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Review of BIM for existing building sustainability performance and green retrofit

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A B S T R A C T

Green retrofit is considered an effective strategy to improve the sustainability of existing buildings which have high energy usage and carbon emission especially at urban area due to scarcity of land. Nevertheless, the conventional method of analyzing and green retrofitting the existing buildings depends on various disjointed processes and decision-makings. Though the development of Building Information Modeling (BIM) offers integrated solutions for green retrofit by evaluating different building sustainability performances based on a centralized digital model, the actual applications of such technology still require further studies. Thereby this paper reviews the previous research related to the use of BIM and relevant computational technologies such as simulation and visual programming for green retrofit of existing buildings. The review shows that the recent research on this area covers case studies, framework developments and reviews. Based on the findings, common BIM sustainability tools, performance parameters and design parameters in the recent research on existing buildings were identified. Furthermore, the issues and challenges faced in the implementation of BIM for green retrofit were raised including missing information, data transfer issue, lack of unified platform as well as the low automation of BIM and building performance tools. Through the review, this paper provides important guidance to the researchers and practitioners to implement BIM for green retrofitting of existing buildings.

Keywords: BIM; existing building; sustainability; retrofitting; simulation; green building

Introduction

The current concerns for climate change and depletion of finite natural sources in parallel with the limitations on land use, has resulted in great attention to retrofit existing buildings. This scenario is critical especially at urban area due to scarcity of land space and compliance of aged buildings to fulfil new standards and regulatory requirements. In particular, the existing buildings constructed in the past do not comply with the current environmental sustainability standards and regulatory requirements, thus measures are necessary to improve the energy usage and carbon emission of these buildings. Retrofit can help to reduce life cycle greenhouse gas emissions compared to reconstruction [1]. However, there were many challenges in green retrofit of existing buildings had to be tackled, including choosing of suitable retrofit method, effectiveness in reducing energy consumption, life cycle cost analysis and return-of-investment period [2, 3].

Achieving efficient energy performance and indoor comfort in existing buildings through green retrofit requires application of the optimal combination of several design strategies, which should be verified with building energy simulations tools during the design-decision making stage [4-7]. Nevertheless, due to different effective factors and several objectives to meet in the process of decision-making in the green retrofit, the problem faced by the design team or decision-maker is in fact a multi-objective optimization problem [5]. Usually the process of selecting the best possible green retrofit measure for a particular project is a problem with conflicting objectives; the optimal solution is usually a trade-off among several factors, such as energy, economy, technical and environmental-based, regulations and social considerations, etc. [8].

Building Information Modeling (BIM) has become trend in construction industry as attempts of integrating technology to smoothen project management and data transfer. BIM can provide a universal platform for architecture, engineering and construction (AEC) industry to work coherently, share information and communicate under the same framework [9, 10]. One of the advantages of using BIM in building design is that it can work with other simulation engine developed for building performance simulation [11]. Since BIM utilizes the power of computing, it is faster and more efficient in handling enormous information gathered from design, construction, maintenance and demolition. The implementation of BIM can potentially facilitate the sustainability performance analyses at early design stage [9, 12] as well as green retrofit of existing buildings [3, 13]. This is because BIM provides a centralized digital model which can be used to assess different environmental performances of a building continuously throughout its life cycle to facilitate for various decision-making in green retrofit [8, 14].

Computational method including visual programming and optimization algorithm can be integrated with BIM to increase the level of automation in design process [15-18]. Computational BIM combines logic, geometry, math and BIM with visual programming; it allows users to define algorithms and workflows for automated generation and manipulation of building information to improve efficiency and level of automation [19]. It has gained attention among the researchers to ease the data transfer across BIM platforms with other simulation engines [20, 21]. The computational BIM helps to solve the compatibility issue between software including data format conversion and fill up of insufficient data. Figure 1 presents an example of computational BIM visual programming script using Dynamo [21]. Besides, computational BIM can also help in optimization of simulation by providing algorithm for automatic feedback of result into model and with additional calibration, more accurate outcome can be achieved. For instance, visual programming can integrate daylighting and thermal simulations, then employ multi-objective optimization algorithm such as Genetic Algorithm to optimize the performance [15, 16, 20].

