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Review

The Potential and Challenges of Bim in Enhancing Energy Efficiency in Existing Buildings: A Comprehensive Review

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Abstract: Issues such as sustainable living, reducing fossil fuel consumption, and increasing energy usage remain critical in the construction industry, as buildings account for approximately 40% of global energy consumption. The shift towards energy-efficient building designs is essential; however, there is a pressing need to reinforce existing structures rather than demolish them, re-emphasising the concept of energy efficiency. The increasing adoption of Building Information Modelling (BIM) processes contributes significantly to the development of predictive design and energy analysis capabilities. This study comprehensively examines the integration of BIM in the existing building stock. Firstly, the information structure used in the assessment of the existing building stock is detailed, including geometric information, semantic information, and energy-related information. The content, criteria, and scope of this information network are explained, and the BIM tools that facilitate the integration and evaluation of this information are compared. Finally, the methodologies of Industry Foundation Classes (IFC), Information Delivery Manual (IDM), and Model View Definition (MVD), which enable information sharing for energy analysis, are detailed, and their use in energy efficiency analysis is examined. Through a literature review, BIM-integrated energy analysis programs are evaluated, file-sharing processes are examined, and the challenges in this area are identified. The findings emphasise BIM's crucial role in future energy analyses. They highlight its potential to save time and financial burdens while ensuring precise outcomes.

***Keywords*:** BIM, energy efficient building, existing building enhancement, energy analysis

Nomenclature

SDGs	Sustainable development goals
BIM	Building information modelling
BDS	Building description structure
3D	Three-dimensional

AR	Augmented reality
BPM	Building process modelling
LoD	Level of development
IFC	Industry foundation classes
BEM	Building energy modelling
IEA	Integrated energy analysis
NBS	National building specification
IAI	The industry alliance for interoperability
MVD	Model view definition
BEPS	Building energy performance simulation
IDM	Information delivery manual

1. Introduction

The built environment represents living space, workspace, entertainment space, and, in short, people's needs. Moreover, it is a spatial and cultural phenomenon [1]. The built environment, which has an essential place in creating the comfort zone of humanity, actually includes buildings, open spaces, and infrastructures. Therefore, it has a crucial role for humans and is considered to be of global importance in aiming for sustainable development [2]. On the other hand, the built environment should pioneer in striving for a clean living space for people (healthy living) and improving social and environmental situations for the present and future generations. However, as a result of the increase in the number of buildings in the built environment due to population causes an increment in energy production and material usage. This negatively affects human health by escalating greenhouse gas emissions [3]. The Sustainable Development Goals (SDGs) highlight the importance of focusing on building design, especially to urgently address energy efficiency [4]. Consequently, the agenda of the SDGs encourages the adoption of building performance at a specified value and the use of appropriate construction materials [5], thus, the implementation, development, and adoption of energy-efficient buildings. With their implementation, not only environmental degradation can be reduced [6], but with pioneering advances in this desired goal, it may become inevitable to observe comfortable and energy-efficient situations.

