Systematic Literature Review of Building Information Modelling and Green Building Certification Systems

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Abstract –

The rapid pace of technological transformation in sustainability assessment in the construction industry has directed the development of tools and policies. Building information modelling (BIM)-based documentation processes for green building certification systems (GBCS) credits continually require re-assessments. The relationship between BIM and GBCS is minimal in the current literature, which motivates the need for this systematic literature review. This study aims to map the synergies and potentials of BIM and GBCS integration for improvements in the sustainability assessment process. A systematic literature review was adopted to map existing gaps, potentials, and future research areas. A total of 84 papers between 2009 and 2020 from top indexed built environment journals. Energy possessed the highest representation of 71% in the environmental sustainability dimension while economic and social had 15% and 11% respectively. LEED possessed the highest representation of 35% in multi-criteria GBCS. The findings revealed predominant neglect of social and economic dimensions of sustainability credits. Regenerative credits such as biodiversity, water, land use and ecology, socio-economic and acoustics are less incorporated into sustainability assessment models. These findings have direct implications on sustainability assessment policy improvements to implement the use of emerging technologies such as internet of things (IoT) and Blockchain.

Keywords –

Building information modelling; BIM; Green building certification system; Net-zero buildings; Systematic literature review; Sustainability

1 Introduction

Sustainability problem solving is complex and requires an integrated approach to effectively address inherent environmental issues [1]. Consequently, the high rate of global resource utilisation in such forms as excessive water, energy, and forest use and raw materials has encouraged the concept of sustainable development with the view to meet the current needs without adverse effects on the future [2, 3]. Buildings are one of the most dominant sources of resource usage and environmental emissions, using about 50% of raw materials, consuming 71% of electricity and 16% of water usage, and producing 40% waste disposed of in landfills [4].

The global Architecture, Engineering and Construction (AEC) industry is currently undergoing a dynamic transformation with the introduction of green building (GB) [5]. This has led to the development of several GB certification systems (GBCS) such as Green Star (Australia, New Zealand, and South Africa), Leadership in Energy and Environmental Design [LEED] (the United States of America and Canada), Building Research Establishment Environmental Assessment Method [BREEAM] (United Kingdom), SBTool (Portugal and Czech), Chinese evaluation standard of green building [ESGB] (China), Building Environmental Assessment Method [BEAM] Plus (Hong Kong), Green Mark (Singapore), Green Building Index [GBI] (Malaysia), Deutsche Gesellschaft für Nachhaltiges Bauen [DGNB] (Germany), and Living Building Challenge (LBC). In addition, researchers have also developed GBCS for developing countries by adapting existing GBCS. Some prominent examples of newly developed GBCS are as follows: BSAM - Sub-Saharan Africa [6, 7], SABA - Jordan [8], and GB tool for existing buildings [9].

The AEC industry is more focused on applying emerging technologies to improve environmental sustainability [10]. Technologies such as artificial intelligence (AI), prefabrication, BIM, business process reengineering (BPR), and total quality management (TQM), among others, have been deployed to facilitate the integration of construction processes and achieve value for money [11].

McGraw-Hill Construction conducted an online survey to investigate a wide range of industry professionals who use BIM tools to deliver green buildings. The survey indicated that BIM could significantly facilitate green construction, and it is expected to be extensively used in the future if relevant challenges can be identified and effectively tackled [12]. BIM surfaced as a solution to facilitate the integration and management of information throughout the building life cycle [12], thus, enabling the effective use of design data for sustainability evaluations [13].

Several functions of BIM have been studied, such as lighting analysis, energy performance simulation, and construction and demolition waste analysis. In addition, different management and incentive aspects associated with BIM adoption have been highlighted, such as its economic benefits,organisational challenges, and motivational challenges [14-16]. A number of BIM applications have been proposed and developed to seamlessly integrate sustainability analysis into traditional design, construction, and operation processes, but there are limited reviews on the connections between BIM and green rating systems [12].