Though BIM offers integrated solutions for green retrofit by evaluating different building sustainability performances based on a centralized digital model, the actual applications of such technology are still relatively new and require further studies and verifications. Furthermore, previous studies have concluded that there is still

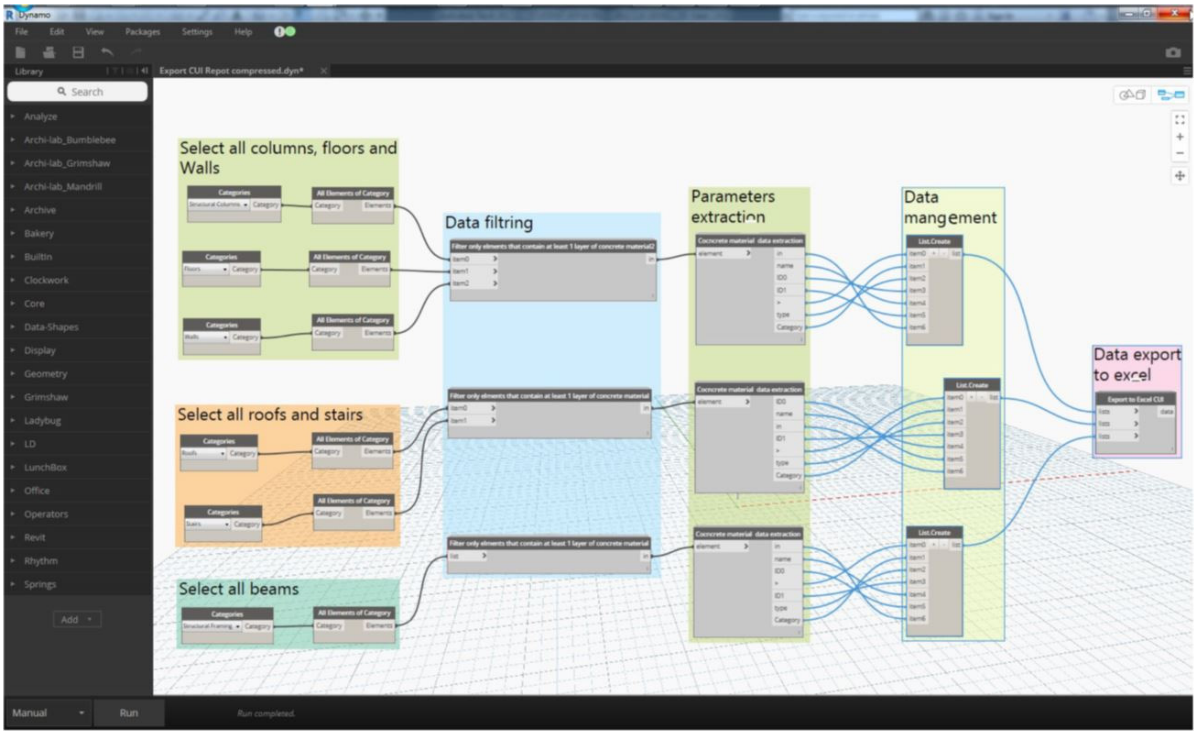

Figure 1. Computational BIM using visual programming script in Dynamo [21].

lack of research on BIM implementation in existing buildings and refurbishment [3, 22]. Thereby the aim of this review is to investigate the current state of implementation of BIM in building sustainability performance analyses and green retrofit of existing buildings. The research works published in renowned database were studied and recent establishments on building performance analyses using BIM were identified. Research gaps were acknowledged and discussed based on the current development. The significance of this review is in identifying the current trend and future needs of this evolving research area for practitioners in the industry and academic researchers. The findings also recommend the development of research framework to address the underlying issues and challenges in the application of BIM for existing building sustainability performance analysis and green retrofit.

