Environment	Workflow of using BIM tools to assess and visualise buildings' elements embodied impact following LCA approach during early design stage
[57]	LCA & LCC	Environment Economic	BIM model integrated with LCA and LCC to assist decision-making in early design phase of buildings and infrastructure
[60]	LCSA	Environment Economic Social	Framework that integrates BIM and LCSA to efficiently design external envelope of an existing buildings
[13]	LCSA	Environment Economic Social	Three-steps workflow to integrate BIM and LCSA during early design stages of building
[50]	LCA & Cost Estimate	Environment Economic	Four-steps workflow to perform LCA in each building phases integrated with existing BIM processes focusing especially on cost estimation
[51]	LCA & SbTool	Environment	Discuss relationship between building LCA and BIM method, relying on sustainable criteria derived from SBTool

4. Discussion

Based on literature review, several insights to pinpoint include:

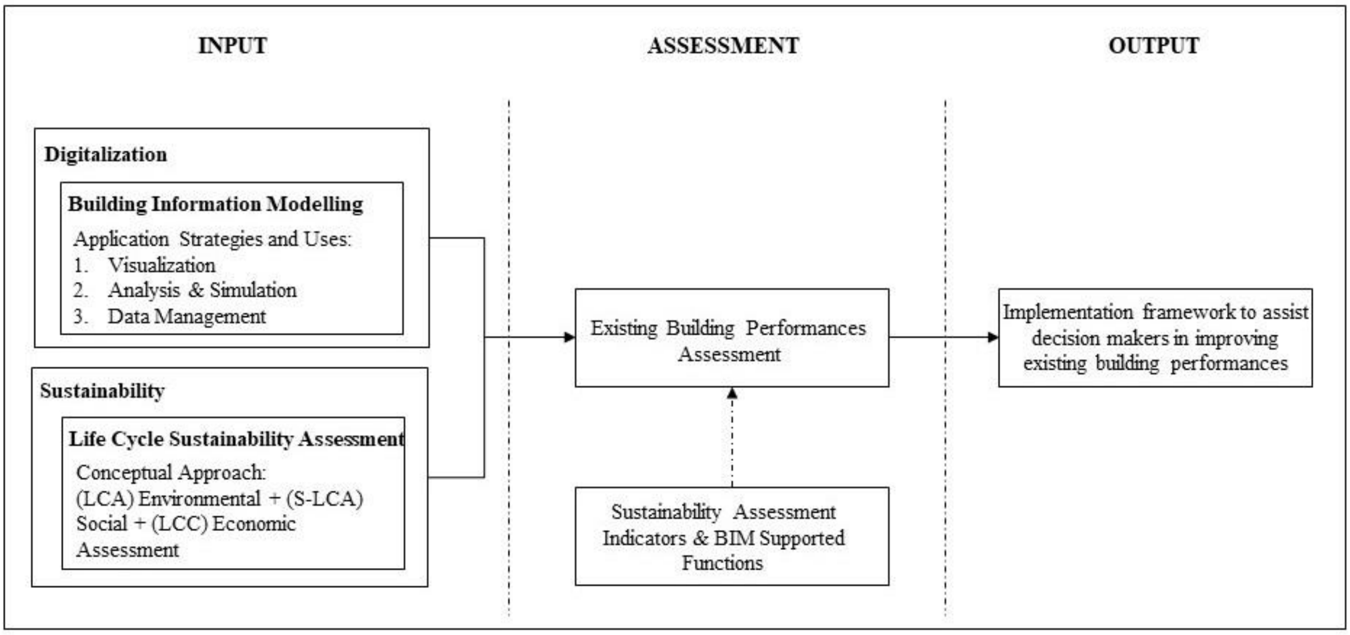
a) Referring to various benefits and functions of BIM, there is a strong potential to using BIM as facilitating tool in improving the sustainability performances of existing buildings yet to be explored.
b) This has been proven by various BIM-life cycles integration studies conducted by previous researchers. However, far too little attention has been paid to integrate all three critical dimensions of sustainability (environmental, economic, and social) in one approach using LCSA. Also, most of the prevailing studies explored implementing BIM-life cycle tool on the design phase of new buildings leaving existing buildings, particularly the operation phase left behind.