The successful integration of BIM and GB assessment requires a lot of data. Quantitative and qualitative data are the backbone of sustainability assessment [13, 17]. However, Zhao *et al.* [18] noted that one of the fundamental gaps in green building is information technology applications. Lu *et al.* [12] revealed that contemporary BIM software packages are still inadequate in delivering a unified analytical solution for a distinct green building assessment, as they cannot simultaneously analyse all green aspects of buildings.

Furthermore, Gandhi and Jupp [19] findings revealed one of the problems of BIM and green integration as a lack of alignment between the activities, processes, and tasks that encourage modelling and analysis and those that encourage the realisation of green building certification criteria. Also, Ansah *et al.* [13] identified interoperability issues as a major setback in implementing BIM for green building assessment due to the loss of quality information. Xu et al. [10] further acknowledged that one of the major challenges with the green construction process is an inaccurate assessment.

There have been several studies on integrating BIM and GBCS [18-25] in recent years. Examples include LEED [15, 20-22], SBTool [23-25], and ESGB [26]. Also, Jalaei and Mohammadi [21] developed a BIM-LEED Revit plugin including a data mining method (K-Nearest Neighbour) that integrated location and transportation, sustainable sites, energy and atmosphere, materials and resources, indoor environmental quality, innovation in design, and regional priority accounting for 6 of 8 credits in LEED v4. Similarly, Kang [22] created a rule-based LEED evaluation method with BIM to facilitate the sustainability assessment process and save time.

Although, many BIM applications have been proposed and developed to seamlessly integrate BIM and GBCS into the traditional design, construction, and operation processes. Nonetheless, there is still a need for comprehensive integration of BIM and GBCS throughout the project lifecycle [12]. As a result, a systematic literature review (SLR) was carried out. Relevant publications between 2009 and 2020 were identified and synthesised accordingly. The year range was based on literature search output after removing papers that were not relevant to the study. The outcome of this research will provide a roadmap and future directions for BIM and GBCS integration.

2 Research Methodology

Kitchenham and Charters [27] defined a systematic literature review (SLR) as:

> *"a methodology used to identify, evaluate and interpret research relevant to a determined topic area, research question or phenomenon of interest."*

Generally, there are five major reasons for executing a literature review as stipulated by Paré *et al.* [28] and Paré and Kitsiou [29]. These reasons include:

- establishing the current state of knowledge on the subject or topic;
- resolving the scope to which certain research area divulges any logical patterns;
- gathering practical findings in line with a research question to support its validity;
- creating new frameworks and theories; and
- ascertaining research topics or areas for future research.

The main focus of this SLR is to provide research topics or areas for future research. The review process is divided into two steps namely; SLR protocol development (Step I) and SLR execution (Step II). The SLR protocol development has four sub-steps (purpose definition, research question formulation, keywords and database selection), while the second step has six sub-steps (search strings refinement and article search, inclusion and exclusion criteria, title and abstract scanning, quality assessment, coding, and data extraction pattern). Carvalho *et al.* [24] highlighted the need for a more elaborate systematic literature review to include more keywords and green building rating tools such as Green Star, DGNB, BEAM Plus, etc. The purpose of the review is to provide answers to the following questions:

- What is the level of BIM implementation in GBCS sustainability areas?
- What are the future research directions in the BIM-GBCS domain?

The keywords for the literature search are shown in Table 1. Based on the keywords identified, a search string was developed and implemented on the Scopus search engine. As seen in Figure 1, the initial search string revealed a total of 400 research papers, while eighty-four (84) were selected for in-depth analysis. The findings of each of the papers are briefly summarised in Table 2.