The scenario given shows that many current buildings use energy inefficiently. This highlights the urgent demand to move to more energy-efficient options soon. Current structures often face challenges due to the widespread use of materials with low thermal resistance. This results in substantial heat loss and environments that frequently do not meet human comfort standards [7-8]. For example, it is estimated that existing buildings in urban areas contribute to 40% of global energy consumption and greenhouse gas emissions [9]. Notably, India currently represents approximately 26% of total energy consumption attributed to buildings. However, projections indicate that this figure is poised to surge to 40% by 2040, driven by the escalating demand for housing spurred by rapid population growth [10]. It is the first country in the UK to set a target and make serious investments to provide low/zero carbon buildings by 2050, as a reaction to the fact that buildings give rise to spend the total energy consumption with 40% [11]. These findings underscore the critical role of addressing the energy consumption of existing buildings. The building envelope should be optimised so as to reduce energy consumption. A well-crafted building envelope is essential for minimising heat loss in winter [12] and preventing excessive heat gain in summer [13], ultimately lessening the reliance on mechanical heating, and cooling systems and boosting overall energy efficiency [14]. Improving insulation and using materials with lower thermal conductivity in both new construction and renovations can enhance existing building envelopes' ability to resist heat transfer. This practical approach offers a significant means to reduce heat flow between indoor and outdoor environments [15]. Acknowledging the considerable obstacles involved in reconstructing existing structures, retrofitting emerges as a pragmatic and cost-effective alternative [16]. The intricate and costly nature of reconstruction makes it an impractical solution, particularly in densely populated urban areas with limited space and infrastructure [17]. Retrofitting interventions encompass a variety of strategies, such as upgrading building systems, enhancing insulation, and integrating renewable energy technologies, tailored to the specific requirements and context of each structure [18]. By investing in energy-efficient retrofits, significant reductions in energy consumption and greenhouse gas emissions can be achieved [19]. Furthermore, retrofitting enhances the resilience and lifespan of existing buildings, thereby promoting economic growth, social equity, and overall community well-being [20]. In summary, retrofitting is a crucial element of sustainable development endeavours, providing a practical and comprehensive approach to upgrading the energy performance and environmental impact of existing buildings. By prioritising retrofitting initiatives and embracing energy-efficient practices, it can be paved the way for a more sustainable built environment and a brighter future for future generations. Improving energy efficiency in buildings can be accomplished by either reinforcing existing structures [21] or demolishing and rebuilding them with energy-efficient designs [22]. However, advancements in technology now enable the simulation of potential benefits or drawbacks, associated costs, material enhancements, performance outputs, and lifespan considerations-all within a computerised environment [23]. This capability is immensely valuable, particularly given trial-and-error approaches' economic and environmental costs [24], from initial material production to eventual reconstruction and demolition. In this regard, the advent of BIM signifies a critical step forward. BIM offers engineers, architects, contractors, and other involved parties an interface and information about various aspects such as project design [25], planning [26], construction processes [27], cost estimation [28], energy efficiency [29], etc., before the actual building or infrastructure construction begins. Thanks to its interface and information capabilities, it facilitates simulation in various scenarios and enables prompt intervention in case of issues [30]. The model helps reduce valuable resources such as material, moral, labour, and time. BIM allows for the comprehensive simulation of mechanical-thermal data, from initial design to cost analysis and energy efficiency assessments [31]. Notably, BIM facilitates accurate pre-construction insights and immediate error correction, thereby mitigating both material waste and project delays [32]. As such, BIM emerges as a pivotal model poised to gain widespread adoption, as depicted in Figure 1, showcasing its manifold advantages.

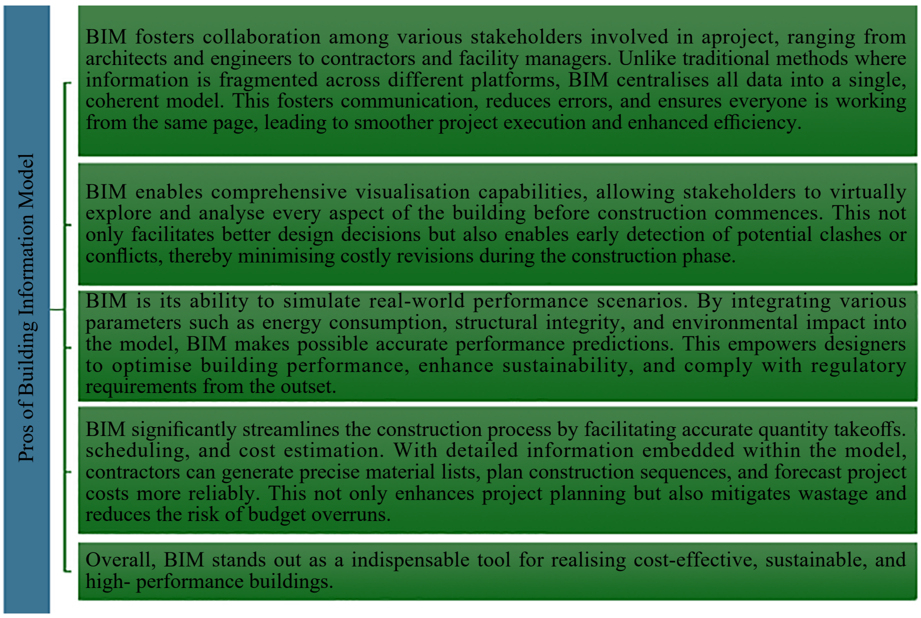

Figure 1. Advantages of utilising BIM

On the other hand, there are some restrictions on using BIM. These are initial costs [33], limited adoption in some sectors, resistance to change, legal and liability issues, complexity management, over-reliance on models, dependency on technology, data security risks, software compatibility, and a learning curve. As depicted in Figure 2, each issue is systematically categorised under headings and accompanied by concise explanations. The underlying implication suggests a need to enhance the frequency of usage, which in turn necessitates heightened awareness. It becomes apparent that as training and user engagement intensify, the sincerity of improvement may also escalate. This proactive approach not only facilitates real-time problem resolution during the design phase but also yields significant savings in terms of time, labour, and costs through timely interventions based on short-term prognostications.