Method

This paper presents a critical review on recent research articles on the use of BIM for existing building sustainability performance analyses and green retrofit. The review focuses on the methods, tools and parameters employed by different researchers in order to understand the issues and research gaps in the relevant area. It seeks the answers for 1) What are the commonly used methods of study, BIM tools and data management methods in this area of research? 2) What are the performance parameters and retrofit design parameters studied? 3) What are the issues and challenges faced and how did the research works address them?

The articles were searched from the peer-reviewed scientific publication database of Web of Science Core Collection and SCOPUS using keywords of “Building Information Modeling”, “BIM”, “retrofit” and “sustainability”.

Although these keywords provided many research articles, only the articles related to existing buildings were selected for the review. Besides, this review only included the recent publications from January 2017 till February 2020.

A total of 84 publications were identified using the abovementioned keywords, databases and publication year. However, some of the publications are actually not particularly implementing BIM for existing buildings or retrofit for sustainability. Some of them applied BIM generally for both existing and new buildings or to retrofit for other purposes, thus they were not included in the review. Finally, only 39 research articles were selected which explicitly applied BIM for existing building sustainability performances or green retrofit.

In this review, the articles were categorized into 1) case study building or use case, 2) framework development and 3) review paper in order to investigate the trend and type of previous studies conducted in this evolving research area. In research using case study building or use case, the application of BIM in actual scenario was conducted. In framework development, the outline of the BIM utilization in green retrofit is described and the demonstration of framework can be either present or not. In review paper, the status of BIM in green retrofit is summarized and the critical review on the issue is proposed. In total, 27 case study or use case, 13 framework development and 7 review papers were reviewed in this paper. Table 1 shows the distribution of articles reviewed according to their published year.

The research articles were then further categorized according to the types of BIM authoring and analyses tools, data input, data management, data exchange file formats, sustainability performance parameters and building design parameters. Then, synthetization of the literature was conducted to determine the issues, challenges and solutions presented in the research works. The overall review procedure framework is illustrated in the Figure 2.

Table 1. Category of paper reviewed

Method of Study	Year of Publication				Total
	2017	2018	2019	2020	
Case study building/ Use case	Cellura et al. (2017) [51]; Gourlis and Kovacic (2017) [34]; Habibi (2017) [38]; Maltese et al. (2017) [40];	Eleftheriadis et al. (2018) [55]; Hu (2018) [49]; Jeon et al. (2018) [58]; Kamel and Memari (2018) [39]; Kim (2018) [33]; Pinheiro et al. (2018) [42]; Shadram and Mukkavaara (2018) [36]	Ahsan et al. (2019) [54]; Branca et al. (2019) [44]; Cecconi et al. (2019) [53]; Chong et al. (2019) [35]; García-Fuentes et al. (2019) [52]; He et al. (2019) [48]; Kamel and Memari (2019) [57]; Lim, et al. (2019) [45]; Lin et al. (2019) [31]; Ozarisoy and Altan (2019) [46]; Sadeghifam et al. (2019) [29]; Tzortzopoulos et al. (2019) [62]; Wei et al. (2019) [43]	Feng et al. (2020) [1]; Habibi et al. (2020) [47]; Kwok et al. (2020) [60]; Rocha et al. (2020) [30]	28
Framework	Dupuis et al. (2017) [56]; Maltese et al. (2017) [40]	Hu (2018) [49]; Kamel and Memari (2018) [39]; Pinheiro et al. (2018) [42]; Scherer and Katranuschkov (2018) [13]; Shadram and Mukkavaara (2018) [36]	Carvalho et al. (2019) [26]; Chong et al. (2019) [35]; García-Fuentes et al. (2019) [52]; Hong et al. (2019) [23]; Li et al. (2019) [41]; Tzortzopoulos et al. (2019) [62]	-	13
Review	Chong et al. (2017) [22]; Eleftheriadis et al. (2017) [50]; Lu et al. (2017) [59]	Sanhudo et al. (2018) [14]	Edwards et al. (2019) [32]; Farzaneh et al. (2019) [37]; Kamel and Memari (2019) [57]	-	7
Total publication reviewed (exclude duplication)					**39**

