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BIM Integrated Framework for Efficient Information Exchange in Green Building Design: A Critical Review

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ABSTRACT

Adequate implementation of Building Information Modelling (BIM) in green building practices, known as green BIM, enables the multidiscipline team to efficiently exchange information to meet the overarching criteria of green building assessment tools (GBATs) like Malaysian Carbon Reduction and Environmental Sustainability Tools (MyCREST). However, issues of inaccurate information exchange during the green BIM process persist, resulting in a flawed decision-making process. Besides, compared to the environmental indicators, the socioeconomic aspect of sustainability has not been adequately considered in GBATs like MyCREST. Furthermore, the enhancement of information exchange in green BIM practice has been underexplored in the literature. This study critically reviews 200 articles published between 2008 and 2024 to identify the critical components for information exchange in the green BIM process. Then, a comparative analysis was conducted on five widely used GBATs to augment MyCREST Design. Afterward, established BIM standards and guides were scrutinized to identify the best practices of digital information exchange. As a result, the MyCREST-BIM Integrated Framework (MyBIF) was developed, encompassing core components like Augmented MyCREST Design, Technology Enablers, and Institutional Support. The developed MyBIF provides researchers and practitioners with valuable insights into real-time collaboration and efficient exchange of information in green building design.

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1. Introduction

In light of the United Nations' call to reduce buildings' environmental, social, and economic impact, sustainable or green building design practices have become a mainstream objective in the construction industry. The construction stakeholders established Green Building Assessment Tools (GBATs) - a set of performance thresholds that buildings should meet to be certified green [1]. Several GBATs have been established globally depending on local standards and climate conditions. These include the United States Leadership in Energy and Environmental Design (LEED), the United Kingdom’s Building Research Establishment Environmental Assessment Method (BREEAM), the Malaysian Carbon Reduction and Environmental Sustainability Tool (MyCREST), the Green Building Index (GBI) of Malaysia, Green Star South Africa, etc. Compared to other GBATs, MyCREST arguably has more significant potential to reduce carbon emissions, as it provides an all-inclusive approach that integrates sustainability criteria with carbon reduction strategies [2]. However, designing sustainable buildings remains complex due to the cumbersome information management of the overarching sustainability criteria (like MyCREST) [3].

Building Information Modelling (BIM), which encompasses policies, processes, and technologies, has emerged as a methodology for industry practitioners to collaboratively manage and efficiently exchange essential building information in a digital format throughout the building’s life cycle [4, 5]. Information exchange is a critical aspect of green building. BIM remains the core element that integrates with other digital tools like Artificial Intelligence (AI), Augmented Reality (AR), and the Internet of Things (IoT) to provide a common platform for the digital exchange of accurate and updated information, leading to more efficient and effective decision-making [6]. As cited by Lu *et al*. [7]; Wu *et al*. [3], the implementation of BIM in the green building design process, referred to as green BIM, allows the diverse design team to accurately exchange information to realize the predominant criteria of green building assessment tools (GBATs) such as Malaysian Carbon Reduction and Environmental Sustainability Tools (MyCREST). Nevertheless, the major issue in green BIM practice is the exchange of unreliable information, leading to inaccurate analysis and flawed decision-making processes [8, 9]. Zanni *et al*. [10] linked this to the main cause of the performance gap between simulated sustainability performance and actual operating sustainability performance of buildings.

Numerous studies have been conducted within the domain of green BIM practices. For instance, Barison and Santos's [11] study focused on enhancing the competency of multidiscipline design teams for adequate use of diverse BIM tools to exchange overarching sustainability information. A study conducted by Jun *et al*. [12] customized BIM authoring software to facilitate information exchange in sustainable building practices. Waterhouse and Philp [13] explored generic strategies for promoting BIM execution in green building design. Kamari *et al*. [14] study highlighted the importance of collaborative decision-making. Wu *et al*. [3] proposed a BIM-driven building greenness evaluation system. In tropical countries like Malaysia, Seghier *et al*. [15] developed a customized BIM-based tool to enhance indoor environmental quality. While several studies have made valuable contributions to the field, it is worth noting that none of these studies have taken a holistic approach to examining the fundamental components that facilitate the accurate exchange of information in BIM implementation within green building design. According to Wu *et al*. [3], there are limited studies investigating the critical components that can ensure the exchange of accurate information in green building design practices.

Moreover, compared to environmental sustainability, the socio-economic aspects of sustainability have not been adequately integrated into MyCREST Design. Furthermore, little or no attempt has been made to address these shortcomings [16]. Therefore, this study aims to develop the MyCREST-BIM Integrated Framework (MyBIF) to facilitate efficient collaboration and information exchange among the multidiscipline design team in the green building design process. The research objectives of this study include:

1. To establish the main components that facilitate information exchange in the BIM-based green building design process.
2. To develop an ideal assessment tool for green building design, especially for tropical counties.
3. To identify best practices for digital information exchange.
4. To develop MyBIF that depicts the optimal relationship between the established components based on best practices.

The research findings provide the building researchers and practitioners with a thought-provoking approach for facilitating real-time collaboration and information exchange among the multidiscipline team during the conceptual design of green buildings. Also, the research results would serve as a valuable reference for developing or enhancing GBATs like MyCREST, which is the epitome of low carbon emission in the construction industry.

2. Methodology

The aim of this study was fulfilled by conducting a critical literature review of studies related to BIM implementation in the green building development process. A critical literature review is a prevailing method that employs rigor, transparency, and duplicability to identify, analyze, and synthesise related studies, to advance knowledge [17]. Fundamentally, knowledge is advanced via identifying gaps in the state of the art to propose areas for further investigation and develop a framework to appropriately position new research activities [18]. The critical review conducted in this study is like those of previous studies, such as Iqbal *et al*. [19], Babalghaith *et al*. [20], and Lou *et al*. [21]. The critical review was executed in 3 phases, as illustrated in Fig. (**1**).

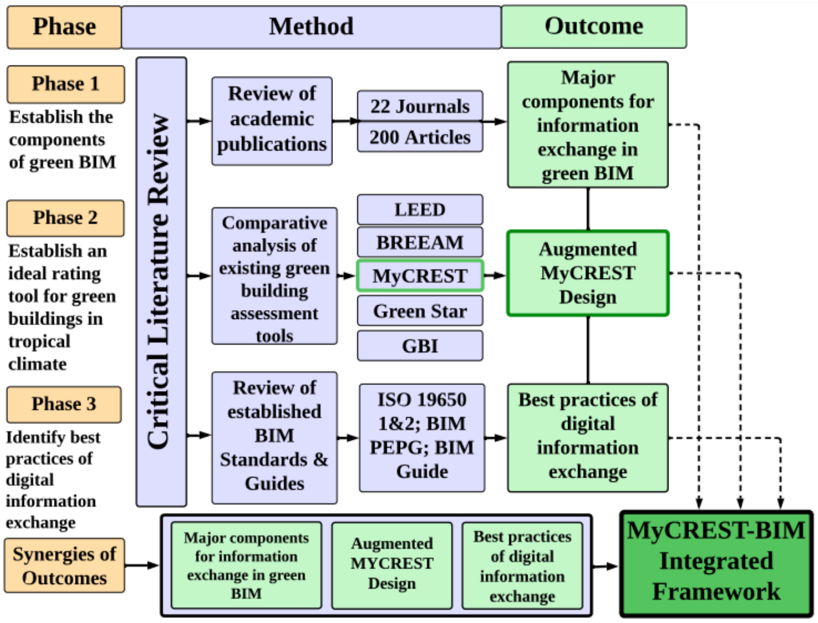

Figure 1: Critical review process.