Following the findings from the literature, a conceptual framework to support the study aim is developed. As shown in Figure 2, the framework comprises three major elements, namely (i) Input, (ii) Assessment and (iii) Output. The 'Output' represents the final aim of this study that is to develop BIM-LCSA implementation framework as a decision-support tool to improve sustainable performances of an existing buildings.

To fulfil the output, two critical fundamental inputs required are (1) LCSA approach to be adopted and (2) BIM application strategies and related uses. Conceptually, LCSA represents the integration of three sustainability dimensions that are environmental, social, and economic. LCSA four steps implementation approach is as previously suggested by UNEP/SETAC. This includes defining the functional unit and boundary of the processes, inventory analysis that involves collecting data pertaining to existing buildings from BIM model and database and performing LCIA. LCIA consist of conducting impact assessment based on the triple dimensions of sustainability that represent LCA, LCC, and SLCA individually. Meanwhile, BIM application strategies include visualisation, analysis, and simulation to present real-life information to project stakeholders and database management. BIM database management may be expanded to include clash detection, costing analysis, quantity take-off, manpower and material schedule.

The assessment phase involves the integration of BIM uses and their supported functions to facilitate indicators assessment. Hence, a set of sustainability indicators will be used as guiding parameters. These indicators were previously collected and compiled from various Green Building Rating Tools (GBRT) and have gone through series of validation processes to ensure it fits the requirement for existing buildings. These indicators were grouped according to LCSA approach representing environmental (40 indicators), social (43 indicators), and economic (4 indicators). Details of these indicators were presented and discussed in [62]. Accordingly, the indicators identified will be evaluated to foresee which function of BIM may consolidate or fulfil their requirements.

Figure 2. Conceptual framework to bridge BIM and LCSA in greening existing buildings



5. Conclusion

This paper offered an initial step to explore the potential of connecting both BIM and LCSA to improve existing buildings sustainability performances. Various BIM supporting functions are explored to help performing sustainability analysis of existing buildings. The proposed sustainability analysis adopting LCSA four-step approach will be based on a set of pre-identified indicators as parameters. These indicators will be consolidated into BIM supporting functions to evaluate the sustainability performances of existing buildings. Several implementation considerations have been discussed too including availability of pre-existing BIM data on the selected buildings as well as data and information exchange between BIM and different sustainability performance tools. The conceptual framework presented is part of ongoing research to establish BIM-LCSA decision-making framework to greening existing buildings. Hence, in future work, the framework is to be further improved by developing a detailed framework that includes implementation methodology and steps to be taken to operationalise the decision-making process among project stakeholders. The final implementation framework is expected to assist project stakeholders including the project manager (or facility manager), building owner, and consultants in deciding towards improving existing buildings' sustainable performance.

As a clarification, the study is limited to the context of using 3D BIM as a primary basis tool engaging its authoring and application tools only. Considering the scope of study focusing on existing buildings, hence the as-built BIM model is required to support data extraction required during the process. Correspondingly, this study does not go deeper into conducting detail methodological processes of LCSA. The concept and four-step approach of LCSA is adapted to ensure indicators identified emphasised all three sustainability dimensions (environmental, economic, and social) during building evaluation and decision-making process. The boundary set to eradicate the need to further explore in detail the technical aspects of BIM such as new plug-in development, software used and others.