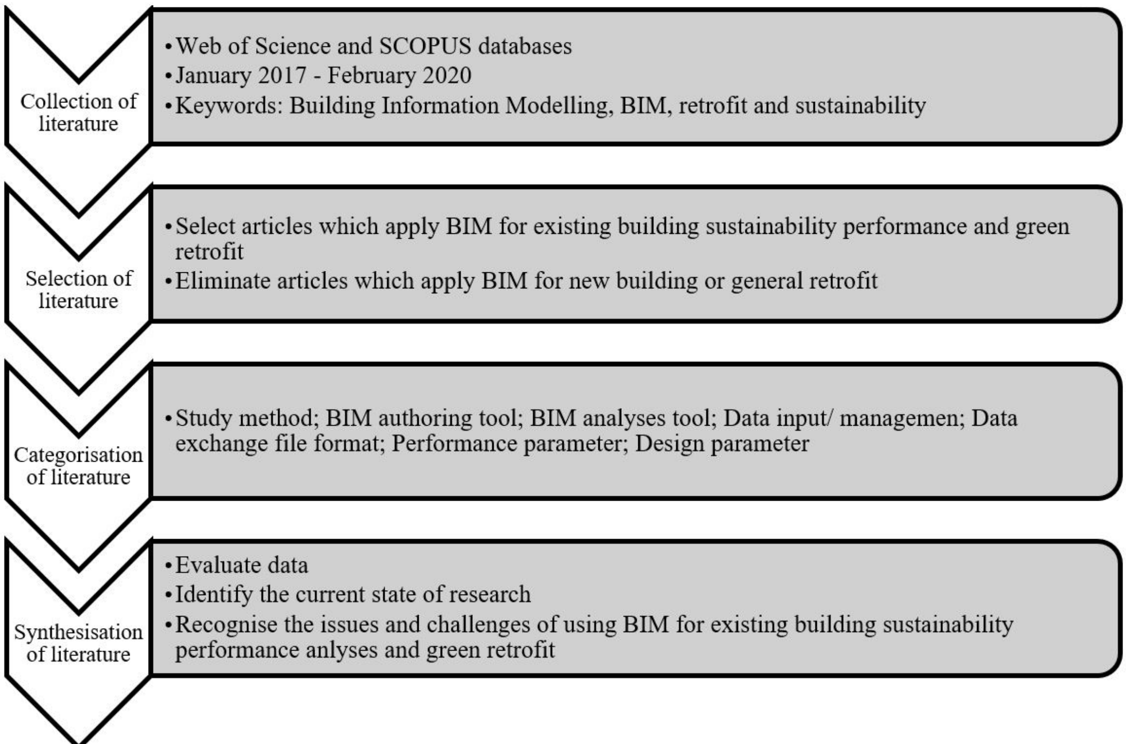

Figure 2. The review procedure framework.

Findings

The findings show that there is limited academic publications on BIM for existing building sustainability performance and green retrofit. The findings of the review are presented according to a few sub-themes namely: (1) BIM tools for building sustainability performance; (2) Data acquisition for existing building, (3) Data management and interoperability; (4) Computational BIM using visual programming; (5) Green retrofit design parameter; and (6) Green building performance parameters.

BIM tools for building sustainability performance

BIM modeling software is the application that creates model and assigns characteristic and properties of design to the model. The most popular BIM modeling tool among researchers is Autodesk Revit; it had been referred in 24 research articles and used in modeling work. Other BIM modeling software such as ArchiCAD was discussed in a review paper [14] with a group of researchers adopted it for energy simulation of green façade retrofit optimization [23].

The review shows that Revit had been the most popular BIM modeling solution since 2012 with more than 50% of UK practitioners prefer to use it [14]. Another report indicated that by 2019 more than 46% of respondents were using Revit, and up to 70% were adopting other Autodesk software [24]. Revit can be used in conjunction with Autodesk in-house building energy simulation engine Green Building Studio, and the energy model can be exported to other simulation engines such as EnergyPlus via common file formats, namely gbXML and DOE2 [25]. Using Revit together with other additional software, it can cover majority green building assessment criteria [26].