Fig. (**1**) illustrates the review phases and the resources evaluated to develop MyBIF. The subsequent subsections below provide a detailed discussion of the 3 phases.

2.1. Selection of Academic Articles on Green BIM

The first phase of the critical review was conducted on 200 highly cited journal articles published from 2008 to 2024 (16-year interval) to establish the significant components of information exchange in green BIM practices. The search for academic articles on green building assessment/rating tools, Building Information Modelling (BIM), and BIM implementation in green building development were carried out following three steps: 1) selection of database for literature search; 2) screening of selected literature; and 3) analyzing selected articles. The Keywords used in the search for related studies include:

(“*Sustainable buildings” OR “Green building” OR “energy efficient buildings” OR “green building assessment tool” OR “green building rating tools”) AND (“Building Information Modelling” OR BIM OR “green BIM*”)

Afterward, a search query combining all the keywords was triggered to search related articles in the Scopus database. This resulted in the retrieval of 390 articles. Then, inclusion and exclusion criteria were employed. Reviews articles and book chapters published in English between 2008 to 2023 were selected. On the other hand, articles published in different languages before 2008 and those published in 2004 were excluded. As a result, 190 articles were excluded, while 200 articles were included in the review. The sources of the selected articles from the top journals are highlighted in Fig. (**2**) below.

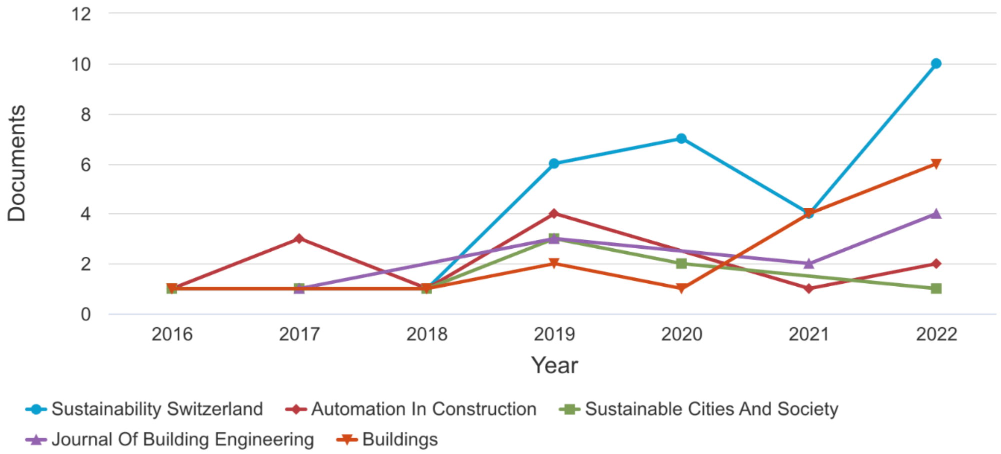

Figure 2: Top journals sources.

Fig. (**2**) shows an increasing trend in the literature, with Sustainability in Switzerland topping the publication chart with over 10 documents, while Sustainable Cities and Societies have the fewest published studies.

Data from Scopus was exported to VOSviewer to map the occurrence of keywords and identify the research trends in green BIM for information exchange. This aligns with previous studies in bibliometric analysis, such as Hatem *et al*. [22]. Based on keyword analysis, a network was developed, providing a holistic understanding of a research area and insights into intertwined relationships of research topics/subtopics. Thus, VOSviewer was used to represent the research landscape visually, map key term relationships, and further quantify research gaps. The map is illustrated in Fig. (**3**).

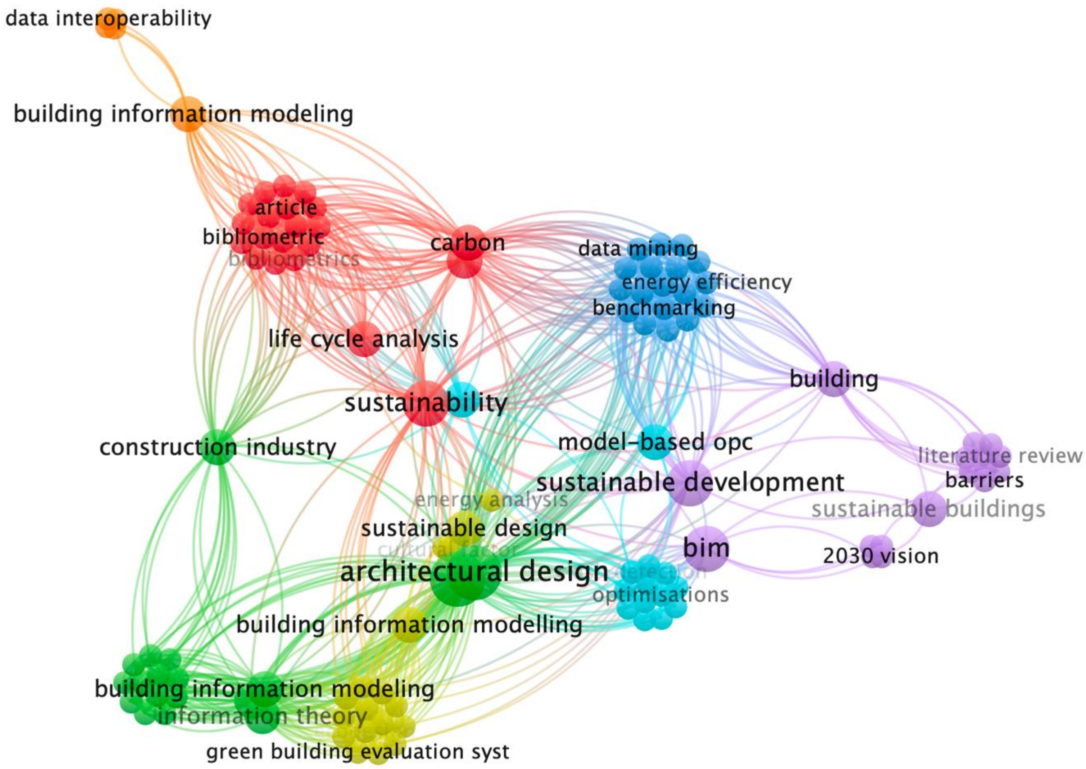

Figure 3: Co-occurrence keywords.

The keyword is further interpreted in Table **1** to show the number of times these keywords occurred.

Fig. (**3**) shows the mapping of keyword trends in the literature of BIM for sustainable building design, extracted from VOSviewer software. The map consists of 5 clusters represented by various colours. For instance, green represents Cluster 1, Red represents Cluster 2, yellow represents Cluster 3, purple represents Cluster 4, blue represents Cluster 5, light blue represents Cluster 6, while orange represents Cluster 7. Keywords like Architectural Design, Sustainable Development, Building Information Modelling, and Sustainability have a larger circle, which means they occur frequently compared to those with smaller circles, like life cycle, energy efficiency, and carbon emissions. The Figure is further quantified in Table **1** below.

Table 1: List of co-occurrences of author keywords on green BIM for information exchange.

Keywords	Occurrences	Total Link Strength
Sustainable Building	345	1283
Building Information Modelling	123	1120
Architectural Design	102	900
Construction Industry	60	876
Data Interoperability	54	690
Life Cycle	40	430
Energy Efficiency	24	223
Carbon Emission	11	145

As expected, Table **1** highlights that Sustainable building emerged as the central keyword, dominating scholarly discourse with a significant occurrence of 345 and a total link strength of 1283. This is followed by Building Information Modelling (BIM), with a total occurrence of 123 and a link strength of 1120. This aligns with the enormous studies on green BIM. In contrast, there is no evidence of information exchange, underscoring the need for further study on the information exchange of green BIM.

