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A Review of the Challenges to Integrating BIM and Building Sustainability Assessment

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Abstract. Building sustainability assessment (BSA) is perceived as one of the major pillars of sustainable development, its adoption is increasing and many governments are embracing them. However, in order to meet the requirements of these processes, complicated tasks which consume considerable amounts of resources are involved. On the other hand, BIM has been acknowledged as a key solution to industry issues and a leading driver for innovation. However, the utilization of BIM to support BSA is still at a premature stage compared to other BIM applications. This paper aims to review relevant literature to determine the research trends within the field and identify the possible reasons behind the slow and reluctant development of this synergy. A three-step systematic literature review approach is adopted. First, literature was surveyed to identify all published Green-BIM studies within the past ten years. Second, identified publications are filtered according to pre-defined criteria to select the most-relevant. The last step involves the analysis of the filtered articles and the categorisation of the findings. The review has indicated a significant research tendency towards the area of Green BIM. However, it was apparent that BIM has yet to be properly aligned with BSA practices. A range of challenges facing the BIM-based BSA process has been identified and classified into three-major classes: BIM-related, BSA-related and Organisation-related

Keywords. Green BIM, Building Information Modelling, Building Sustainability Assessment

INTRODUCTION

In the light of the COVID-19 outbreak in 2020, which has caused a global economic depression, the world will be facing unprecedented social, economic and environmental challenges in its endeavour to overcome the consequences of this pandemic. There might be a drive towards achieving a rapid recovery through accelerating irresponsible industrial growth and urban development, which may cause deterioration of environmental security and depletion of eco-systems. Topics like carbon emissions, global warming and climate change are emerging strongly within world policies and research priorities. Worldwide laws and regulations require industries to adopt innovative solutions to boost sustainable outcomes [1]. Construction comes at the forefront of unsustainable industries, where the negative impact of buildings on environment, economy and society has been widely criticised [2]. According to the 2019 Global Status Report for Buildings and Construction Sector, issued by the United Nations Environment Programme, buildings consume over one-third of global energy and 25% of global water, while emit 30% of world greenhouse gas emissions and generate around 40% of its waste. These facts have raised the interest in sustainable development and increased the demand for green buildings [3]. This was demonstrated in the emergence of different sustainable practices within the industry, among these are building sustainability assessment systems (BSA), which are guidelines and systematic portfolios of qualitative and quantitative consistent metrics, with defined categories, benchmarks and procedures. They were established to evaluate the sustainability performance of buildings based on numerous evaluation criteria within different areas and translate it into a rating that can be used to compare different projects. Among the most common BSA international methods are the Building Research Establishment Environmental Assessment Method (BREEAM) by the Building Research Establishment (BRE) in United Kingdom, and the Leadership in Energy and Environmental Design (LEED) method by the United States Green Building Council [4].

The adoption of BSA by practitioners has significantly increased during the recent past years [5]. On academic level, the topic has gained recently more research attention [6]. Tens of BSA schemes have been issued due to its nature being region-oriented methods. In some countries the use of BSA is compulsory for specific type or scale of projects. Although the general scope of the majority of BSA schemes remains quite consistent and sharing almost the same assessment categories, the requirements to attain those credits and their relative weights may vary between different BSA methods.

In order to conduct BSA assessments and provide evidences needed by these schemes, project teams need to possess expertise and knowledge in a myriad of disciplines [7]. They must manage reciprocal task interdependencies and address a complex of information sharing requirements across multiple specializations [8]. This makes BSA a complicated process, where assessments are usually inconsistent and resource demanding. Additionally, assessments are often carried at the end of projects, when making amendments is more challenging and has higher impact on cost and time [9]. The use of BSA methods is also clashing with the short deadlines of a projects, making it difficult to implement [6].

In response to these challenges, Building Information Modelling (BIM), loomed out as a key solution, due to its proven capabilities. BIM has been one of the most discussed topics in the building industry, and has been advocated globally as the preferred tool for building information management. It is an assuring development that initiated a revolution in the way of visualizing, analysing, sharing and documenting project information [10]. Parametric option comes at the top of the most employed BIM-features, and refers to the capability of BIM models to capture and attach multi-disciplinary data to its building components, including sustainability-related metrics. Moreover, there is a possibility to create additional personalized parameters, in case the BIM platform existing parameters are not sufficient, which allows the access to a wider range of building data [6]. This had eased information tracking and enhanced automated generation of documentation. Moreover, BIM is well known for its potential to enable coordination and collaboration, as it provides a centralised single source of project information, which allows the access and extraction of data at any time. The innovative development of these features may deliver an excellent opportunity to facilitate sustainable design and simplify BSA.

Green BIM refers to the utilisation of BIM to support sustainable practices. Plenty of applications have been proposed in this regard, examples include: energy performance analysis [11], temperature and humidity simulation [12], carbon emission analysis [13], air pollution calculations [14], fire protection [15], building safety [16], lighting simulation [17], quantities and cost estimation [18], and waste management [19]. Likewise, BSA emerged as one of Green BIM applications [20]. However, the proposed models are mostly unwelcomed by practitioners, suffering from impracticality and lacking comprehensiveness, while still far away from being mature enough to be widely adopted [21].

In recent years, studies have demonstrated the challenges experienced when either BIM or BSA are implemented in construction projects, but very limited research has addressed the challenges of integrating both concepts. A number of systematic literature reviews has been published about the BIM-based BSA during the last five years: [22-32]. Few of them have investigated the limitations, while the majority has focused on BIM functions and project stages.

Therefore, there is a lack of a comprehensive appraisal that goes beyond project phases and technical details, to the full spectrum of challenges and barriers of BIM-based BSA applications. This paper aims to fill that gap, by outlining and classifying these challenges, through extensive review and analysis of the proposed BIM-based BSA models in literature within the last ten years, with no limitation to specific BSA scheme, BIM technology or project phase.

METHODOLOGY

The main objectives of this paper are to identify the challenges facing the BIM-based BSA; while provide insights into the topic common variables and parameters within the past ten years, based on the analysis of the different models and frameworks, published during that timeframe. Therefore, research question is: What are the obstacles hindering the integration of BIM and BSA?