Table 2. Type of simulation performed by software and frequency in reviewed paper

Software	Type of simulation	No. of article
DesignBuilder	Energy use Carbon emission Green Building Assessment	4
IES-VE	Energy use Carbon emission Green Building Assessment	5
Ecotect	Energy use Solar and daylighting	3
EnergyPlus / OpenStudio	Energy use Carbon emission Green Building Assessment	14
Green Building Studio	Energy use Carbon emission Green Building Assessment	7
DAYSIM	Solar and daylighting	2
Total number of article (excluding duplication)		**20**

For building sustainability performance simulation software, there are several open-source or proprietary software that had been used in past research for different types of simulation purpose. Table 2 shows the software used among the reviewed paper with type of simulation performed and frequency of usage in paper. From this study, majority of the software are capable to perform energy analysis and carbon emission. Some of them can conduct Green Building Assessment (LEED, BREEAM, Green Star) for the building for sustainability audit.

From the literature reviewed, EnergyPlus was adopted in 75% of research work utilizing building performance simulation software. It is an open-source simulation engine developed by US Department of Energy for energy consumption of building and support for LEED energy audit report. It can be used as plugin in BIM environment by translating the data source from BIM output into comprehensive input for EnergyPlus by using OpenStudio, which is a software development kit used in conjunction with EnergyPlus and build-in input data file (IDF) editor. Another popular simulation engine, Ecotect had been discontinued by Autodesk in 2015 and replaced by Green Building Studio which is integrated to Revit [27, 28].

Previous studies showed that most researchers opt to open source EnergyPlus which have many supporting document or embedded analysis software in Revit for ease of data transfer [14]. For example, EnergyPlus was used for energy analysis of tropical housing for optimization of building envelope materials [29]. Besides, BIM and EnergyPlus were employed to determine the most economical alternative for a semi-outdoor bus station retrofit [30].

There are researchers attempted to use other simulation engine for energy analysis, for example IES-VE had been used in conjunction with Revit for green building energy analysis in a case study of traditional public market from Taiwan [31]. However, studies found that the use of simulation engine during the early design phases of refurbishment projects is very limited; the energy usage in construction and production of materials cannot be accessed by any simulation engine [32]. Thus, the review concluded that different simulation software is needed to analyze varied environmental performances; there is lack of unified and integrated platforms for BIM tools. Hence, the data management process between one tool and another tool is essential to make sure the accuracy for outputs.

Data acquisition for existing building

The general data flow for building performance analysis is illustrated in Figure 3. Geometrical information and building materials used are the essential data required for BIM for construction of building model. The model data is then translated to readable input for simulation software. Extra data such as environment parameters (climate, solar, wind, surrounding landscape) are usually required to be added manually at this stage as they are absent in BIM but critical for sustainability analysis.

When an as-built BIM model for existing building with Level of Development (LOD) of 500 is not available, the raw data input for BIM can usually be obtained from the construction drawing or documentation. However, for existing or historic building when the documentation had lost or building that had been renovated, building information has to be obtained through alternative methods. The most common methods for geometrical data acquisition are 3D laser scanning, photogrammetry and Geographic Information System (GIS). Among the papers reviewed, 5 research works had used laser scanning, 3 works opted for photogrammetry and 4 works employed GIS method.

Although 3D laser scanning can generate Point Cloud which can be used as a basis for geometry definition, the process of translating the Point Cloud to BIM model may result in errors. Thus, additional manual corrections and modelling are required. On the other hand, the methods of photogrammetry and GIS are more affordable but their accuracy is lower compared with 3D laser scanning [33].

Data management and interoperability

The interoperability between the data from BIM to simulation software is also crucial as any mistake during data transfer will yield incorrect result or even halt the simulation. The data translation is usually managed via two alternatives: plug-in of simulation engine into BIM software or conversion of data by open source file formats.