2.2. Comparative Analysis of Various Green Building Assessment Tools (GBATs)

To actualize the research aim, the second phase involves conducting a comparative analysis of existing Green Building Assessment Tools (GBAT) criteria. Comparative analysis is a crucial process that involves comparing different items to identify their similarities and differences. This analysis plays a significant role in developing new GBATs or improving existing ones, aiding in identifying key criteria and benchmarks [23] via an extensive review of academic literature such as Hu *et al*. [24], Illankoon *et al*. [25]; Wu *et al*. [3], 5 most important and globally prevalent GBATs were selected for comparisons, such as LEED, BREEAM, MyCREST, GBI, and Green Star South Africa. The selected GBATs represent four regions of the world: America, Europe, Asia, and Africa. For more accurate information, the GBAT documents were downloaded from the organisations' websites to identify their criteria and compare them with one another. For instance, the LEEDv4 was downloaded from the official website of the United States Green Building Council [26]

The comparative analysis was carried out in two phases. Firstly, a comparative study was conducted on the criteria of the 5 GBATs, following the steps applied by Illankon *et al*. [25]; Zhang *et al*. [27]. Afterward, the socioeconomic criteria of MyCREST Design were compared to the criteria identified in previous studies that developed new GBATs or augmented existing ones. The essence of the comparative analysis is to determine the key areas of convergence and distinction in the criteria of the selected GBATs to enrich the scarcity of MyCREST. The outcome of the comparative analysis is the establishment of additional criteria for MyCREST Design, to cohesively cover the economic, environmental, and social sustainability, thereby making MyCREST an ideal GBAT.

2.3. Analysis of Established BIM Standards and Guides

In the third phase of the review, established international BIM standards, particularly the International Organization for Standardization (ISO) 19650 1 & 19650 2, were examined. These standards focus on the use of BIM for the management of digital information in the building lifecycle. The BIM Project Execution Planning Guidelines (BIM PEPG) were reviewed to establish a standardized and systematic workflow for strategic BIM implementation. This document guides the various stages and processes of BIM project execution [28]. The Malaysia Construction Industry Development Board (CIDB) BIM Guide was also reviewed. The BIM Guide is part of CIDB's initiative under the Construction Industry Transformation Program 2016-2020 (CITP). Its purpose is to identify best practices that will help the construction industry in tropical climates, such as Malaysia, to transition from BIM level 1 to BIM level 2 maturity [29].

3. Major Components for Information Exchange in Green BIM

Green buildings contribute to a sustainable future by addressing economic, environmental, and social aspects, making them a compelling choice for building owners, occupants, and society [30]. However, Zhao *et al*. [31] view that the design of green buildings continues to be a challenging and intricate task due to the fragmented nature of the process. Furthermore, the inclusion of comprehensive sustainability criteria in GBATs introduces an additional layer of complexity to the green building design process, as highlighted by Wu *et al*. [3]. According to Succar (2009), BIM has emerged as a comprehensive framework comprising policies, processes, and technologies that enable the effective management of essential building data in a digital format throughout the entire lifecycle of a building. BIM serves as a critical central repository for collecting digital project information, enabling designers to make modifications to building components within a unified model [7]. This functionality allows for seamless propagation of changes across all views and deliverables within the BIM system.

Thus, Liu *et al*. [32]; and Taha *et al*. [33] believe that adequate synergize of BIM and sustainable building design practices, known as green BIM, require the critical consideration and application of the major components that can enable industry practitioners to efficiently utilize the available technology enablers such as BIM authoring tool and related performance analysis software to exchange accurate information and successfully execute projects. Numerous studies have been published on applying BIM to enhance information exchange in the green building design process. Therefore, this current study critically reviews previous studies to establish the fundamental components for facilitating information exchange in green BIM practices. The reviewed studies are summarized in Table **2**.

Table 2: Previous studies on components of information exchange in green BIM (2008 to 2023).

Sources	Major Components for Information Exchange in Green BIM					
	Green Building Assessment Tool	**Technology and Enablers**	**Institutional Support**	**Competency and Training**	**Deliverables & Information Requirements**	**Critical Decision Points**
[34]	✓			✓		
[4]		✓			✓	
[7]	✓	✓				
[35]	✓	✓				
[36]						✓
[10]	✓	✓		✓		
[8]	✓	✓		✓		✓
[37]				✓		
[38]		✓			✓	
[39]					✓	
[40]					✓	
[31]	✓					

Table 2: contd….

Sources	Major Components for Information Exchange in Green BIM					
	Green Building Assessment Tool	**Technology and Enablers**	**Institutional Support**	**Competency and Training**	**Deliverables & Information Requirements**	**Critical Decision Points**
[11]				✓		
[29]	✓	✓				
[41]			✓			
[42]		✓			✓	
[14]						✓
[43]					✓	
[44]				✓		
[45]				✓		
[6]		✓		✓		✓
[46]	✓	✓				
[47]	✓	✓				
[48]		✓				
[15]	✓	✓				
[49]			✓			
[50]			✓			
[51]	✓	✓			✓	
[52]	✓	✓				
[53]	✓					
[54]	✓					
[55]	✓	✓				
[56]		✓				
[57]		✓				
[58]	✓					
[59]	✓					
[60]						✓
[61]						✓
[62]		✓				

Table **2** presents a non-exhaustive review of previous studies on green building and assessment tools, BIM, and BIM implementation in green building development.

Table **2** illustrates that studies like Succar [4] established general elements of BIM: technology, process, and policy, but did not consider sustainability. Barison and Santos [11] explored the competency and training and competency of the diverse design team. Wu and Isaa [29] demonstrated how technology applications can be integrated into the green BIM process for the effective exchange of information with respect to LEED-based projects. Waterhouse & Philp [13] emphasized the importance of institutional support in driving the green BIM design process. Kamari *et al*. [14] concentrated on the critical decision points, where vital decisions are made regarding the Level of development and Level of Information in the green BIM process. Zanni *et al*. [10] identified the deliverables critical to BIM implementation in sustainable building in humid climates. Succar and Poirier [43] developed an information communication technology module for adequate management of building information. Lui *et al*. [32] looked into green building assessment/rating tools and their contribution to BIM-based green building delivery.

Certainly, these studies have made significant contributions to knowledge in green BIM literature. However, the primary components for enhancing the exchange of accurate information during the execution of BIM in green building design practices have not been considered critically in previous studies [63]. One of the significant drawbacks of implementing BIM in green building design is the exchange of inaccurate information, resulting in a flawed decision-making process [64]. Jain *et al*. [48] attributed this to the significant performance gap between simulated sustainability performance and the actual operating sustainability performance of buildings. Therefore, the major components for facilitating information in green BIM were identified as follows: Green Building Assessment Tool, Technology and Enablers, Institutional Support, Competency and Training, Deliverables & Information Requirements, and Critical Decision Points. The established major components will be applied to advancing knowledge in terms of developing a novel BIM-based framework for facilitating information exchange in the conceptual design of green buildings.

Notably, the performance of green buildings depends on the rating tool that guided the development. Thus, selecting an ideal GBAT that considers equally the social, economic, and environmental aspects of sustainability is pivotal.