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References

[1] UN Environment and International Energy Agency, "Towards a zero-emission, efficient and resilient buildings and construction sector: Global Staturs Report 2017," United Nations Environmental Programme (UNEP)2017.
[2] S. C. Chua and T. H. Oh, "Green progress and prospects in Malaysia," *Renewable and Sustainable Energy Reviews,* vol. 15, pp. 2850-2861, 2011.
[3] S. Raslanas, A. Stasiukynas, and E. Jurgelaitye, "Sustainability assessment studies of recreational buildings," *Proceedia Engineering,* vol. 57, pp. 929-937, 2013.
[4] S. N. Kamaruzzaman, E. C. W. Lou, N. Zainon, N. S. M. Zaid, and P. F. Wong, "Environmental assessment schemes for non-domestic building refurbishment in the Malaysian context," *Ecological Indicators,* vol. 69, pp. 548-558, 2016.
[5] Global Alliance for Buildings and Construction, International Energy Agency, and United Nation Environment Programme, "2019 Global Status Report for Buildings and Construction; Towards a zera emissions, efficient and resilient buildings and construction sector," 2019.
[6] P. J. Yang *et al.*, "Sustainability needs and practices assessment in the building industry of China," *Energy Policy,* vol. 57, pp. 212-220, 2013.
[7] B. C.-M. Leung, "Greening existing buildings [GEB] strategies," *Energy Reports,* vol. 4, pp. 159-206, 2018/11/01/ 2018.
[8] A. Vilches, A. Garcia-Martinez, and B. Sanchez-Montañes, "Life cycle assessment (LCA) of building refurbishment: A literature review," *Energy and Buildings,* vol. 135, pp. 286-301, 2017/01/15/ 2017.
[9] Z. Zhou, S. Zhang, C. Wang, J. Zuo, Q. He, and R. Rameezdeen, "Achieving energy efficient buildings via retrofitting of existing buildings: a case study," *Journal of Cleaner Production,* vol. 112, pp. 3605-3615, 2016/01/20/ 2016.
[10] L. F. Cabeza, L. Rincón, V. Vilariño, G. Pérez, and A. Castell, "Life cycle assessment (LCA) and life cycle energy analysis (LCEA) of buildings and the building sector: A review," *Renewable and Sustainable Energy Reviews,* vol. 29, pp. 394-416, 2014/01/01/ 2014.
[11] M. Röck, A. Hollberg, G. Habert, and A. Passer, "LCA and BIM: Visualization of environmental potentials in building construction at early design stages," *Building and Environment,* vol. 140, pp. 153-161, 2018/08/01/ 2018.
[12] R. Santos, A. A. Costa, J. D. Silvestre, and L. Pyl, "Integration of LCA and LCC analysis within a BIM-based environment," *Automation in Construction,* vol. 103, pp. 127-149, 2019/07/01/ 2019.
[13] C. Llatas *et al.*, "Towards a Life Cycle Sustainability Assessment method for the quantification and reduction of impacts of buildings life cycle," *IOP Conference Series: Earth and Environmental Science,* vol. 323, p. 012107, 2019/09/06 2019.
[14] S. Chen, K. Feng, and Y. Wang, "The Application of Building Information Modeling in Sustainable Construction: A Literature Review," in *ICCREM 2018: Sustainable Construction and Prefabrication - Proceedings of the International Conference on Construction and Real Estate Management 2018*, 2018, pp. 21-37.
[15] S. Azhar, J. Brown, and R. Farooqui, *BIM-based Sustainability Analysis: An Evaluation of Building Performance Analysis Software*. 2009.
[16] E. Kriegel and B. Nies, *Green BIM*. Indianapolis: Wiley Publishing, 2008.
[17] R. Hammond, N. O. Nawari, and B. Walters, "BIM in Sustainable Design: Strategies for Retrofitting/Renovation," presented at the International Conference on Computing in Civil and Building Engineering, Orlando, Florida, USA, 2014.
[18] T. Olawumi and D. D. Chan, *Identifying and Prioritizing the Benefits of Integrating BIM and Sustainability Practices in Construction Projects: A Delphi Survey of International Experts*. 2018.