In order to work out an accurate answer for the research question, this paper adopts a qualitative extensive literature review approach. It explores the subject by collecting, investigating and analysing unstructured, detailed and rich-in-content data. According to Snyder [33], systematic reviews are the most effective for addressing a particular definite research question between the different review types, due to its strict search strategy requirements. The followed systematic literature review approach is similar to what have been adopted by Safari and AzariJafari [32], Carvalho et al. [20], Ansah et al. [29] and Lu et al. [22], by involving three main stages as follows:

Stage One: Literature Search and Survey

This stage begins by determining the rules, sources and key words that will be applied to survey literature. A combination of two keywords was used: "BIM" is the first, and the second is a BSA-related term as "LEED, BREEAM and Assessment". No limitations were set to specific source, authors, or origins, to ensure maximum coverage of the topic, while publish dates were restricted to the last ten years (between 2011 and 2020) to avoid outdated work. No restrictions were set to a BSA scheme, a BIM software or a project phase. Google Scholar was chosen as the database source, according to Gusenbauer [34] and Martín-Martín et al. [35], it is the world's largest academic search engine and a superset of other scientific databases as Scopus and Web of Science. Google Scholar was also selected for its search and filter capabilities, Advanced search tool was used to identify all articles published between 2011 and 2020, containing the keywords combination within their titles. Six keywords: 'Green', 'Sustainability', 'LCA' referring to life cycle assessment, 'Assessment', 'Certification', 'LEED' and 'BREEAM', each combined with 'BIM', were used for the initial stage of literature survey. As a result, a total of 1025 peer-reviewed publications were found and downloaded as shown in Table (01). Columns shaded in grey denote articles related to BSA.

Stage Two: Selection and Filtration of Publications

According to the research aim and question, it was decided that downloaded studies shall be filtered according to the following pre-defined conditions, that ensure study reliability:

1- Exclude articles addressing non-BIM-based BSA within Green BIM field.
2- Exclude duplicates.
3- Exclude non-English articles to avoid translation challenges.
4- The document type was limited to peer-reviewed scientific journals, as they are believed to be the most reputable and influential sources of knowledge [36].
5- A BIM-based BSA prototype model shall be presented, and validated within the study. Studies with conceptual frameworks only were excluded.
6- An international BSA scheme shall be adopted as a reference.

Thus, this stage encompasses a detailed filtering process for the full set of 1025 downloaded publications, through reviewing title and abstract of each individual article, to eliminate duplicates and delineate the studies complying with the afore-mentioned criteria. Figure (01) illustrates the filtration criteria adopted. As a result, 30 key studies were maintained for the next stage.

Stage Three: Review and Content Analysis

This stage involves the performance of a qualitative content analysis of each of the 30 key studies. The main objective is to extract and identify the full set of challenges encountered during the application of the models, proposed within these papers. These are directly concluded through case studies reported limitations, or indirectly through authors inductive reasoning and interpretation. The challenges are then classified into a number of categories and subcategories, while analysed articles are tabulated into an extended matrix, in a chronological order as shown in Table (02), where column (G) displays a summary of the identified challenges within each study, while column (H) states the sub-category assigned for each challenge. Other columns cover general information as: year of publication; authors; journal; adopted BSA scheme; addressed BSA categories; used BIM software; and used data exchange format. This information will be essential for drawing some statistical observations that might be employed to provide more insights into the topic trend over the past ten years.

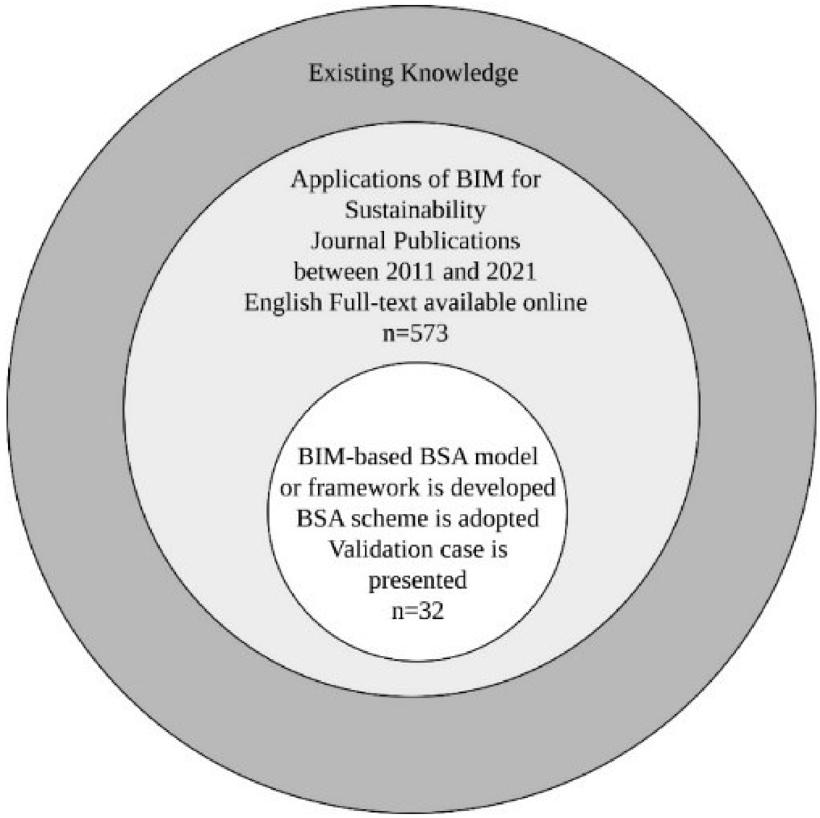

FIGURE 1. Articles Identification and Filtration Process

Year	Number of publications found (BIM applications for Sustainability)							(BIM-based BSA) Publications	(BIM applications for Sustainability) Publications	Total BIM Publications
	BIM +Green	BIM +Sustainability	BIM +LCA	BIM-based BSA related publications						
				BIM +Certification	BIM +Assessment	BIM +LEED	BIM +BREEAM			
2011	14	3	3	1	6	5	1	13	33	1670
2012	20	4	1	3	15	6	1	25	50	2130
2013	35	14	3	7	25	2	0	34	86	2750
2014	23	12	9	8	27	4	0	39	83	3260
2015	28	21	9	3	40	7	0	50	108	4990
2016	32	18	4	5	41	5	0	51	105	7730
2017	54	19	11	6	49	5	0	60	144	10500
2018	41	21	26	3	38	4	1	46	134	9200
2019	50	21	18	6	55	2	2	65	154	8470
2020	40	24	27	8	74	5	0	87	178	5310
Total	337	157	111	50	370	45	5	470	1075	56010