Table 1. Keywords for systematic literature review

BIM	Green building and assessment tools	Method
BIM OR "Building information modeling" OR "Building Information Modeling (BIM)" OR "Building information model" OR "Building an information-model" OR "BIM (building information modeling)" OR "Building Information Modelling"	"green building" OR "green construction" OR "sustainable building" OR "high performance building" OR "building environmental performance" OR "ecological building" OR sustaina* OR "Green building concept" OR LEED OR CASBEE OR GBI OR DGNB OR BREEAM OR "Green Star" OR "Green Mark" OR "Green Globes" OR ESGB OR GBL OR ECOEFFECT OR ECOPROFILE OR ESCALE OR HK-BEAM OR "BEAM Plus" OR "GB Tool" OR "SB Tool" OR "Home Star" OR HQE OR "Energy Star"	"Assessment Method" OR "Assessment Rating Method" OR Certification OR "Green Building Certification" OR Evaluation OR "Labeling Method or System" OR Guideline OR Benchmark OR "Assessment Standard" OR "Green Building Rating Tools"

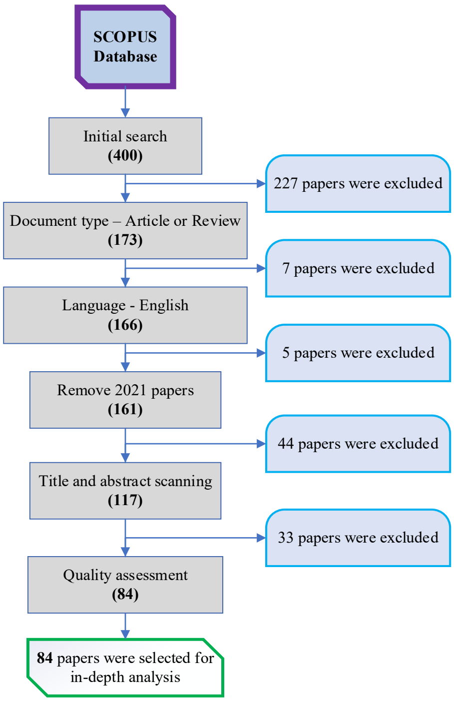

Figure 1. Overview of the paper elimination process

3 Analysis and Discussions

3.1 Descriptive Analysis

This section of the paper presents a descriptive analysis of the papers considered in this SLR. The presentation was based on the frequency of papers, GB sustainability area, and GBCS considered.

Frequency of Papers between 2009 and 2020

The frequency of publications between 2009 and 2020 is presented in Figure 2. It is seen that the year 2020 has the highest number of publications accounting for 29% of the total papers used in this study while no publication was recorded in 2012. Overall, it can be deduced that annual publications have grown haphazardly over the years. Also, it can be said that the increasing interest in GB is due to government policies and the coronavirus pandemic [30-32].

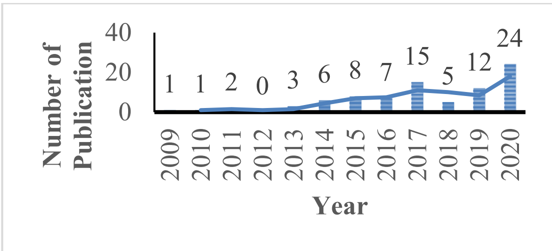

Figure 2. Frequency of Publication

Classification of Papers by GBCS Considered

It is important to note that many studies are mainly focused on the multi-criteria tool while only one paper by Acampa *et al.* [17] mentioned some of the existing lifecycle-based assessment tools (BEES, BEAT, and EcoQuantum). Forty percent (40%) of the studies did not report any GBCS, 35% used/mentioned LEED as a basis for their research while 10% used/mentioned BREEAM. Other GBCS such as Green Star (7%), SBTool (5%), GBI (5%), etc. has been seldom considered in the existing literature. Furthermore, some of the existing studies by Khoshdelnezamiha *et al.* [33], Olawumi and Chan [34], Mahmoud et al. [9], and Ahmad and Thaheem [35] have developed new rating tools (5%) to complement the shortcomings of the existing GBCS.

Journal of Selected Papers

Table 3 shows the top 10 journals in which the selected papers were published. Nearly 40% were published in *Sustainability [Switzerland]* (15.48%), *Automation in Construction* (9.52%), *Sustainable Cities and Society* (7.14%), *Journal of Green Building* (4.76%), and *Applied Sciences [Switzerland]* (2.38%). The table contains highly ranked journal papers that guarantee the reliability of data to be gathered during the SLR.