[19] P. Bynum, R. A. Issa Raja, and S. Olbina, "Building Information Modeling in Support of Sustainable Design and Construction," *Journal of Construction Engineering and Management,* vol. 139, no. 1, pp. 24-34, 2013/01/01 2013.
[20] S. Soltani, "The Contributions of Building Information Modelling to Sustainable Construction," *World Journal of Engineering and Technology 2016* vol. 4, pp. 193-199, 2016.
[21] T. Ahmad, A. Aibinu, and M. J. Thaheem, "BIM-based Iterative Tool for Sustainable Building Design: A Conceptual Framework," *Procedia Engineering,* vol. 180, pp. 782-792, 2017/01/01/ 2017.
[22] Y. Lu, Z. Wu, R. Chang, and Y. Li, "Building Information Modeling (BIM) for green buildings: A critical review and future directions," *Automation in Construction,* vol. 83, pp. 134-148, 2017/11/01/ 2017.
[23] Z. Liu, D. K. Chen, D. L. Peh, and D. K. W. Tan, "A feasibility study of Building Information Modeling for Green Mark New Non-Residential Building (NRB): 2015 analysis," *Energy Procedia,* vol. 143, pp. 80-87, 2017/12/01/ 2017.
[24] P. Gholizadeh, B. Esmaeili, and P. Goodrum, "Diffusion of Building Information Modeling Functions in the Construction Industry," *Journal of Management in Engineering,* vol. 34, no. 2, p. 04017060, 2018/03/01 2018.
[25] R. Eadie, M. Browne, H. Odeyinka, C. McKeown, and S. McNiff, "BIM implementation throughout the UK construction project lifecycle: An analysis," *Automation in Construction,* vol. 36, pp. 145-151, 2013/12/01/ 2013.
[26] R. Volk, J. Stengel, and F. Schultmann, "Building Information Modeling (BIM) for existing buildings — Literature review and future needs," *Automation in Construction,* vol. 38, pp. 109-127, 2014/03/01/ 2014.
[27] J. J. McArthur, "A Building Information Management (BIM) Framework and Supporting Case Study for Existing Building Operations, Maintenance and Sustainability," *Procedia Engineering,* vol. 118, pp. 1104-1111, 2015/01/01/ 2015.
[28] L. Joblot, T. Paviot, D. Deneux, and S. Lamouri, *Literature review of Building Information Modeling (BIM) intended for the purpose of renovation projects*. 2017, pp. 10518-10525.
[29] C. M. Eastman, C. Eastman, P. Teicholz, and R. Sacks, *BIM Handbook: A Guide to Building Information Modelling for Owners, Managers, Designers, Engineers and Contractor* Hoboken, NJ: Wiley, 2011.
[30] R. J. Scherer and P. Katranuschkov, "BIMification: How to create and use BIM for retrofitting," *Advanced Engineering Informatics,* vol. 38, pp. 54-66, 2018/10/01/ 2018.
[31] S. Habibi, "The promise of BIM for improving building performance," *Energy and Buildings,* vol. 153, pp. 525-548, 2017/10/15/ 2017.
[32] M. Khaddaj and I. Srour, "Using BIM to Retrofit Existing Buildings," *Procedia Engineering,* vol. 145, pp. 1526-1533, 2016/01/01/ 2016.
[33] E. Gholami, A. Kiviniemi, T. Kocaturk, and S. Sharples, *EXPLOITING BIM IN ENERGY EFFICIENT DOMESTIC RETROFIT: EVALUATION OF BENEFITS AND BARRIERS*. 2015.
[34] D. Ilter and E. Ergen, "BIM for building refurbishment and maintenance: current status and research directions," *Structural Survey,* vol. 33, no. 3, pp. 228-256, 2015.
[35] C. Valente, I. S. Modahl, and C. Askham, "Method development for Life Cycle Sustainability Assessment (LCSA) of New Norwegian Biorefinery," 2013.
[36] Y. Dong and S. Ng, "A modeling framework to evaluate sustainability of building construction based on LCSA," *The International Journal of Life Cycle Assessment,* vol. 21, 02/17 2016.
[37] M. Finkbeiner, S. Erwin, A. Lehmann, and T. Marzia, "Towards Life Cycle Sustainability Assessment," *Sustainability,* vol. 2, 10/22 2010.
[38] M. Hannouf and G. Assefa, "Life Cycle Sustainability Assessment for Sustainability Improvements: A Case Study of High-Density Polyethylene Production in Alberta, Canada," *Sustainability,* vol. 9, no. 2332, 2017.
[39] P. Tarne, M. Traverso, and M. Finkbeiner, "Review of Life Cycle Sustainability Assessment and Potential for Its Adoption at an Automotive Company," *Sustainability,* vol. 9, no. 670, 2017.
[40] UNEP/SETAC, "Towards a Life Cycle Sustainability Assessment " 2011.
[41] S. Valdivia, C. Ugaya, J. Hildenbrand, M. Traverso, B. Mazijn, and G. Sonnemann, "A UNEP/SETAC approach towards a life cycle sustainability assessment - Our contribution to Rio+20," *The International Journal of Life Cycle Assessment,* vol. 18, 11/23 2012.
[42] A. Zamagni, "Life cycle sustainability assessment," *The International Journal of Life Cycle Assessment,* vol. 17, no. 4, pp. 373-376, 2012/05/01 2012.
[43] W. Kloepffer, "State-of-the-Art in Life Cycle Sustainability Assessment (LCSA); Life Cycle Sustainability Assessment of Products," *Intenrational Journal of Life Cycle Assessment,* vol. 13, no. 2, pp. 89-95, 2008.