TABLE 1. Search keywords and findings

DISCUSSION AND FINDINGS

Initial Insights

As shown in Figure (02), the identified Green-BIM publications have demonstrated a growing increase. Similarly, the number of articles addressing the synergy between BIM and BSA, one of Green BIM applications, is growing at the same pace, over the same period of time. This demonstrates the belief that BIM has the full potential to support projects stakeholders to enhance sustainability performance of buildings, and facilitate BSA practices. It also creates a need to explore the difficulties and challenges that obstruct the further development of BIM-based BSA. This is in-line with the findings of Doan et al. [37], who carried a group of interviews in New Zealand to explore the awareness about the integration of BIM and New Zealand BSA scheme 'Green Star'. Where feedback implied an envisagement of high potentials in BIM for BSA, however, the tools and framework to transform theory into practice are still missed.

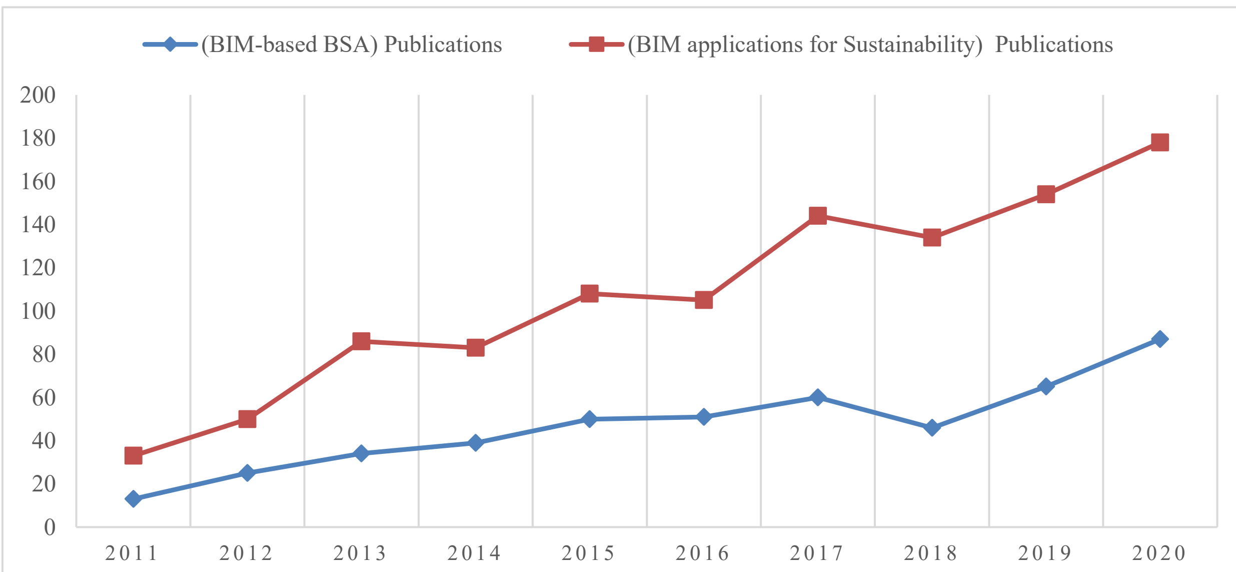

FIGURE 2. Comparison between BIM-based BSA Publications and Green BIM Publications between 2011 and 2020

Technology Limitation

Sustainable design and green buildings have long been and will continue to rely on Green-BIM technology advancement [7]. Green-BIM technologies refer to the use of BIM developed tools, advanced functionalities and software for supporting sustainability tasks as automating processes, reducing work load, and increasing the reliability of buildings performance assessment [5]. These are divided into two groups: BIM authoring tools for modelling purposes, as Revit and ArchiCAD; and BIM-based Building Performance Analysis (BPA) tools for simulation and analysis purposes as IES and Ecotect [38]. Reviewed applications have also demonstrated an extensive employment of non-BIM tools as Microsoft Office, Web Map Services and Cloud applications. As indicated in Figure (03), Autodesk Revit was used 24-times as the most common, while more than 30-other software were involved. There are hundreds of BIM tools available in the market today, it was claimed that the use of fewer technologies is a necessary step towards promoting the efficiency of the BIM-based BSA [21]. Similarly, Azhar et al. [39] suggested merging BIM authoring and analysis into one platform for reducing the process errors. Despite this diversity, existing BIM technologies are incapable of analysing and assessing all BSA aspects. There is no robust linkage between BIM and

BSA certification systems [18], and the data placeholders within BIM authoring tools are insufficient for handling all BSA aspects [40]. Some BSA requirements need the execution of complicated calculations that cannot be performed by existing BIM tools but only through manual interference [41]. Moreover, the use of multiple applications requires the frequent transfer of data, which opens the door for user interface issues [42], data loss risk [43], irrelevant information, double counting and multiple entries [44]. On the other hand, Building Performance Analysis (BPA) software were found to be inaccurate, leading to unreliable results [45]. The need for improved BPA tools was outlined by Raffee et al. [46]. Jalaei and Jrade [47] have identified discrepancies between the results of three BPA tools: Ecotect, Green Building Studio and IES-VE, due to different calculation methods used, in addition to the variation between building systems types.