Figure 2. Some cons of having BIM

Thanks to BIM software, stakeholders can be empowered to evaluate the energy efficiency of a building design by utilising a multitude of variables. These measurements enable them to anticipate improvements in energy performance and implement corresponding precautions effectively. The variables encompass various aspects, ranging from building envelope components [34] and envelope components with heating as well as cooling [35-36], lighting systems [37], and renewable energy measures [38].

The building envelope plays a crucial role in determining a building's energy efficiency. As a result, various materials and systems can serve as the building envelope, each with its own thermal conductivity and emissions characteristics. Among these, thermal insulation emerges as a critical strategy for optimising operational energy requirements and costs by reducing heating and cooling demands, especially during extreme weather conditions. This underscores the importance of leveraging BIM simulations, which have garnered significant attention in recent years. Reviewing existing literature shows that BIM stands out as a valuable asset in addressing common challenges such as financial strains and project delays. BIM facilitates well-informed decision-making throughout the project lifecycle by providing detailed insights from initial building design to mechanical and energy performance analyses.

As a consequence, despite the growing recognition of BIM's potential, there remains incomplete understanding of its advantages in retrofitting existing structures, and the information systems within BIM are not fully explored. This limited understanding is a barrier to wider adoption of BIM processes. Therefore, this study aims to address these gaps by clarifying the benefits of retrofitting with BIM tools and conducting a detailed comparison of BIM's information structures and tools. Additionally, it will outline the specific requirements of BIM for enhancing energy efficiency and highlight gaps in the literature, particularly in information-sharing processes. This comprehensive review aims to advance knowledge and understanding of integrating BIM into energy-efficient retrofitting, ultimately facilitating smoother adoption and utilisation of BIM-based energy analysis tools.

2. Background

Considering that green building or energy efficient building construction processes will take decades, it is obvious that retrofitting the existing building stock is a more effective process in terms of achieving the target [23]. Energy efficient enhancing of the existing building stock requires a very difficult and complex process. The organisation of the know-how within existing buildings has been shown by many researchers [39-45], to be possible with BIM.

Ljuban et al. [46] reveals the advantages of BIM processes over traditional construction processes in their study. Duah [47] argues that retrofitting existing buildings to make them more energy efficient contributes immensely to energy savings and associated economic, environmental and health benefits to occupants. Although energy retrofitting has some benefits, its adoption comes with obstacles. Kusi et al. [48] emphasise that the use of BIM has advantages not only for the energy efficiency of buildings but also for the reduction of carbon emissions.

Ghanbari et al. [49] proposes a combination of BIM with Design Builder and Meteonorm software to assess the environmental impact of renovating buildings in the operational process. The research through a case study in the city of Tehran shows that by combining the most effective insulation, glazing, heating system and doors, a 15% reduction in energy consumption and a 44% reduction in CO_2 emissions can be achieved through the impact on various building components.

Mughal et al. [50] conclude that the construction sector consumes about 55% of Pakistan's annual energy and has a large share in total energy consumption. Therefore, they develop a contemporary and effective model for green retrofitting of existing buildings based on BIM which aims to reduce the energy consumption of buildings. The research aims to retrofit the existing building by altering the design parameters for an inefficient building envelope based on the results of BIM simulation and data optimisation to refine the overall energy consumption. BIM tools such as Autodesk Revit and DesignBuilder are used to evaluate the enhanced energy efficient design by comparing different design alternatives. After a detailed analysis, this research reveals that the existing building consumes a high amount of energy annually. With the help of BIM tools, a list of 'green' solutions, i.e. optimum designs, is generated, from which the optimum and cost-effective design can give rise to a total energy saving of 46%.

Danial et al. [51] emphasise the importance of retrofitting existing buildings to improve energy efficiency. They emphasise that most existing buildings are not sustainable and that simply building new buildings is not enough to achieve energy efficiency. The study claims that existing buildings consume about 60% of global energy consumption. They argue that low energy consumption ought to be achieved through renovation of existing buildings. This study is to develop a framework for the integration of BIM and retrofit categories and is realised by combining the most effective in-depth retrofit strategies, which ultimately lead to a 68% reduction in annual energy consumption.