[44] N. Hossaini, B. Reza, S. Akhtar, R. Sadiq, and K. Hewage, "AHP based life cycle sustainability assessment (LCSA) framework: a case study of six storey wood frame and concrete frame buildings in Vancouver," *Journal of Environmental Planning and Management*, vol. 58, no. 7, pp. 1217-1241, 2015/07/03 2015.
[45] F. Jalaei and A. Jrade, "Integrating Building Information Modeling (BIM), energy analysis and simulation tools to conceptually design sustainable buildings," vol. 1, pp. 556-565, 2013.
[46] L. Á. Antón and J. Díaz, "Integration of Life Cycle Assessment in a BIM Environment," *Procedia Engineering*, vol. 85, pp. 26-32, 2014/01/01/ 2014.
[47] M. Najjar, K. Figueiredo, M. Palumbo, and A. Haddad, "Integration of BIM and LCA: Evaluating the environmental impacts of building materials at an early stage of designing a typical office building," *Journal of Building Engineering*, vol. 14, pp. 115-126, 2017/11/01/ 2017.
[48] B. Soust-Verdaguer, C. Llatas, and A. García-Martínez, "Critical review of bim-based LCA method to buildings," *Energy and Buildings*, vol. 136, pp. 110-120, 2017/02/01/ 2017.
[49] S. Seo, S. Tucker, and P. Newton, "Automated Material Selection and Environmental Assessment in the Context of 3D Building Modelling," *Journal of Green Building*, vol. 2, no. 2, pp. 51-61, 2007/05/01 2007.
[50] A. Naneva, M. Bonanomi, A. Hollberg, G. Habert, and D. Hall, "Integrated BIM-Based LCA for the Entire Building Process Using an Existing Structure for Cost Estimation in the Swiss Context," *Sustainability*, vol. 12, no. 9, 2020.
[51] J. P. Carvalho, I. Alecrim, L. Bragança, and R. Mateus, "Integrating BIM-Based LCA and Building Sustainability Assessment," *Sustainability*, vol. 12, no. 18, 2020.
[52] T. Ahmad and M. J. Thaheem, "Economic sustainability assessment of residential buildings: A dedicated assessment framework and implications for BIM," *Sustainable Cities and Society*, vol. 38, pp. 476-491, 2018/04/01/ 2018.
[53] F. Jalaei and A. Jrade, "Integrating building information modeling (BIM) and LEED system at the conceptual design stage of sustainable buildings," *Sustainable Cities and Society*, vol. 18, pp. 95-107, 2015/11/01/ 2015.
[54] M. H. Dawood, "BIM based optimal life cycle cost of sustainable house framework," in *2016 3rd MEC International Conference on Big Data and Smart City (ICBDSC)*, 2016, pp. 1-5.
[55] S. Liu, X. Meng, and C. Tam, "Building information modeling based building design optimization for sustainability," *Energy and Buildings*, vol. 105, pp. 139-153, 2015/10/15/ 2015.
[56] M. Marzouk, M. Hisham, M. Elsheikh, and K. Al-Gahtani, "Building information model for selecting environmental building materials," in *7th International Structural Engineering and Construction Conference: New Developments in Structural Engineering and Construction*, United States, 2013, pp. 1679-1684: Research Publishing Services.
[57] M. Meslec, S. Ashworth, and C. Druhmann, "Integrating Life Cycle Sustainability Analysis with BIM " presented at the EFMC, Sofia Bulgaria, 2018.
[58] U. Persson and S. Olander, "Methods to estimate stakeholder views of sustainability for construction projects," 2004.
[59] T. Ahmad and M. J. Thaheem, "Developing a residential building-related social sustainability assessment framework and its implications for BIM," *Sustainable Cities and Society*, vol. 28, pp. 1-15, 2017/01/01/ 2017.
[60] H. A. Toosi and M. Lavagna, "Optimization and LCSA-Based Design Method for Energy Retrofitting of Existing Building," *the Learning Network of Sustainability*, 2018.
[61] J. Basbagill, F. Flager, M. Lepech, and M. Fischer, "Application of life-cycle assessment to early stage building design for reduced embodied environmental impacts," *Building and Environment*, vol. 60, pp. 81-92, 2013/02/01/ 2013.
[62] N. S. Zulkefli, F. A. Mohd-Rahim, and N. Zainon, "Preliminary Review on Sustainable Indicators to Greening Existing Buildings Based on LCSA Components," *Malaysia Construction Research Journal*, vol. 9, no. 1 (Special Issue), pp. 81-93, 2020.