Hardware deficiency acts as another technological barrier; for example, BPA tools can often run smoothly with less complex models, while become populated with higher model details. The processing power of computers, server capacity, networks and internet connection quality are all areas that must be developed in order to achieve an effective BIM-based BSA [48], and these are often associated with overwhelming cost implications.

Data Exchange

The quality of the communication and the data exchanged between different project members play a vital role in utilizing BIM for BSA. Challenges reside in the lack of interoperability between different BIM software, beside the inability to manage exchanged information in a unified suitable format. Teicholz [49] attributed the major cause behind the construction industry regression between 1964 and 2003 to the lack of interoperability between the information technology applications. Today, we have no single standard or data structure format that supports BSA, existing protocols are limited, with inadequate capabilities. An appropriate information exchange mechanism is a key need to address interoperability challenges [29].

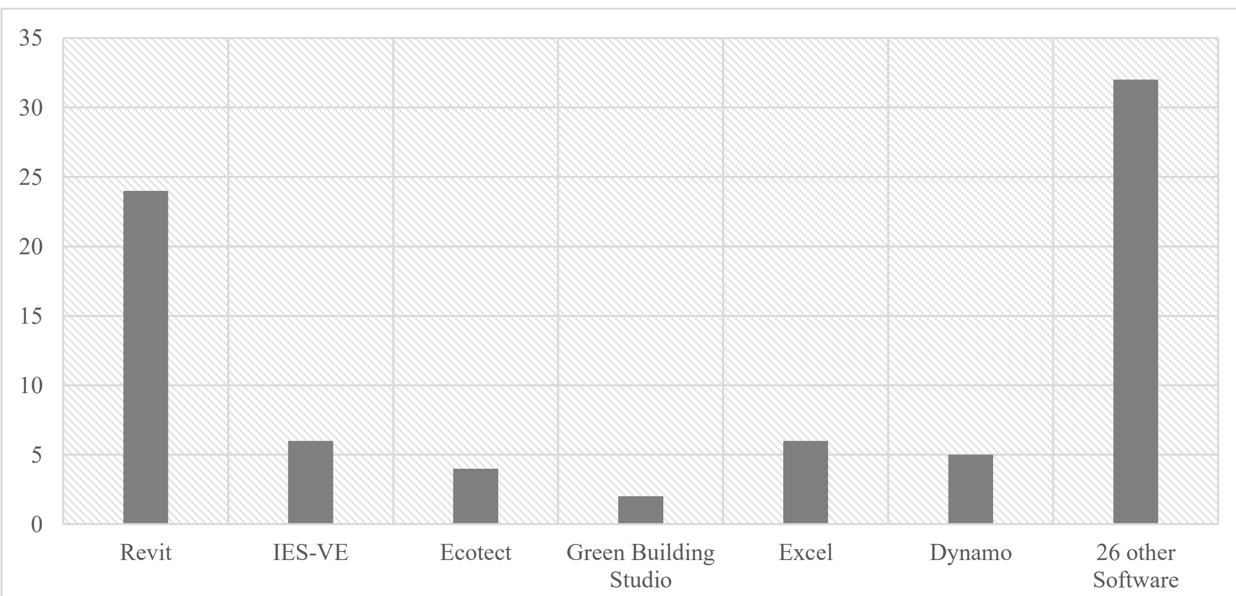

FIGURE 3. Number of times each Software was used within reviewed literature

Figure (04) shows that the most Common exchange formats used are: Industry Foundation Class (IFC); Extensible Markup Language (XML); and Construction Operations Building Information Exchange (COBie); an international standard data structure that enables extraction of BIM information in tabular spreadsheet forms.

Using these formats as means of information interchange has led to a more interoperable open data environment. However, they are criticized for being unable to satisfy BSA requirements, due to their failure to represent all information across all building performance domains, in addition to data loss during the transfer from BIM models to other formats. Addressing the full set of BSA information pertaining all building elements using current data structures is unachievable [50]. There is a need to expand and create additional property sets within these exchange schemes, to cover the entire sets of BSA criteria.

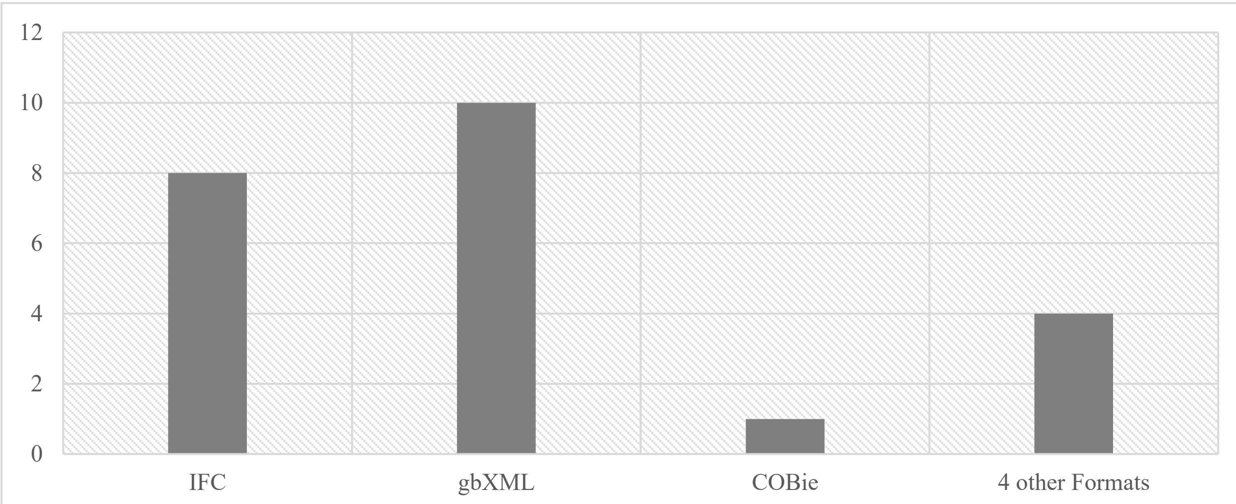

FIGURE 4. Number of times each Data Exchange Format was used within reviewed literature

Level of Development

The quality of the BIM model and the level of its details is critical to the whole BIM-based BSA process. The majority of the research reviewed applications requires a high-detailed information-rich model, where all assessment needed parameters are fulfilled, otherwise the process will suffer from incompleteness and inaccuracy. For example, Alwan et al. [51] noticed discrepancies between automated and manual results of their experiments, which were attributed to the inadequacy of the developed BIM model. Likewise, Carvalho et al. [21] found that the criteria pertinent to project location as transportation will not benefit from BIM if the neighbourhood is not modelled precisely and in detail. On the other hand, Seghier et al. [52] concluded that Concrete usage index (CUI) can be calculated using BIM only in case concrete elements were modelled correctly with detailed parameters input.