Revit had support for several simulation engine plug-ins for energy analysis, such as IES-VE, OpenStudio, DesignBuilder etc. Several case studies had implemented these plug-ins successfully to achieve the desired analysis [34-36]. The usage of plug-in greatly simplifies the data transfer as they had been validated by the developer of

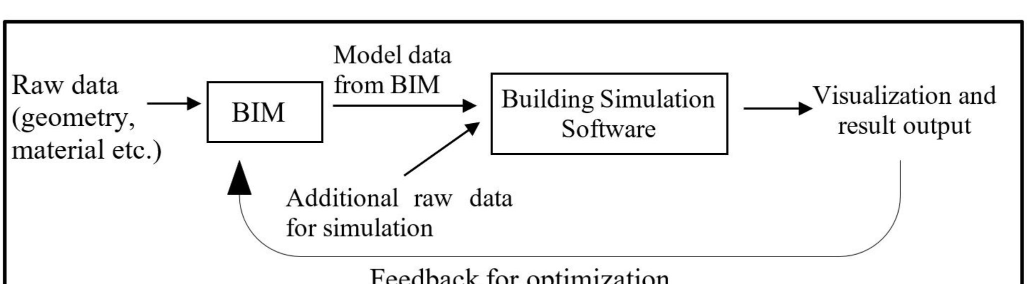

Figure 3. General data flow in building environmental performance simulation.

plug-in. However, less customization on the algorithm is available because they are designed for specific purposes; thus the accuracy and precision of output data are decided by developer.

In order to have more control on the simulation engine, some researchers had chosen to do simulation at external software and in most of time the conversion of file format from BIM to simulation engine is necessary. The usage of open source file format includes Industry Foundation Classes (IFC) and Green Building Extensible Markup Language (gbXML) to transfer the building attribute from BIM to simulation platform.

From the papers reviewed, there were 8 works adopted the IFC file format whereas 12 research adopted gbXML scheme, hence gbXML is more popular for environmental performance analysis research. Nevertheless, each file format has its own characteristic and researchers had outlined their development and limitation [37]. A framework can also involve both file formats for more sophisticated analysis [26].

Some notable projects that had involved using gbXML included the integration of Revit with IES-VE, Ecotect and DaySim for energy efficiency and indoor environmental quality analysis [38]. A framework using gbXML and modified OpenStudio is also developed to conduct thermal analysis, which is more time efficient, less error-prone and user-friendly [39].

For implementation of IFC scheme, previous study developed a three stages design framework for BIM based building performance analysis using standard IFC specification [13]. A framework was proposed to conduct Green Building Assessment based on IFC implementation [40]. Furthermore, another framework was also formulated for façade retrofitting using Revit and EnergyPlus through IFC scheme to feedback to Revit model for optimization [41]. Although the development of IFC had been developed since year 2000 and well defined in ISO 16739, Pinheiro et al. had found that most BIM tools still do not support IFC export capability [42].

To sum up, the advantage of IFC is that it contains all building information from construction till operation, but its disadvantage is the large data file size. Whereas, gbXML is commonly used for energy simulation due to its simple data management with environmental information. However, gbXML can only represent building as rectangular shape.

Computational BIM by using visual programming

The usage of visual programming in conjunction with BIM and simulation engine, also known as computational BIM, had recently gained attention among the researcher. Application of visual programming can modify the BIM model definition, incorporate automation in simulation and provide feedback [37]. Two visual programming that had been used within BIM environment among researchers are Dynamo and Grasshopper.

Dynamo has been a popular alternative for user to create program inside Revit for different tasks suited for corresponding field of work. For instance, Dynamo had been used for the structural engineering in conjunction with BIM [43]. Revit-Dynamo was also used together with PETRA for energy and cost analysis of public school [44]. Moreover, Lim et al. employed Revit-Dynamo to optimize green retrofitting of existing building envelope for energy performance [45].

Grasshopper, a visual programming integrated with Rhino3D, had also been adopted by researchers besides Dynamo. Previous research had proposed a framework using both Dynamo and Grasshopper to optimize the building embodied and operational energy [36].