4. Malaysian Carbon Reduction and Environmental Sustainability Tool (MyCREST): The Ideal GBAT

Although Mo and Boarin [65] argue that GBATs' limit design alternatives to "points-chasing," the benefits of GBAT with respect to designing buildings with high sustainability performance cannot be overemphasized. The GBATs criteria aim to improve the environmental performance of buildings and enhance occupants' comfort and productivity [3]. Globally, many GBATs have been established to meet local requirements, climatic conditions, and standards. LEED, for instance, addresses sustainability issues for arctic, alpine, and tropical climate conditions. BREEAM was developed for measuring the sustainability performance of buildings in temperate climates. The Green Star in South Africa, GBI Malaysia, MyCREST, etc., have been established to address the high energy consumption of buildings in the tropics.

MyCREST has three main elements: MyCREST Design, MyCREST Construction, and MyCREST Operation & Maintenance (O&M). This study focuses on MyCREST Design, which has 9 categories and numerous subcategories. MyCREST is projected as the core GBAT for this study, considering its potential to significantly reduce embodied and operational carbon emissions [2]. However, MyCREST has some flaws and limitations that need to be addressed to make it an ideal GBAT for tropical climates. A thorough examination of the comprehensive MyCREST Design Guide shows that 7 out of 9 categories of MyCREST Design concentrate on the environmental aspect of sustainability. Social sustainability was considered in two categories, that is, Occupant & Health and Social and Cultural Sustainability, while economic sustainability was only considered in the subcategory of Water Efficiency, where highlights were given on the efficient use of resources to reduce cost. The findings align with Lam *et al*. [66] and Abdel-Tawab *et al*. [63] study that the socio-economic aspect of sustainability has not been adequately integrated into the GBATs.

The need to develop a GBAT with criteria that cover the environmental, social, and economic sustainability and suit the local climate conditions was emphasized by Wu *et al*. [3]; Abdel-Tawab *et al*. [63], among others. Thus, augmenting the MyCREST Design by incorporating more socioeconomic sustainability is pivotal to make MyCREST a globally accepted GBAT and an ideal GBAT for tropical buildings. An effective way to develop new tools or augment existing ones is to conduct a comparative analysis with existing tools [66].

4.1. Comparison of MyCREST with other GBAT Criteria

Numerous studies have been conducted to enhance existing rating tools by comparing the similarities and differences and exploring ways to apply the advancements in technology to facilitate the green building assessment process. For example, Shi [67] conducted a comparative study on existing rating tools and proposed strategies for developing an effective assessment system in developing countries. Alyami and Rezgui [68] compared BREEAM, LEED, Sustainable Building Tool (SBTool), and Comprehensive Assessment System for Building Environment Efficiency (CASBEE) to develop a model for an effective environmental assessment method in Saudi

Arabia. Illankoon *et al*. [25] identified key criteria for developing new rating tools that will enhance the environmental performance of buildings. Huo *et al*. [69] compared 5 international GBATs to develop a theoretical framework for appropriate site planning and design. Wu *et al*. [3]. analyzed the existing systems for evaluating green buildings, both domestically and internationally, to create an evaluation model of a building's greenness.

However, there are major inefficiencies in the current literature, especially in the holistic comparative analysis of GBATs tackling criteria related to CO_2 [70]. Furthermore, there is a research gap in establishing a foundation for creating new green building rating tools that assess green buildings according to the three dimensions of economic, social, and environmental sustainability [71, 72]. Hence, this study presents a novel 2-step approach to comparative analysis. In the first step, the 9 categories of MyCREST Design were compared to the categories of existing GBATs, particularly LEED, BREEAM, MyCREST, GBI, and Green Star SA, to identify their similarities and differences. The outcome of the analysis is presented in Table **3**.

Table 3: Main criteria of LEED, BREEAM, MyCREST, GBI, & green star SA.

Comparison Categories	LEED	BREEAM	MyCREST Design	GBI	Green Star SA
Stakeholders' engagement	Integrative Process (prerequisite)	Management	Pre-Design	Sustainable Site Planning & Management	Management
Environmental Sustainability	Location and Transport, Sustainable Sites, Water Efficiency, Energy and Atmosphere, Materials and Resources, Indoor Environmental Quality,	Health and well-being, Energy, Transport, Water, Waste, Materials Land use and ecology, Pollution.	Infrastructure & Sequestration, Lowering Operational Carbon-Energy Performance Impacts, Occupant & Health, Lowering The Embodied Carbon, Water Efficiency Factors, Demolition & Disposal Factors, Sustainable & Low Carbon Initiatives.	Energy Efficiency, Indoor Environmental Quality, Material & Resources, Water Efficiency.	Indoor Environment Quality (IEQ), Energy, Transport, Water, Materials, Land Use & Ecology, Emissions
Social Sustainability	Location and Transport, Sustainable Sites, Indoor Environmental Quality,	Health and well-being, Transport, Water, Materials.	Occupant & Health, Social And Cultural Sustainability, Elective Points for Healthcare Buildings,		Indoor Environment Quality (IEQ),
Economic Sustainability	Water Efficiency, Materials and Resources, Regional Priority/Incentives,	Materials	Water Efficiency Factors	Material & Resources, Water Efficiency.	Materials
Climate	For diverse climates including tropical climates	Temperate climate	Tropical climates	Tropical climates	Sub-tropical
Carbon emissions reduction Strategies			Sustainable & Low Carbon Initiatives, Lowering The Embodied Carbon, Lowering Operational Carbon-		
Innovation	Innovation,	Innovation	Sustainable & Low Carbon Initiatives	Innovation	Innovation

Table **3** shows the initial comparative analysis, where the 5 GBATs are compared based on 7 categories. The findings from the comparative analysis show that the GBATs have some differences and similarities in their criteria.

In terms of similarities, all GBATs similarly allocated several categories to environmental sustainability, such as energy efficiency, water, Indoor Environmental Quality (IEQ), Materials, waste, etc. Furthermore, MyCREST, GBI, & Green Star SA address buildings in tropical climates. In contrast, there are several differences among the GBATs. LEED, for instance, covers building assessment in diverse climates, while BREEAM is primarily for Temperate climates and has the highest number of categories (8) for environmental sustainability. This coincides with Ansah *et al*. [73]; Zhang *et al*. [27]'s criticism that GBAT criteria mainly concentrate on the environmental aspect of sustainability, ignoring the economic and social aspects. Notably, MyCREST remains the only tool that designates 3 main categories: Sustainable & Low Carbon Initiatives, Lowering Embodied Carbon, and Lowering Operational Carbon-Energy Performance Impacts, for reducing carbon emissions. Although MyCREST considers social sustainability in categories such as social and cultural sustainability and healthcare buildings, BREEAM and LEED remain outstanding in this regard. BREEAM has 4 main categories: Health and well-being, Transport, Water, and Materials, assigned to the social sustainability aspect of occupants' health, productivity, and aesthetics. Also, LEED assigned Location and Transport, Sustainable Sites, and Indoor Environmental Quality categories to enhance occupants' comfort and productivity. In Green Star SA, a subcategory of Indoor Environment Quality (IEQ) is considered social sustainability, particularly occupants' comfort. GBI also did not adequately consider social sustainability [74].