According to the American Institute of Architects (AIA), the Level of Development (LOD) is a protocol created to describe the BIM model content level of details at a certain given time during the project. Ramaji et al. [53] described it as the degree to which a receiver of the model can rely on its embedded information, and understand its usability and limitations. On this ground, LOD can be considered as a key solution to better align BIM functionalities with BSA requirements. Unfortunately, it has been proven that sustainability parameters are not currently tied to LOD definitions [5].

Lack of Standard Workflow

There is an absence of well-defined workflow, clear industry standards and professional codes with Green BIM practices [54]. Industry players often treat BIM as a technology add-on while elude the efforts in adapting their businesses operation to accommodate the necessary organizational and management changes needed when adopting BIM [55]. Ayman et al. [5] elaborated that in order to investigate the integration of any aspect within BIM, technologies should not be the only aspect to examine. However, the majority of reviewed literature had focused mainly on the technological development of BIM for BSA, rather than addressing the deficiencies within the workflow. This aggravates the deficiency of workflows and standards that BIM-based BSA is suffering from. Yet, several studies have acknowledged different aspects of process workflow, as the impact of the Green-BIM protocols immaturity [56], the consistent standards and its effect on promoting BIM-based BSA [5], Green-BIM design management issues and process maps [8], and Green-BIM procurement systems [24].

BIM Database

BIM database refers to the repository of BIM digital building components, developed by industry manufacturers and suppliers, to be used during the modelling process. Using BIM libraries can save significant time and increases convenience and consistency of BSA processes. Unfortunately, current BIM libraries are deficient, immature and comprising generic building items that lack definition and detail, which aid designers to determine the associated BSA credits [57]. The approach of developing a Green-BIM database to support BSA has been adopted by few studies [1,58,59].

BSA Data Complexity

A major challenge reported and experienced by project teams is the difficulty to address the variety of information domains needed for BSA discipline-specific building simulations and analyses [7]. Many BSA criteria are left unexplored, because they entail subjective human judgement. Typically, a full BSA process requires the exploration of a mixture of criteria that are evaluated by a wide range of both quantitative and qualitative measures [60]. Quantitative criteria can be easily measured within BIM environment, as energy consumption or materials quantities. While qualitative data involves descriptive type of data, that can be only observed and not measured. Assessment of qualitative criteria such as design innovation and impact over society, relies mainly on user testimony and requires variable interpretation by professional assessors, which makes it difficult to be incorporated into BIM environments. As shown in Figure (05), It has been noted that most of BSA common categories were addressed by the reviewed studies, however, energy, resources and materials received the highest focus, being a quantitative subject, while areas as society, management and wellbeing received less attention, due to their qualitative nature. A study [8] showed that 12% of Australian BSA credits, such as management issues, were almost impossible to be addressed using existing BIM tools. One solution is to find a way to transform qualitative variables into measurable quantitative predictions, other way might be to develop BIM capabilities that are capable of qualitative assessment.

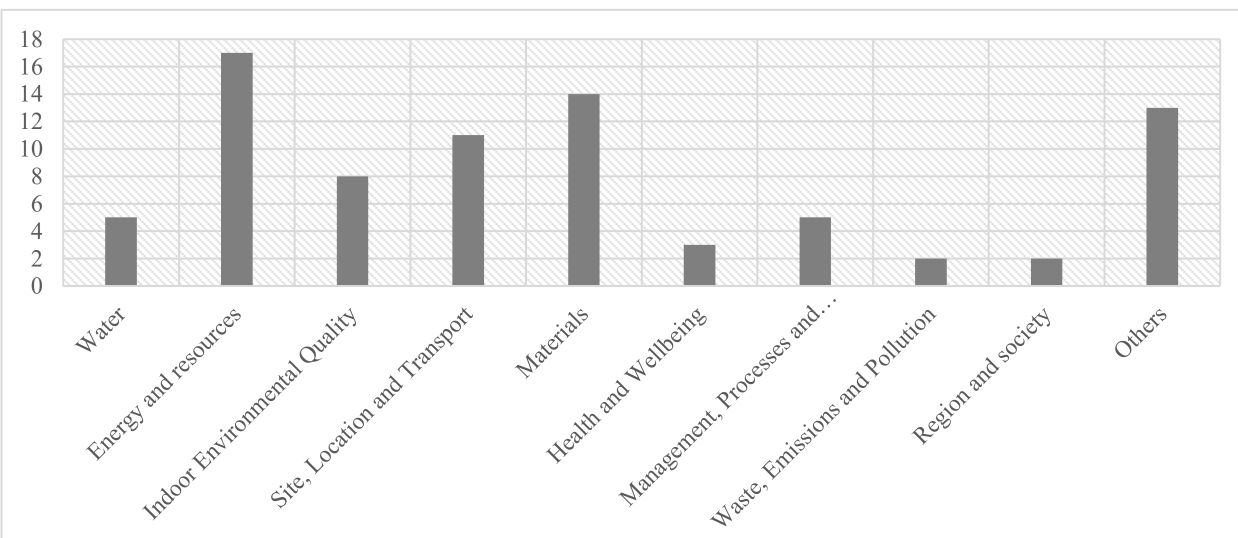

FIGURE 5. Number of times each BSA Categories was addressed within reviewed literature

BSA Schemes Diversity

Hundreds of different BSA schemes are used worldwide. Figure (06) shows more than 10 schemes were used within the reviewed 30 studies. United States LEED was by far the most adopted by 23 studies out of the total 30. Other used schemes include United Kingdom BREEAM [1], Singapore Green Mark [61], Malaysia Green Building Index [46], New Zealand Green Star [10], Hong Kong BEAM Plus [40], Portugal SBTool [21], African BSAM [62], and Europe CESBA [9]. It has been claimed that this diversity has led to different BSA ratings for the same project [63], which created inconsistency and disparities between the findings of different studies.