The review shows that the use of computational BIM can increase the level of automation for green retrofit performance evaluation and design decision-making. Besides, it can be used to automatically feedback the optimized data to update the BIM model [45]. Nevertheless, the current research on this aspect is still relatively limited, hence further research is needed to explore its application for green retrofitting design decision-making process.

Green retrofit design parameter

Green retrofit of a building can be done via different approaches. From the articles collected, some common design parameters for retrofitting are building orientation, windows or glazing, heating, ventilation, and air conditioning (HVAC), façade material and roofing. As shown in Table 3, most of the green retrofits focus on building material, followed by roofing and glazing.

The investigation of building material in retrofit had gained most attention and can be associated with its impact on most performance parameters including energy and carbon emission of the building. Understanding the influence of building materials on the building performance can increase effectiveness of retrofitting measures even though the existing building materials might not be replaced directly. Research on effect of building component material selection on the energy efficiency of building had been conducted [29]. Besides, optimization of building energy performance was also conducted by retrofit of building envelope [46].

The modifications of roofing and glazing materials are also popular alternative for green retrofit. For roofing retrofit, the installation of photovoltaic (PV) panel can be an effective green retrofit measure as the existing buildings usually have lower energy efficiency and utilization of PV panel can help to compensate the energy consumption [47]. Changing of glazing material was also often been done to improve the building performance by either increasing natural light for less energy in lighting or reducing heat radiation into the building for less HVAC loading [48].

Differs from other green retrofit parameters which are passive design, HVAC consumes energy to function and

Table 3. Frequency of retrofit design parameter in reviewed paper

Retrofit design parameter	No. of article
Orientation	2
Windows (Glazing)	12
Building material	17
HVAC	9
Roofing	14

its operation is also accompanied with high maintenance cost. Hence, the significant reduction in monthly electric bill is surely an attraction and motivation for retrofit. In some circumstances simple HVAC retrofit can achieve up to 45% cost saving [49].

The review indicates that material properties related design variables such as building envelope materials and glazing types were commonly studied by the previous research. This might due to the ability of BIM parametric modeling which the material properties can be altered easily for performance analysis. However, there is still lack of comprehensive case studies that include multiple design variables to optimize green retrofit measures.

Green building performance parameters

Table 4 lists out the performance parameters in green retrofit with their respective frequency in reviewed articles. Almost half of the total articles reviewed have related BIM implementation with building energy, showing that majority of green retrofit was focused on energy saving. Operational energy has more interest among the researchers, whereas embodied energy of building is usually determined by the initial construction design and cannot be reduced significantly by retrofitting. Improving the operational energy is more feasible to mitigate by fair modification of building components.

The usage of BIM can facilitate the simulation of building life cycle analysis starting from design stage until the end of demolition. Since the energy consumption and proportion of embodied or operational energy are different during each stage, it is crucial for designer to predict the energy pattern of building to determine best retrofit solution. BIM has been implemented for life cycle analysis for building energy [50]. BIM was also used as a LCA tool which was accurate till 0.01% deviation when compared to standard LCA study [51].

Cost analysis of a retrofit project is also important for investors' feasibility study. Most common parameter interested by investor are initial cost, annual cost saving and payback period. Case study had been carried out on optimization of retrofit measures to compare their final energy consumption, investment cost and life cycle cost [52, 53]. BIM tools such as Revit and Ecotect were used for energy and cost payback period analysis [54, 55].

Previous research has successfully implemented BIM to analyze different sustainability performance parameters for existing building and/or green retrofit. Nonetheless, various BIM analysis tools were required to evaluate different performances and there is lack of a unified BIM platform to cover all these parameters.

Table 4. Number of papers according to green building performance parameter

Green building performance parameter	No. of article
Embodied energy	7
Operational energy	23
Carbon emission	4
Life cycle analysis	11
Solar exposure	7
Green Building Assessment	5
Cost analysis	10

Discussion

This review showed a growing number of research works conducted on implementation of BIM for existing building sustainability performance analysis and green retrofit in the past 3 years. Most of the articles published in 2017 discuss frameworks or reviews, while the more recent articles (2018 to 2020) mainly focus on the implementations of BIM in terms of case studies. Nevertheless, there are several research gaps and challenges still need to be overcome. They include missing information, data transfer issue, lack of unified platform and poor optimization and automation.