Table 3. Top 10 Journals of Selected Papers

S/N	Journal	Frequency	*Percentage (%)
1	Sustainability	13	15.48%
2	Automation in Construction	8	9.52%
3	Sustainable Cities and Society	6	7.14%
4	Journal of Green Building	4	4.76%
5	Applied Sciences (Switzerland)	2	2.38%
6	Architectural Engineering and Design Management	2	2.38%
7	ARPN Journal of Engineering and Applied Sciences	2	2.38%
8	Buildings	2	2.38%
9	Energy and Buildings	2	2.38%
10	International Journal of Sustainable Building Technology and Urban Development	2	2.38%

*Percentage is based on the overall contribution of the journal based on the 84 papers

3.2 Thematic Analysis

Level of BIM implementation in GB Sustainability Area

Using the Green Star NZ as a yardstick, a large portion of the papers focused on the environmental aspect of sustainability which includes; management (4%), indoor environment quality (35%), energy (71%), transport (20%), water (26%), materials (54%), land use and ecology (35%), emissions (23%), and innovation (18%). On the other side, the social (11%) and economic (15%) aspects of sustainability were not often researched. These findings connote that the management, innovation, water, and transport areas under the environmental dimension of sustainability need more research.

Lu *et al.* [12] emphasised that BIM is still not capable of assessing buildings' environmental and social sustainability in a holistic manner. Furthermore, Zanni *et al.* [36] and Lu *et al.* [12] indicated four sustainability areas not supported by BIM software packages: management, ecological issues, innovative techniques and performance, and transportation conditions. The discussion in this part of the paper is structured based on Green Star Design and As-Built New Zealand v1.0 (Green Star NZ) certification system. It includes nine credit categories namely, management, indoor environment quality, energy, transport, water, materials, land use and ecology, emissions, and innovation [37]. In addition to the credit categories of Green Star NZ, the social and economic dimension of sustainability that is lacking in the GBCS [7] will also be discussed concerning BIM integration.

The management and innovation criteria are often given less attention in most of the existing GBCS despite their presence in many sustainability research [38, 39]. This is evident in Green Mark GBCS, where less than 2% of the entire credits is allocated to "*Management*" [7]. Gandhi and Jupp [19] mentioned that assessing management and innovation components of green building assessment tools is almost unfeasible with BIM. Hence, future studies could concentrate on developing a qualitative oriented and adaptable approach for credits not achievable with BIM [40].

There have been few studies on integrating BIM and IEQ components in GBCS over the years. Al-Sulaihi *et al.* [41] developed a framework to integrate IEQ data into the BIM model in order to detect and track IEQ problems. Marzouk and Abdelaty [42] integrated BIM and wireless sensor network (WSN) for effective monitoring of thermal comfort in subways, an essential ingredient of IEQ. The study revealed that BIM better visualises the building components and IEQ metrics. It also enables efficient control of HVAC systems in an energy-efficient manner. Furthermore, HSE [43] revealed the six factors that influence the thermal comfort of occupants as 1) air temperature, 2) radiant temperature, 3) air velocity, 4) humidity, 5) clothing insulation, and 6) metabolic heat.

Pučko *et al.* [44] introduced a systematic approach for energy and cost analysis of building envelop using ArchiCAD, DesignBuilder and Vico Office. Venkatraj *et al.* [45] used Kieran Timberlake's Tally and Autodesk Green Building Studio (GBS) to compute embodied and operating energy respectively. The study quantitatively revealed that altering the amount of insulation, glazing type, window to wall ratio and depth of external shades to reduce operating energy may lead to the use of energy-consuming. Rodrigues *et al.* [46] compared the performance of GBS and ECO.AP for energy analysis. It was revealed that GBS is suitable at the early design stage of a building with poor performance. Galiano-Garrigós *et al.* [47] revealed that GBS, Herramienta Unificada Lider-Calener (HULC), Sefaira and DesignBuilder perform better than other energy supply tools because their values were close to the real values. Galiano-Garrigós *et al.* [47] suggested that incorporating crossed ventilation or thermal energy inertia could help minimise the differences in values between simulations and real energy and CO_2 emissions values.