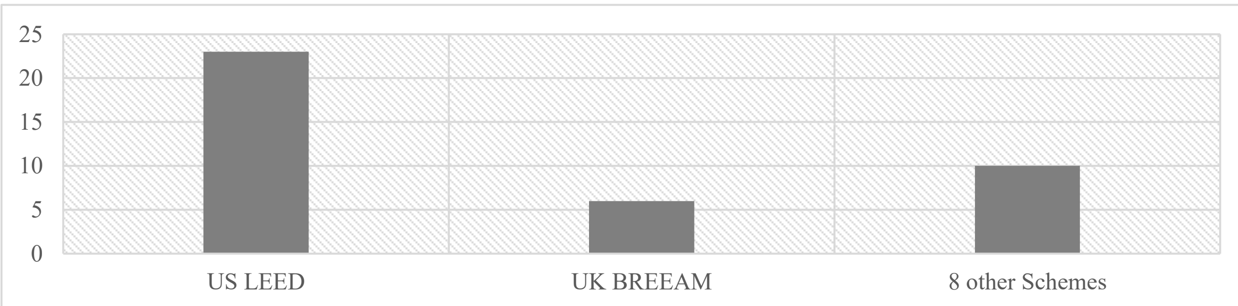

FIGURE 6. Number of times each BSA Scheme was adopted within reviewed literature

Culture and Awareness

BIM and BSA are relatively new concepts to the industry and organizational cultures are not adapted yet to integrate them. Some firms still envisage BIM and sustainable development as too complicated to adopt, which drives them to be more reluctant to change and attached to conventional practices of work. It is quite necessary for the industry stakeholders to be willing to incorporate developed advanced tools as a standard practice, which can be obtained through adequate education, training and raising awareness in addition to showcasing benchmark projects. Lack of awareness, skills and knowledge of BIM and BSA systems was ranked among the most substantial challenges to the BIM-based BSA practice [37]. BIM energy performance analysis tools for example are rarely used by designers, mainly due to the skills needed to run energy models and interpret their outputs [57]. Only a fraction of industry firms is knowledgeable about Green BIM [55], and an even smaller portion of those are able to utilise the potentials of BIM to support BSA.

Lack of Resources

Financial constraints and economic limitations are both primary reasons behind the slow progress of BIM-based BSA development. Project owners are hesitant to procure BIM services, adopt sustainable solutions, or employ innovative processes to avoid cost inflation and risks associated with unfamiliar workflows [64]. Embracing BIM technologies, applying sustainability solutions or conducting BSA assessments with all of its documentation, modelling, registration and other required tasks, are believed to have significant cost implications, which may add further burden over projects budgets.

CONCLUSION

The positive impact of the integration of Building Information Modelling (BIM) and Building Sustainability Assessment (BSA) over the industry has become a fact, proven and agreed upon by the construction community. Over the past decade, the research addressing this topic has increased significantly. However, the industry still lacks a mature application that is capable of fully integrating an effective BIM-based BSA solution. This indicates the existence of limitations and uncertainties, impeding the development of BIM-BSA integration and preventing its transfer from theory to practice. This paper presented a comprehensive review of BIM-based BSA studies, published between 2011 and 2020, to identify and categorize the full spectrum of challenges facing project teams and industry members when implementing BIM-based BSA. A Matrix and a bubble diagram have been developed to act as a key guidance for industry professionals and researchers, when attempting to enhance the integration of BIM and BSA in the future. Based on this review, it is concluded that BIM is not yet properly aligned with BSA process, with the identification of tens of challenges and barriers. The performed review and analysis resulted in the identification of more than 70-challenges as shown in Table (02). These were categorised into 3-major categories: (BIM-related, BSA-related and Organisational-related), and 9-subcategories: (Technology, Data Exchange, Workflow, LOD, Database, Scheme's diversity, Data complexity, Culture and Resources) as shown in Figure (07). While, figure (08) illustrates the number of times each category has been addressed within the reviewed literature. 'Technology' was the most addressed category by far. This finding confirms the fact that current Green-BIM practices are heavily technology-driven instead of process-driven [22].

Additionally, the study has identified some remarkable facts that might be of significant use to future research, such as the most used software (Autodesk Revit); the most common data exchange format (gbXML); the most adopted BSA system (US LEED); and the most BSA assessed category (Energy and Resources). However, the study has got some limitations. First, literature review was limited to English free and online-available articles only, and second, articles survey was mainly based on titles, which might all lead to the exclusion of essential studies. On the other hand, the input data was limited to academic publications, and since the topic under-discussion is a rapidly evolving area, highly impacted by technological development and market conditions, this necessitates the consideration of practitioner input by involving experts and professionals working in this field. It is therefore recommended that future research would consider explore the practical point of view. This may help add foreseen perspectives and provide further validation of the literature review results presented within this study.