The lack of raw data collection especially for existing or historical buildings had to be addressed by researchers in order to have accurate analysis outputs. Usually the building data is obtained via either on-site field measurement, existing database or assumption from user. Not all existing buildings have as-built BIM model with LOD 500. Efforts are needed to simplify the modeling process by eliminating unnecessary building information. For example, previous research had proposed a method to fill the data gap for LCA at LOD 100 [56].

Previous research discovered that not all Revit data were exported properly using gbXML and need to be added manually [57]. Such manual data input process is tedious for user and prone to error. Differences in building envelope condition can lead to significant deviation on energy consumption which can be up to 20% [58]. The low accuracy of BIM-based prediction models has been a potential research gap in green building analysis [59]. Researchers had urged for an integrated model checking function in BIM tools [14]. Hence, the developers of BIM and simulation software should have more involvement and collaboration with AEC industry so that their solutions are more intuitive and versatile for construction industry.

There are some compatibility issues occurred during data transfer across BIM and simulation engine. Most issues occurred either when the BIM files are generated by BIM tools such as Revit or during importing the BIM files by simulation tools [57]. These errors may lead to improper energy model, inaccurate result or even halt the simulation. Despite efforts of developing open source formats such as IFC and gbXML, the findings of previous studies concluded that there was weak interoperability among various BIM applications [59, 14]. Improved interoperability among BIM software and energy-simulation tools is urgently needed for more effective adoption [22, 60].

The development of BIM software and simulation engine is usually independent and only few corporations can provide integrated solution due to the lack of clear industry standards or codes for the various aspects of green BIM applications [59]. Lack of integration between BIM and simulation software into a unified platform has caused difficulties for BIM users to perform simulations. Besides, there is no simulation software that can analysis all performance indicators for green building analysis, thus multiple tools might be needed, which may affect the accuracy of simulation.

The automated data feedback to BIM from simulation result and update of BIM model also require more research focus. Currently, update of simulation or optimization outcome into original BIM model is not possible and require adoption and re-modeling [34]. Besides, researchers expected to have automatic generation of BIM model from raw data acquisition [61].

Although several frameworks had been proposed, the optimization of modeling and simulation process of green retrofit still requires improvement for better accuracy result and more user-friendly interface. Kim found that default BIM-to-BEM conversion by Revit does not support efficient abstraction of geometry, which makes simulation less efficient [33]. In attempt to provide easier interface, Tzortzopoulos et al. had presented a simpler BIM framework to decide retrofit strategy [62].

The review pointed out that developing frameworks for BIM-based green retrofit is needed to facilitate the implementation of the model-based technology in the AEC industry; such framework should address the challenges as discussed above. Furthermore, the integration of BIM with computational method such as visual programming is still relatively low based on the current review, hence it should be further explored to enhance the decision-making process and increase the level of automation.

Conclusion

The implementation of BIM in existing building sustainability performance and green retrofit had grown in demand for emerging technology and more sophisticated construction procedure. The current state of BIM in green retrofit had been reviewed in this paper including types of BIM and building performance software commonly employed as well as the parameters involved in the modeling and simulation process.

The findings have identified the challenges of using BIM for green retrofit of existing building. Missing information, data transfer issue, lack of unified platform, poor optimization and automation among BIM and building performance software are being the main issues that had to be addressed for better user experience and more complete green retrofit ecosystem.

This paper provides the current trend and future needs of this evolving research area to the researchers and practitioners to implement BIM for green retrofit of existing buildings. However, the current review is constrained to a small number of articles due to little research works have applied BIM for existing building sustainability performance and green retrofit. Especially for computational BIM using visual programming, its application is still rather limited. Further studies are recommended to look into the identified gaps and development of framework for future research.

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