However, the economic aspect was heavily sidelined, as only a few sub-criteria were assigned to this section to efficiently use water, materials, and other resources to minimize expenses. Apart from LEED, with 3 main categories: Water Efficiency, Materials and Resources, and Regional Priority/Incentives assigned to address economic sustainability, other GBATs did not adequately consider cost reduction. In the case of MyCREST Design, only a sub-category of Water Efficiency Factors considers cost reduction in the purchase of materials. Also, MyCREST does not have a category specifically focused on "Materials and Resources" like LEED and BREEAM. Certainly, existing GBATs did not consider the economic aspect of sustainability compared to environmental sustainability [25]. The findings from the comparative analysis have justified the need to augment MyCREST Design to address issues related to socioeconomic sustainability. The second phase of comparative analysis was conducted to fill in the socioeconomic. Precisely, the social and economic sustainability of MyCREST Design (identified in Table **3**) was compared with those established in LEED, BREEAM, and published academic literature. The comparative analysis is presented in Table **4**.

Table 4: Comparative analysis of published socioeconomic sustainability of GBATs.

Sustainability		GBATs			Academic Publications					
		MyCREST	LEED	BREEAM	[25]	[69]	[26]	[3]	[75]	[70]
Social	Social & Cultural Sustainability	✸			✸			✸		
	Occupant & Health	✸		✸	✸		✸	✸		✸
	Stakeholders Training	🟥				✸	✸		✸	✸
	Occupants & Community Engagement	🟥			✸				✸	
	Stakeholders Engagement	✸	✸	✸	✸			✸		
	Education & Awareness	🟥				✸	✸			✸
	Transportation	🟥	✸	✸						
Economic	Green Cost Reduction Strategies	🟦			✸			✸		
	Economic development	🟦	✸							
	Water Efficiency Factors	✸	✸	✸	✸	✸	✸	✸	✸	✸
	Materials & Resources	🟦	✸	✸	✸		✸	✸		

Table **4** shows the result of the comparative analysis of the socioeconomic aspect of MyCREST, LEED, BREEAM, and academic publications. The findings show that some of the social criteria of MyCREST Design were also highlighted in previous studies. For instance, a study conducted by Illankoon *et al*. [25]; Wu *et al*. [3] emphasizes the need for including criteria like stakeholders' engagement, social and cultural sustainability, and occupants' health in GBATs. However, some socioeconomic criteria established in previous studies are either missing or not adequately addressed in MyCREST Design. For example, criteria like Occupants & Community Engagement is missing in MyCREST Design. According to Illankoon *et al*. [25]; Zhang *et al*. [26], among the main social sustainability indicators that have not been considered in existing GBATs, are the Occupants & Community Engagement. The effect of occupants' behavioral discrepancy in the use of energy appliances remains a major cause of the high energy consumption of green office buildings [76]. Thus, it is paramount to include the occupants and community to ensure the delivery of buildings that represent the community's needs and inform the occupants on the approaches to use certain building components and appliances [75]. Also, the inclusion of social categories like Education and Awareness and Stakeholders Training and economic categories like Cost Reduction Strategies were highlighted as indicators that will revolutionize sustainable building practices [69; 26; 70]. These socioeconomic sustainability criteria were not considered in MyCREST Design, as shown in the comparative analysis (Table **4**).

Yet, existing studies have not established standard criteria for economic and social sustainability in rating tools [3]. Despite the shortcomings regarding socioeconomic sustainability, no studies at the time of this research have enhanced the MyCREST Design [8]. Based on the comparative analysis and review of previous studies, this study proposes enhancing the MyCREST Design by including the missing social and economic sustainability highlighted in Table **4**. These include social sustainability, such as stakeholders training, occupants & community engagement, education & awareness, and transportation and economic sustainability like green cost reduction strategies, economic development, and materials & resources. The findings align with previous studies such as Huo *et al*. [69], Ding *et al*. [70], Zhang *et al*. [27], Wu *et al*. [3], and existing GBATs like BREEAM and LEED that lay more emphasis on the socioeconomic sustainability. Therefore, this study proposes the inclusion of the identified socioeconomic sustainability in the MyCREST Design Structure, as shown in Fig. (**4**).

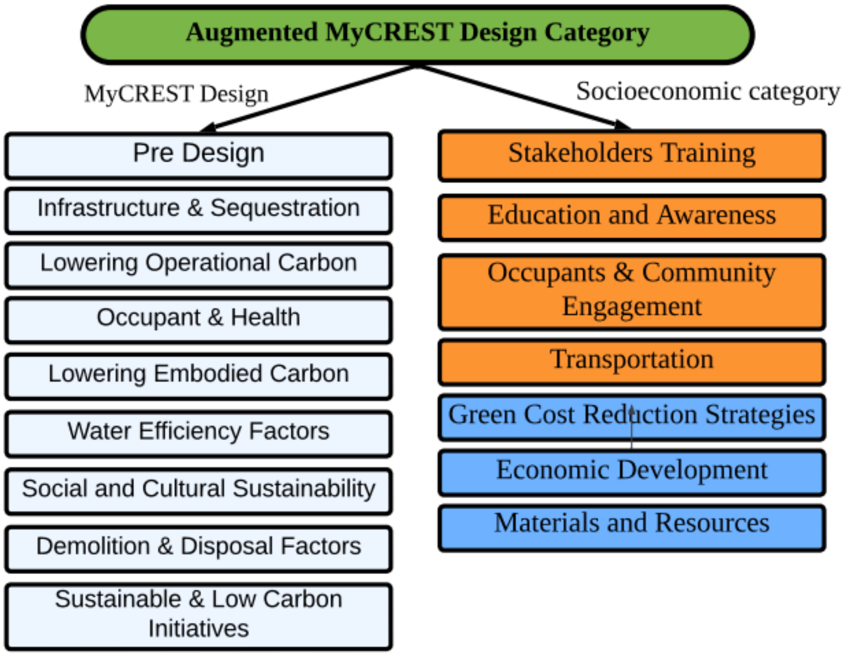

Figure 4: Augmented MyCREST design category.

Fig. (**4**) illustrates the augmented MyCREST Design which was developed after a critical comparative analysis. The Augmented MyCREST Design has the potential to become the ideal GBAT for tropical buildings that critically consider carbon emission reduction and the triple bottom line of economic, social, and environmental sustainability. Additionally, the tools remain an exceptional tool for carbon emission reduction in tropical climates. This is pertinent, especially as the building's carbon emissions rebounded after Covid 19 pandemic to 2% more than the all-time high (39%) recorded in 2019 [77]. Thus, construction practitioners and environmental stakeholders' global call to rapidly cut down the building sector's carbon footprint, this study projects MyCREST as a core GBAT due to the carbon emission reduction potential, which is the epitome of reducing the buildings' carbon emissions.

However, there is a lack of a well-defined approach for implementing digital technology like BIM tools in MyCREST-oriented building design [2]. Thus, this study evaluates the best practices of digital information exchange.

5. Best Practices of Digital Information Exchange

In the construction context, digital information exchange entails the use of diverse digital software to efficiently exchange information to optimize design and value delivery [78]. The execution of digital technology like BIM and other related tools in sustainable building design practice has attracted enormous attention, which is evident in the enormous studies on green BIM. However, despite the enormous studies, green BIM application is characterized by issues such as loss of information, exchange of inaccurate data, interoperability issues, and poor collaboration [79]. The major impact on the design practice is the exchange of unreliable data, which is the major reason for the gap between simulated sustainability performance and actual operating carbon-related emissions in green buildings [80]. Liao *et al*. [6] attributed this to the lack of training of the construction stakeholders and construction organizations' noncompliance with established BIM guides and standards.