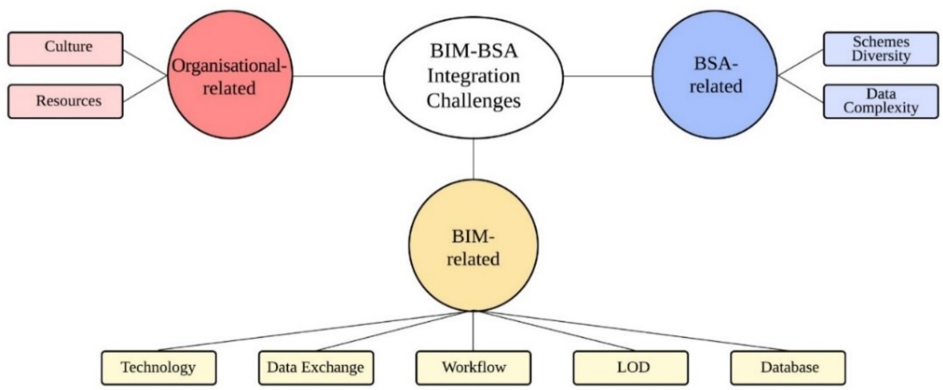

FIGURE 7. Categories and sub-categories of the concluded BIM-based BSA challenges

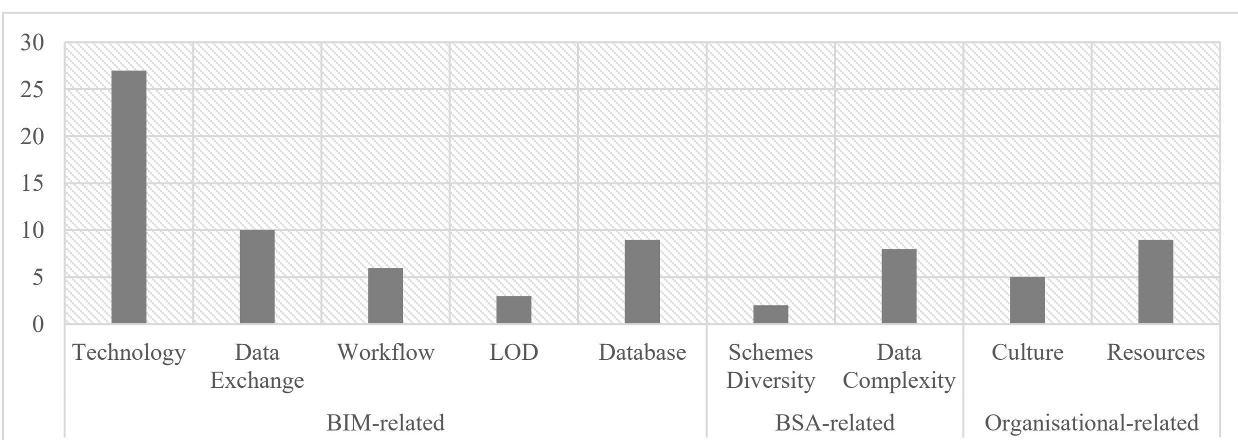

FIGURE 8. Number of times each Challenges sub-category was addressed

A Year	B Authors	C BSA Schemes	D BSA Categories	E BIM Software	F Exchange Format	G Identified Challenges	H Proposed Sub-Category
2011	[18]	LEED	WE, EA, IEQ	Revit, IES-VE	gbXML	Inaccuracy of the building information model.	Technology
						Limited availability of building data.	Database
						Discrepancies between software and manual results.	Technology
2012	[60]	LEED	SS	Revit	COBie	Information loss arising from the translation from BIM to COBie.	Data Exchange
2012	[7]	LEED	-	Revit, STRATUS Cloud, IMAGINit Clarity	IFC, XML, ODBC	Inefficient communication.	Culture
						Practices cannot be replicated.	Culture
						GBA variety of domain information needed.	Schemes Diversity
						BIM technology limitation.	Technology
						IT Infrastructure limitation and cost.	Resources
2013	[63]	BREEAM, LEED	Ene, EA	TAS, Energy Plus, IES-VE SketchUp	Weather files	Different simulation tools result in different energy consumption figures and different BSA ratings.	Technology
						Accuracy and consistency within different BPS tools cannot be guaranteed	Technology
2013	[59]	LEED	SS, EA,	Revit, Athena Impact Estimator, Excel,	-	Lack of information about sustainable materials within BIM database.	Database
						Lack of interoperability between design and analysis tools.	Data Exchange
						BIM libraries limitation.	Database
2014	[47]	LEED		Revit, IES-VE,	gbXML	Information loss during transfer between software.	Data Exchange

			MR, IEQ, ID, RP, SS, WE, EA	Ecotect, .NET API		Some data need to be entered manually by the user.	Technology
						BIM sustainability database limitation.	Database
						Building components needs to be quantified for easy calculation.	Data Complexity
2014	[52]	Singapore Green Mark, Malaysia GreenRE	Concrete Usage Index	Revit, Dynamo, Excel	-	Requires manual calculations and interference.	Technology
						Software limitation.	Technology
						Needs a deep knowledge of VPL software.	Resources
2014	[40]	Hong Kong BEAMPlus	SA, MA, EU, WU, IEQ, IA	Revit	-	There were insufficient existing parameters in the Revit model to cater for all of the information required for the assessment.	Technology
						Some credits cannot be assessed using BIM because they require the submission of documentation.	Data Complexity
						Some credits cannot be assessed using BIM because they require additional calculations that cannot be done by BIM.	Data Complexity
						Some credits cannot be assessed using BIM because they require onsite testing and measuring.	Data Complexity
2015	[65]	BREEAM, LEED	Man, Hea, Wat, LE, Ene, SS, EA, IEQ, MR, AP	Revit, Green Building Studio, Ecotect, IES-VE, AchiWIZARD, Envest, PEREN, Bentley, SketchUP	SKP, gbXML	Limitations of the interoperability capabilities between BIM software and environmental analysis tools.	Data Exchange
						No specialized software for organizing and classifying data, in order to facilitate a multiple criteria assessment.	Technology
						Adequate LOD needs to be developed for assessment.	LOD