It is observed that most of the studies were aimed at developing a plugin, while only Li *et al.* [48] developed a methodology by integrating Dynamo and "Amap" WMS. Furthermore, LEED GBCS is the only one considered in all the four studies that have attempted the automation location analysis credits. Over 70% of existing studies use Google Map API due to its versatility and flexibility. However, there is a need to explore other WMS to explore strengths and weaknesses. It has been established that the “Amap” WMS has geographical and language limitations, influencing its adoption in other locations.

Water is an essential part of GB, which account for a significant portion of most existing GBCS. There is a lack of research regarding automating BIM for water efficiency analysis [49], although some existing BIM-GB applications such as EnergyPlus, EcoDesigner and Ecotect offer metrics on water usage analysis. Recently, Liu *et al.* [50] developed a water efficiency framework for sustainable building design and construction management, which is yet to be validated. The framework would act as a road map for potential software development in future. However, there is a need to develop an adaptable plugin or framework for GBCS based analysis.

Al-Ghamdi and Bilec [51] conducted a comparative assessment of three common LCA tools (SimaPro, Athena Environmental Impact Estimator, and Kieran Timberlake’s Tally). The study revealed discrepancies in the selected LCA tools due to different methodologies and databases used for calculations. As a result, there is 10% and 17% variation in terms of embedded and operational impacts, respectively. Similarly, Schultz *et al.* [52] conducted a comparative analysis between Athena Impact Estimator and Kieran Timberlake’s Tally. It was stressed that there is a disconnection between design and sustainability assessment at the early stage of buildings. Furthermore, it was revealed that there is a lack of an elaborate database for the LCA of materials. Also, there is a need for existing and new sustainability tools to incorporate the concept of transparency and to benchmark in LCA evaluation.

Ahmad and Thaheem [35] stressed that BIM still has a long way to go to integrate the social dimension of sustainability into BIM. Also, the economic aspect of sustainability is not left out of this trend. Incorporating corporate social responsibility (CSR) and BIM into GBCS gives it the ability to act as a “social integrative system” [53]. Reychav *et al.* [53] established that existing BIM guidelines only focused on stakeholder management, teamwork, and participation. It was revealed that tenants are not involved in a project's design and construction stage, which negates the equity aspect of social sustainability. The research also presented CSR as a basis for BIM and sociocultural sustainability integration.

Additionally, Zanni *et al.* [54] argued that a clear line of communication aid an effective, sustainable building design process. This emphasises the need to keep project stakeholders, including end-users (tenants), abreast with up-to-date information regarding the project. Similarly, Kim *et al.* [55] used the number of workers needed to represent the social aspect of a large-scale development master plan sustainability assessment. Subsequently, Ahmad and Thaheem [35] developed a conceptual framework for social sustainability assessment BIM plugin applicable to residential buildings.

Future Research Directions in BIM-GBCS Domain

Firstly, it is evident that there is still disagreement among authors regarding the GBCS credits assessable with BIM, which has led to gaps between BIM technologies and GBCS. However, different GBCS used in various countries have their differences, one of the major reasons for this disagreement. Nonetheless, it was observed that most of the studies that stated certain percentages have not thoroughly validated their speculations. This will help automate GBCS processes, which are mostly manual at the moment and reduce waiting time for GBCS certificates. Consequently, a study is required to validate the speculations in previous research regarding the number of credits assessable with BIM. Secondly, several authors have revealed different percentage differences between the results of BIM-GB software packages with no guideline in benchmarking the outputs for these software packages. Furthermore, the lack of transparency between the computation processes of different software packages has also fuelled the differences in their outputs.