Among the widely accepted BIM guides is the BIM Project Execution Planning Guidelines (BIM PEPG). According to the BIM PEPG outlined by CIC [28], the successful implementation of BIM in projects requires the identification of BIM goals and uses, designing the BIM project execution process, developing information exchange requirements, and defining the necessary infrastructure to support BIM implementation. It is of utmost importance that the BIM plan is developed at the early design stage to address the Employer's Information Requirements (EIR); and adequately define the BIM LOD & LOI, BIM deliverables, and the design roles to reflect the relationships between diverse and interdependent tasks and activities [29]. Due to the generic nature of BIM PEPG and the lack of emphasis on BIM-based sustainable building project delivery, several bespoke versions have been developed to suit the goal, climate, and local requirements.

In a tropical climate like Malaysia, the Construction Industry Development Board (CIDB), established the BIM Guide to assist the industry players in defining BIM deliverables and roles and responsibilities of the diverse team [2]. The guide emphasizes the need to develop a Master Information Delivery Plan (MIDP) as part of the BIM execution plan required by the EIR and the development of a Task Information Delivery Plan (TIDP) detailing tasks and plans for the successful execution of the project. The BIM Guide 5 draws from the BIM established standard ISO 19650; the main standard proposed in this study as a benchmark for digital information exchange. The International Organization for Standardization (ISO) 19650 provides a clear pathway for implementing BIM to effectively manage information in the building lifecycle. ISO 19650-1 stresses using clear and concise language so that information can be easily understood by everyone [81]. On the other hand, ISO 19650-2 outlined best practices for information exchange during the delivery phase, including identifying the information requirements for each stage of the project and establishing the processes and procedures for delivering the information [81]. The essence of adhering to this ISO cannot be underemphasized. This ISO ensures that the design team follows a well-established roadmap in exchanging accurate information during the green BIM process.

Besides, the use of industry-standard information delivery formats is recommended to ensure that information is delivered in a consistent and structured manner. Quality assurance processes should be established to ensure the information delivered meets the required quality standards. Also, information should be validated and approved at each stage of the project to ensure that it meets the required standards [81]. Additionally, the standard recommends that information is handed over in a format that is suitable for the intended use. In line with the BIM standard ISO 19650 Parts 1 and 2, construction companies must ensure that all design teams have achieved BIM Level 2 Maturity, enabling seamless information exchange within a Common Data Environment (CDE). Unfortunately, the state of BIM maturity in the Malaysian construction industry remains at Levels 0 and 1, indicating that conventional methods are still used for information exchange [2]. However, there is a positive outlook as CIDB anticipates an increase in the number of experienced construction practitioners due to ongoing efforts to promote the adoption of green BIM applications. Hence, in line with the government's commitment towards sustainability and digitalization in the building sector, this study proposes the combination of the established components, including the augmented MyCRET Design, in a structured framework to enlighten practitioners on the optimal relationship of the components required to facilitate information exchange in green BIM practices.

6. MyCREST-BIM Integrated Framework (MyBIF)

Since the emergence of BIM and sustainable building development, several green BIM frameworks have been established, focusing on various scopes, to facilitate digital information exchange. For instance, Succar [4] developed a framework of various BIM conceptual parts, such as fields, stages, steps, and lenses, that can provide the stakeholders with the foundation for delivering BIM projects. Cheng and Das [38] developed a modular web service-based framework for exchanging sustainable-related information. Gan *et al*. (2018) developed a holistic framework that uses BIM technology to evaluate buildings embodied and operational carbon. Succar and Poirier [43] developed the Lifecycle Information Transformation and Exchange (LITE) framework for predicting information flows across an asset's lifecycle. Marzouk and Thabet [64] established a green BIM collaborative framework to facilitate performance-based decision-making.

In tropical countries, Olawumi and Chan [59] developed the green-BIM assessment framework to enhance the environmental performance of buildings in sub-Saharan Africa. Rooshdi *et al*. [82] proposed a BIM framework for sustainable highway design in Malaysia. However, the investigation of the framework of components critical to facilitating the collaborative exchange of accurate information in BIM-based sustainable building design remains underexplored hitherto [64, 83, 84, 85]. To date, there is a lack of a comprehensive framework incorporating the triple bottom line of sustainability, Environmental, social, and economic, to guide professionals toward exchanging accurate information in green BIM practices [73, 86, 87].

Thus, this study advances knowledge in green BIM by developing the MyCREST-BIM Integrated Framework (MyBIF). Precisely, after a critical review of related studies, six major components for information exchange in the green BIM process were established, which include Competency and Training, Technology and Enablers, Deliverables and Information Requirements, Institutional Support, Critical Decision Points, and Suitable Green Building Assessment Tools (GBATs). The choice of the GBATs depends on the cultural demand and climate conditions of the area where the building will be developed. In the context of this study, a tropical climate is considered due to the high carbon emissions of buildings in the tropics [8]. Hence, MyCREST was projected as the ideal GBAT. The shortcomings of MyCREST were addressed by augmenting the MyCREST Design via a rigorous comparative analysis (Section 4.2). Furthermore, BIM guides like BIM PEPG and CIDB BIM Guide, and BIM standards like ISO 19650 1 & 2 were reviewed to determine the best practices of digital information exchange. Afterward, the relationship between the identified green BIM components and their sub-components was established via a well-structured novel MyBIF. The framework is illustrated in Fig. (**5**).

Fig. (**5**) shows the MyCREST-BIM Integrated Framework (MyBIF) that encompasses the fundamental components for facilitating accurate information exchange when executing BIM in green building design practice. Details on the relationship between the components are provided accordingly.

6.1. Competency and Training

One of the significant components for the successful implementation of BIM in green building design practices is the training and competency of the design team to use the diverse BIM software and other related tools to exchange accurate information [11] collaboratively. However, Hussain *et al*. [44] reiterated that the shortage of well-trained and competent construction professionals has remained a major constraint regarding information exchange in green BIM practices. Agostini *et al*. [88] argued that limited financial resources have hindered small and medium-sized enterprises (SMEs) from providing adequate employee training and competency development opportunities. On the other hand, Semaan *et al*. [45] postulated that construction firms lack incentive structures that reward BIM proficiency and innovation, resulting in critical issues such as a lack of motivation among stakeholders to invest in BIM training and competency. In tropical regions such as Malaysia, a significant portion of construction professionals lack sufficient training in executing BIM for sustainable building projects, as highlighted by CIDB [2]. As a result, complex and comprehensive green building models are outsourced to a third party, leaving the core design team out of the loop, exposing vital information, and misplacing building data.