2015	[66]	Canada LEED	EA, MR	Revit	-	Model is limited to one BSA scheme and only two assessment categories.	Technology
						Documentation and soft cost, time and effort associated with the BSA registration and certification.	Resources
2015	[51]	LEED		Revit, IES-VE, Project Vasari	gbXML	The information generated by the BIM models that can be used for sustainability analysis is limited.	Technology
						Not covering all BSA categories, and not replacing manual assessment, subject to manual checking.	Technology
						Data exchange between BIM tools needs to be enhanced.	Data Exchange
2016	[1]	BREEAM	Mat	ArchiCAD, Visual Studio, Excel	IFC	Require manual effort in developing Green BIM libraries.	Database
						Model is limited to particular software.	Technology
2016	[67]	BREEAM	Sustainability of Structural solutions	Revit, API, C#	IFC	Difficulty in including all the sustainability definitions in the initial phase of the modelling.	LOD
						Varied views on sustainability issues in the sector due to the fragmentation of the industry.	Culture
						Lack of universally accepted BSA system.	Schemes Diversity
						Lack of dynamic parametric modelling of transactions between BIM and sustainability assessment tools.	Data Exchange
						Software developers need to promote implementation of API in BIM tools.	Technology

2016	[68]	LEED	EA	Revit, Trace 700, gbXML Viewer, FZK Viewer	gbXML	It is necessary to develop a gbXML editor that can immediately rectify any errors.	Data Exchange
2016	[69]	LEED	MR, Economical aspect	Revit, Excel, VENISM, Stella	-	More focus needs to be placed on operational phase of facilities.	Workflow
						More focus needs to be placed over sustainability economic and social aspect.	Data Complexity
2016	[46]	Malaysia Green Building Index	-	Revit	IFC	Interoperability between different BIM applications needs to be enhanced.	Data Exchange
2017	[61]	Singapore Green Mark	CRD, BEP, RS, SHB	-	-	Lack of understanding by individuals of how BIM-BSA integration could be achieved.	Resources
2017	[70]	LEED	EA	Revit, Sefaira, Excel,	-	Limited to only one category.	Technology
						Not fully automated, requires manual analysis by user.	Technology
2017	[10]	New Zealand Green Star	EN, IEQ, WA, MT, MN	-	-	Not all criteria can be guaranteed by utilizing BIM application.	Data Complexity
						Lack of awareness about the benefits of such integration.	Resources
						Cost implications.	Resources
						Entrenched resistance to change.	Culture
						Lack of governmental incentives.	Resources
2017	[9]	LEED BREEAM CESBA	Daylight	-	IFC	IFC property sets are inadequate for computing sustainability rating.	Data Exchange
2018	[25]	LEED	SS (Storm water runoff)	Revit, Dynamo	gbXML	Diversity of the LEED credits does not allow for a simple overall automation.	Data Complexity

						The current BIM tools for BSA are immature.	Technology
						BIM models should have an LOD high enough for assessment, and low enough for the model simplicity.	LOD
						Dynamo are not ready to support BSA applications.	Technology
2018	[64]	LEED	MR	Revit, Monte-Carlo Simulation	-	Cost associated with sustainability assessment.	Resources
						Full life-cycle impact shall be considered.	Workflow
2018	[71]	LEED	MR	Revit, Excel	-	The BSA process is always carried in late design stages.	Workflow
						Suppliers and manufacturers need to develop BIM certified materials and building components.	Database
2019	[57]	BREEAM, LEED	Ene, Hea, Wst, Mat, Pol, EA, IEQ, SS	IES-VE, SBEM, DesignBuilder, AECOsim, EcoDesigner, Ecotect,		The potential for using BIM in refurbishment projects specifically for achieving BSA requirements has not been yet reviewed or put into practice.	Workflow
						Scan-to-BIM and Digital twins need more research focus and development.	Technology
						BIM models should contain an integrated library of whole life cycle energy information for each material and this library would be standardized between models.	Database
2019	[72]	LEED	MR	Revit, STAAD PRO, Monte-Carlo Simulation	-	Construction, Operation and End-of-life stages of a project shall be covered in sustainability assessment.	Workflow
2019	[73]	LEED	MR	Revit, Google Maps,	-	BIM tools are missing maps, location and transportation analysis.	Technology
						There is still a lack of a direct linkage between BIM and GIS.	Technology

						Model relies on Google Maps capabilities and on information added by suppliers.	Technology
2019	[74]	LEED	LT	Dynamo, Amap, Python,	IFC	Proposed tools are no programmable and are limited by their serving phase.	Technology
						The used Maps tool is limited to China.	Technology
						Data extracted from Web service API is insufficient and inaccurate.	Database
						Dynamo visualization and geometrical information are limited.	Technology
2019	[21]	SBTool	Environment, Economic, Social	Revit, Dynamo,	IFC, gbXML, Revit direct link	Different BIM tools are involved.	Technology
						Current BIM software are not adapted to assess many sustainability criteria.	Technology
						Lack of BIM knowledge and skills.	Resources
						Maximum benefits can only be achieved when the companies have integrated BIM in their processes.	Culture
						Data exchange formats are not fully developed yet, some interoperability problems may occur, and information may not be completely transmitted from one model to another.	Data Exchange
						Stakeholders collect and define all the needed information and guidelines for the project before the modulation stage.	Workflow
2020	[75]	LEED	LT, SS, EA, MR, IEQ, ID, RP	Revit, Green Building Studio, Google Maps,	gbXML	Accuracy of the model depends on the amount of information provided from old LEED certified projects.	Database
						Not all sustainability issues are addressed.	Data Complexity

2020	[76]	Building Health Performance (BHP), LEED, Dwelling Performance Rating System (DPRS)	Comfort, Safety, Environment performance, Operation management, Economic performance	Revit, Ecotect, ArcGIS,	gbXML	Current BSA methods suffer from complexity, difficulty in data collection and adaptability.	Data Complexity

US LEED: EA-Energy & Atmosphere, MR-Materials & Resources, IEQ-Indoor Environmental Quality, SS-Sustainable Sites, WE-Water Efficiency, ID-Innovation & Design, LT-Location & Transport,

UK BREEAM: LE-Land use & Ecology, Ene-Energy, Hea-Health & Well-being, Tr-Transport, Wa-Water, Pol-Pollution, Wst-Waste, Mat-Materials, Man-Management

TABLE 2. BIM-based BSA reviewed 30 Articles

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