As a result, the following questions have emerged based on the observations of the disagreement obvious in the existing literature:

- How to develop an improved GBCS encompassing critical GB sustainability criteria that can be used to validate the actual credits assessable with BIM technologies?
- How to minimise the gaps between the outputs of existing BIM-GB analysis tools and develop a benchmark for their outputs?

Sustainability consists of three critical pillars, which include social, economic, and environmental dimensions. Nonetheless, the social and economic dimensions of sustainability have little or no points in most of the existing GBCS. This questions the overall aim of sustainability assessments in buildings when all dimensions of sustainability are not considered. Although, studies have attempted to design new GBCS that will include more points for social and economic dimensions [7-9]. However, most of these new GBCSs are still yet to encompass the social and economic dimensions to a satisfactory level. Studies by Ahmad and Thaheem [35] explored the concept of social sustainability in the BIM-GBCS domain without integrating the developed indicators and frameworks into any of the existing GBCS. Furthermore, a framework to satisfy the economic evaluation of buildings in GBCS and the need to integrate these social and economic indicator frameworks into the existing GBCS is required.

Conclusively, the neglect spotting revealed critical areas that have been overlooked, under-researched, and lack empirical support. The neglect gaps are summarised below:

- Other sustainability areas such as biodiversity, water, land use and ecology, socio-economic and acoustics have been potentially overlooked by researchers in the BIM-GBCS domain.
- The need to extend further research to include other prominent GBCS which have been neglected because most existing studies focused on the LEED GBCS.
- Lack of framework or guideline for evaluating software packages to be used in GBCS evaluations.
- There is a lack of empirical support for ontology-based BIM-GBCS and current literature focus only on the Chinese ESGB.

Based on the extensive literature review, gap-spotting and consideration of different perspectives outlined, the following key areas are essential for future research in the BIM-GBCS domain as summarised below:

- ***Development of a holistic framework for BIM-GBCS integration***: there is scanty literature on the holistic application of BIM for GBCS. Different GBCS have unique credit categories as a result of geographical differences.
- ***Development of framework or guideline for evaluating software packages to be used for GBCS evaluations***: there is a need to develop a framework or guideline that will assist GB professionals in selecting the best software packages to be used for the building evaluation.
- ***Minimising the gap between simulation outputs from GB analysis tools and real-world values***: It is observed that there are still differences between GB analysis tools and real values. In some scenarios, these differences are large, and it questions the integrity of existing GB analysis tools.
- ***Integrating BIM and ontology for GBCS credits evaluation***: Currently, there are few pieces of literature on ontology in the BIM-GBCS domain despite the benefit ontology offers that have been reported in previous studies.
- ***Integrating BDA, blockchain and IoT for BIM-based GBCS evaluation***: Combining the potentials of big data analytics and the internet of things for BIM-based GBCS evaluation will enhance the GB evaluation process and as well reduce manpower requirements and process costs.

4 Conclusion

BIM has grown to be a useful tool in the AEC industry. The use of BIM to support GBCS has received huge attention from researchers. Particularly, between 2019 and 2020, the number of published works increased significantly by 50%. This can be attributed to the effect of government policies and the coronavirus pandemic. This study presents a systemic literature review of the relationship between BIM and GBCS. Owing to the review of journal articles ($n = 84$) between 2009 and 2020, this study summarised the: (1) GBCS currently BIM-enabled, (2) level of BIM implementation in GBCS sustainability areas, and (3) areas for further research in the BIM-GBCS domain.

The main findings of this study include the following; Firstly, the current body of research has solely concentrated on the environmental dimension of sustainability while the social and economic dimensions are neglected in the BIM-GBCS. There is a need to maintain a balance across the dimensions of sustainability. Secondly, the study revealed that biodiversity, water, land use and ecology, socio-economic and acoustics had been potentially neglected in the BIM-GBCS domain. As a result, there is a need for thorough research to address these gaps. Additionally, the study will serve as a background for future research works in the BIM-GBCS domain as it highlights the gaps for future studies.

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