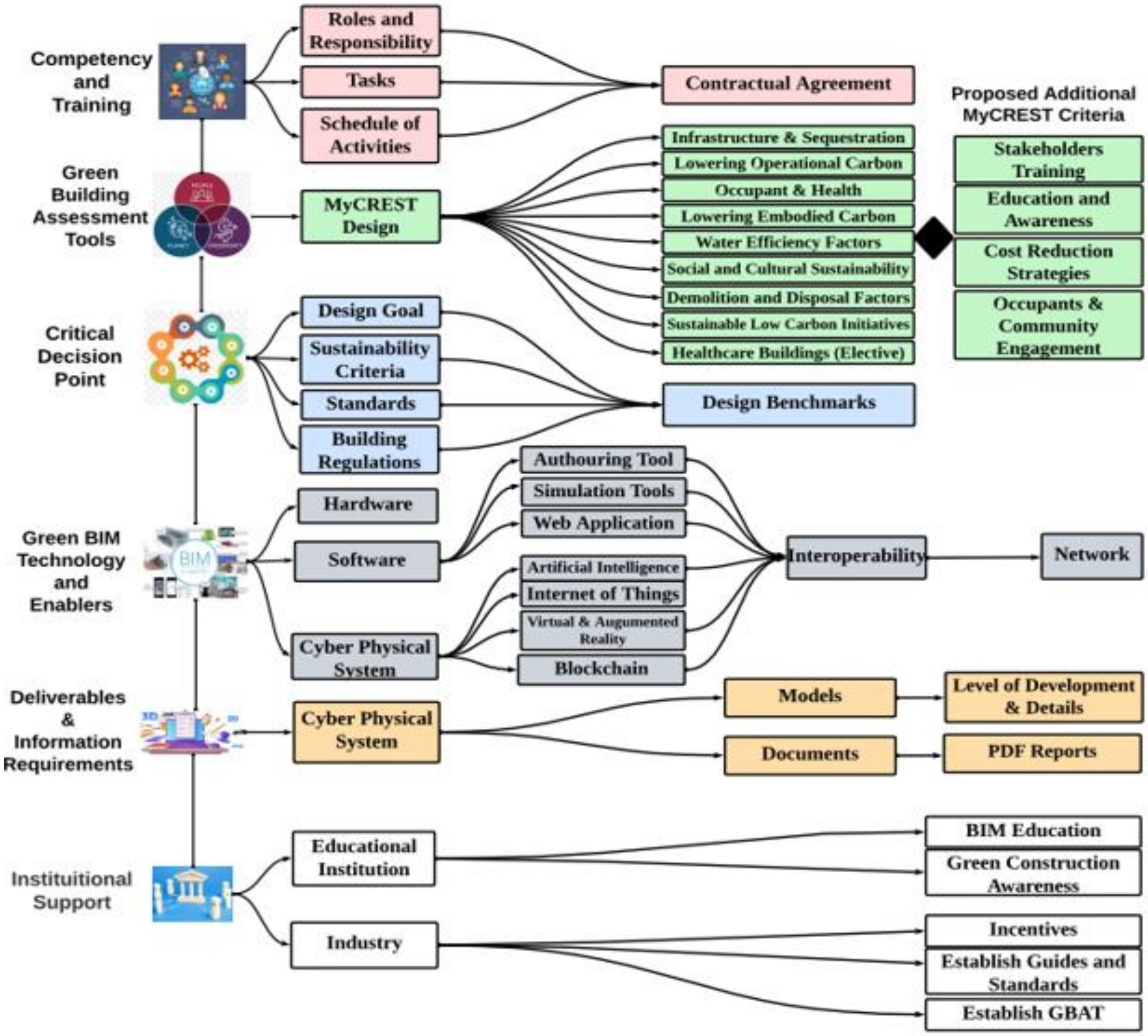

Figure 5: The MyCREST-BIM integrated framework (MyBIF).

Nevertheless, only a few studies, Barison and Santos [11], Hussain *et al*. [44], and Muller *et al*. [89], among others, have explored the strategy for enhancing the competency and training of the design team for efficient information exchange in green BIM practices. There is a lack of an established standardized BIM training and competency assessment framework that could ensure consistent and high-quality training outcomes for practitioners, especially in tropical countries [89]. Thus, construction firms must specify mandatory BIM competency requirements and continuous training policies that evolve with new technology, according to the special tasks of the diverse design team [11]. To prevent role fragmentation and segregation, it is crucial to clearly define new design roles such as BIM Manager, BIM Coordinator, BPA Specialist, and Sustainability Consultant in the Contractual Agreement/Legal Tender [10]. It is worth noting that role fragmentation can cause delays, cost overruns, and resource wastage, ultimately resulting in client dissatisfaction [16]. This should be avoided by providing a clear and detailed specification of the task, roles, and scheduling of activities in the agreement contract to ensure the effective exchange of information during the green building design process [29].

6.2. Green Building Assessment Tool (GBAT)

GBAT is a core component of green BIM. Thus, it is paramount for the design team to ensure that the overarching sustainability criteria of GBATs are achieved. Lu *et al*. [7] suggested that sustainability aspirations should be integrated into the design process early. Jain *et al*. [48] viewed a feasibility study as one of the first approaches to ascertaining the possibility of actualizing the targeted GBAT criteria. Emphasizing the significance of passive design strategies to optimize Indoor Environmental Quality, minimize energy consumption, and reduce carbon emissions is of utmost importance [90, 91]. Having augmented MyCREST Design criteria, as shown in Fig. (**3**), it is necessary to devise ways to actualize the added criteria. As regards engaging the occupants and community during the design process, the design team is required to investigate the types of activity to be carried out in the building and the number of occupants to help make viable design decisions [10]. Also, involving occupants and establishing occupants' manuals will help reduce the occupants' behavior discrepancies in energy use.

In the aspect of Education and Awareness, it is paramount to embed in the MyCREST Design, strategies for creating awareness of the benefits of sustainable and MyCREST-oriented designs, and the organization of short courses for students [16]. Apart from that, cost should be of primary concern when it comes to building projects. Thus, emphasis should be laid on the strategies to minimize green costs across the building lifecycle from the predesign stage to operation, and even demolition or deconstruction [92]. This aligns with JKR & CIDB's [2] statement that determining the green cost at the early design stage is among the best practices for implementing BIM in MyCREST-oriented buildings. Adopting the augmented MyCREST design and elaborating on the criteria will help the construction industry address the sustainability issues of buildings.

6.3. Technology and Enablers

Technology plays a crucial role in collaboration and data management to facilitate accurate information exchange in the BIM-based green building design process. Among the essential technologies (software) include the BIM authoring tool, which allows for timely design analysis through the evaluation and optimization of different design options for a more sustainable solution [93]; and BIM-related parametric modelling tools and energy modelling tools that simulate building sustainability performance to reduce the building's carbon footprint [35]. To facilitate information exchange synthesis between the diverse tools, interoperability software such as Industry Foundation Classes (IFC), and Visual Programming (VPL) Languages such as Dynamo have been developed. To augment the functionality of the numerous tools for appropriate green BIM implementation and information delivery, technology enablers, including online collaborative platforms such as Dropbox and Google Drive, and CDEs with added functionalities, are also utilized [94].

Green BIM technology is a broad aspect and arguably the most researched BIM literature. However, despite the proven benefits of technology and enablers in the construction context, its adoption for collaborative information exchange in green building design remains low [93]. Hitherto, construction professionals still exchange information using the conventional method [95, 96]. Though construction experts argue that face-to-face meetings cannot be ruled out in design Charlotte, the need for virtual meetings cannot be overemphasized. This is evident in the global lockdown. because of the COVID-19 global pandemic, where professionals are forced to adopt a virtual approach to information exchange and decision-making. Construction firms that are not familiar with online collaborative systems experienced significant delays in project delivery.

Hence, it is pivotal to explore and emphasize the use of emerging technologies for information exchange in green BIM practice. Such as integrating BIM with sensors to provide real-time feedback on building performance and energy use [97]. Use of gamification and virtual reality technologies to engage building occupants and encourage sustainable behavioral practices [98]. Blockchain technology facilitates secure and transparent data sharing and tracking throughout the building lifecycle [99]. 3D printing technology can be used to enable the creation of customized and sustainable building components, reducing waste and improving energy efficiency [100]. Integration of BIM with other emerging technologies such as virtual reality (VR), augmented reality (AR), Internet of Things (IoT), and artificial intelligence (AI) to enhance green building design and construction [80]. These approaches will enable efficient communication of building data necessary for delivering buildings with high sustainability performance.

6.4. Deliverables and Information Requirements

BIM deliverables, including documents, geometric models, metadata, drawings, rules, and regulations, play a crucial role in the execution of BIM in green building projects by enabling effective collaborative information management among project stakeholders [38]. Notwithstanding, these BIM deliverables have not been adequately utilized, evident in the heavily driven traditional paperwork used for information exchange, which hinders real-time collaboration [29]. As a result, a few studies Giel and Issa, [39]; Kassem *et al*. [40] have emphasized strategies for the adequate use of BIM deliverables, but most of these studies were limited to specific aspects of BIM, such as clash detection or cost estimation. Thus, Jalaei [92] opined that BIM deliverables need to be clearly defined throughout the design process. Otherwise, it becomes an issue for the design team to make accurate simulations and analysis, which in turn results in rework and, thus, delays in the project program.

As a crucial green BIM component, the BIM deliverables format, content, as-built information, and detailed information about elements in the model ought to be clearly defined to achieve a seamless BIM workflow required for effectively achieving the sustainability indicators of green buildings [100]. The development of the LOD and LOI principles guarantees efficient management of information sharing. Therefore, it is crucial to adhere to the required design quality that improves analysis and performance, as well as a sufficient definition of BIM LOD and LOI to match the schedule's employed sequence [29].

6.5. Institutional Support

Institutional support is an important component in the green BIM process. The government, educational institutions, and construction professional bodies are Among the major institutions with a high potential to promote BIM application in green building design. In countries like the UK and the USA, green BIM practices are heavily promoted by the government and other construction organizations via policies that mandate the use of BIM in all projects. In tropical countries like Singapore, the Building Construction Authorities (BCA) have been at the forefront of promoting green BIM through the provision of incentives and training for professionals. In the Malaysian context, CIDB Malaysia, the Ministry of Works, and other stakeholders have made progress in enhancing green BIM development through the establishment of MyBIM training cenres and the provision of incentives for training. However, institutional support has been under-explored in published green BIM literature [49].

Ohueri *et al*. [8] pointed out that more needs to be done in the aspect of BIM policy mandates and the provision of incentives for continuous BIM training. Also, tertiary institutions must develop BIM curricula to produce graduates who can face the digitalized and ever-evolving industry. Educational institutions can play a crucial role in promoting the adoption and implementation of BIM in green building design by providing students and professionals with adequate knowledge and skills [8]. Professional organizations can also provide institutional support through the development of BIM standards and best practices [2].

Certainly, some challenges limit institutions from fully supporting the green BIM process such as the lack of standardization in BIM education, as well as the cost of implementing BIM education programs [8]. Additionally, government regulations may not be uniform across different jurisdictions, and professional organizations may face challenges in developing universally accepted standards and best practices. Thus, institutions should constantly review strategies on green BIM as technology continues to evolve [8].

6.6. Critical Decision Points

Critical Decision Points (CDPs) are significant milestones in the various stages of the building design process where critical decisions must be made to ensure the success of the project [50]. According to Razmi *et al*. [36], one of the primary benefits of using BIM in green building design is that it allows for the evaluation of different design alternatives and their potential environmental impacts and makes timely, informed decisions about which approach to take. For example, at the site selection CDP, BIM can be used to assess the environmental impact of different site locations and identify the most sustainable option. Similarly, at the materials selection CDP, BIM can be used to compare different materials and their environmental impact over the lifecycle of the building [6].

Established standards, building regulations, design goals, GBAT criteria, and limitations strictly guide these decisions. Besides, the critical components that facilitate information exchange in green BIM practices ought to be incorporated on time to ensure that the decision-makers have reliable information [17].

There has been considerable research on the role of critical decision points in implementing BIM in green building design. For instance, Razmi *et al*. [36] viewed that critical points allowed for more accurate and informed decision-making about energy-efficient design strategies. Mahmoud *et al*. (2022) and Zanni *et al*. [10] stressed the need to provide a detailed definition of the design goals and criteria to guide the design process, apply best practices in established standards, and comply with building regulations. Similarly, Wu and Issa [29]; emphasized the need for collaboration and communication among project stakeholders and the importance of incorporating timely, sustainability criteria into the design process for critical decision-making. Despite that, Kamari *et al*. [14] strongly believe that critical decision points in the green BIM process are not identified on time.

Thus, Kamari *et al*. [14] cited that it is necessary to apply soft-gate alongside hard gates for more accurate decisions and eventual realization of the sustainability objectives. Additionally, the creation of a BIM manual is essential for key decision-making and reference purposes [10]. The timing of these decisions is critical since it is more expensive to duplicate work that has already been completed once agreements have been reached early on in the process [48]. During the initial project briefing, it is important to specify the sustainability benchmarks and criteria that will be used to make crucial decisions on the design of green buildings.

7. Conclusion

The CO_2 emissions from the building sector have adversely contributed to exacerbating climate change and occupants' discomfort. Green building development has more potential to enhance the sustainability performance of buildings. Both the academic and the construction stakeholders are increasingly considering the use of BIM technologies to support the green built environment. Based on the best practices that integrate holistically, the BIM field - technology, policy & process, and the triple bottom line - economic, environmental, and social sustainability; the Novel MyCREST-BIM Integrated Framework (MyBIF) was rigorously developed. Firstly, the main components facilitating information exchange in the BIM-based green building design process were identified after a critical review of academic publications on green building and assessment methods, BIM, and BIM execution in green building practices. The main components include competency and training, suitable green building assessment tools, technology and enablers, deliverables and information requirements, institutional support, and critical decision points.

Secondly, this study projects MyCREST as the suitable GBAT, due to its carbon emission reduction strategies which were not considered in detail in other existing GBATs. However, like other GBATs, MyCREST has some weaknesses, which were augmented in this study after a comparative analysis of MyCREST and other GBATs such as LEED, BREEAM, GBI, and Green Star SA. Additionally, the socio-economic aspect of MyCREST was compared with those established in LEED, BREEAM, and academic literature. This resulted in the augmentation of MyDERST Design by including 7 socioeconomic categories to MyCREST design, including occupants & community engagement, education and awareness, stakeholders training, and green cost reduction strategies. The need for an ideal assessment tool for green building design in the tropics cannot be ignored considering the adverse effect of building in terms of carbon emissions which rose to over 41% in 2022, and poor consideration of the social and economic aspects of sustainability. Thirdly, considering the complexity of the green BIM practices, and the diversified nature of the established components, established BIM guides and standards were reviewed, resulting in the identification of the best practices of collaborative information exchange, and eventual delivery of buildings with high sustainability performance.

Afterward, the MyBIF was developed to show the optimal relationship between the components and their sub-components necessary for the exchange of accurate information in the green BIM process. The novelty of this study lies in the methodological rigor applied in developing the MyBIF, the established unique green BIM components, and the augmented MyCREST design. The research findings can provide an essential reference for both researchers and practitioners on the critical components of information exchange in green BIM. MyBIF will provide the researchers with valuable insights on how the expertise of the multidiscipline team can be harnessed to effectively use the diverse domain software to exchange accurate information during the green building design practice. This is missing in the literature on green BIM. The study's findings would be valuable for academics and construction professionals interested in creating green building evaluation techniques. Moreover, this study promotes the adoption of MyCREST. Ultimately, the output of this study will enlighten practitioners on the best approaches to reducing carbon emissions and promoting the socioeconomic aspects of sustainability in the built environment.

However, MyBIF is developed based on a critical review. Thus, further study needs to be conducted to validate it empirically. Also, future studies can extend the framework to other countries' sustainability rating tools, thereby driving sustainable construction in line with the UN’s sustainable development goals.

Conflict of Interest

The authors have no relevant financial or non-financial interests to disclose. As such, there is no conflict of interest.

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Authors’ Contributions

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