In accordance with Forastiere et al. [52] as the urgency to mitigate climate change intensifies, achieving a zero carbon target in the built environment has become a critical goal. Retrofitting buildings plays a vital role in mitigating energy consumption and carbon emissions in existing buildings. This paper presents an approach that combines BIM with multiple domains to target zero carbon targets in building retrofit projects. The proposed approach is based on a dynamic, multi-parametric analysis that combines indoor comfort, energy savings, CO_2 equivalent reduction and the social cost of carbon, taking into account investment costs. Renewable energy technologies such as photovoltaic panels and solar thermal systems are emphasised to achieve the desired zero carbon outcomes. Real-time monitoring mechanisms enable continuous performance evaluation and adaptive improvement strategies for further energy savings.

As it is seen, in recent years, the literature gives great importance to energy in the retrofitting of existing structures. In this context, when the retrofitting of existing structures is analysed, Jagarajana et al. [39] present a review study on Green retrofitting. Within the scope of this study, green retrofit policies, business processes, stakeholder awareness have made strong contributions to the literature, but the file properties did not provide information on the importance of energy in retrofit studies. Sanhudo et al. [53] present a review study on the use of BIM in retrofitting existing building stock. In this context, the file properties and file contents required for energy analysis are explained. Ganah and Lea [54] focus on BIM standards in their review of the literature but retrofit and energy concepts are excluded.

Literature review shows that it is very advantageous to retrofit existing structures with BIM tools. However, in general, the advantages of BIM tools are not fully understood, and the information system is not fully known. This situation slows down the transition to BIM processes. In this study, the advantages of improving with BIM are explained in detail and BIM information structure and BIM tools are detailed comparatively. In addition, the requirements of BIM in the energy context are listed and the literature gaps related to information sharing processes are completed.

3. Research methodology

As seen in Figure 3, the study consists of four stages. Firstly, the capabilities of BIM are presented. BIM capabilities are presented in two stages: new construction processes and existing building stock. Since the study is related to the existing building stock, the rest of the study focuses on the use of BIM in the existing building. In this context, the information structure used in the evaluation of the existing building stock in BIM processes is detailed. In the second step, the information structure in the existing building is evaluated as geometric information, semantic information and energy related information. Information on the contents, criteria and scope of this information network is presented. In the third step, BIM tools that enable the integration and evaluation of all this information are explained comparatively. In the last stage, IFC, IDM and MVD methodologies that provide information sharing for energy analysis in BIM based programmes are explained. The methodologies used for sharing the information required for energy analysis are presented.

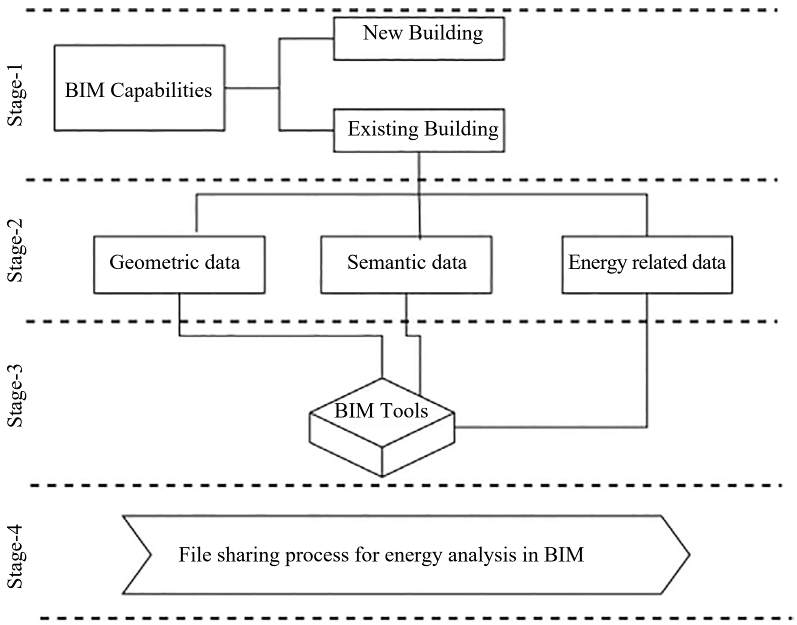

Figure 3. Research methodology

4. BIM capabilities

In 1975, Eastman used the term Building Description structure to refer to a hierarchical structure [55] of building components in the composition of a digital model, which was how the basic idea of BIM methodology was first discussed. The system the author described enables the development of elements related to shape, position, and property data [56]. The BIM system, which emerged in the early 2000s, is basically a process developed to solve the problem of information flow among stakeholders (architects, engineers, contractors, owners, and operators) in the construction industry [57]. In other words, it integrates geometric and non-geometric information, enabling a comprehensive digital three-dimensional (3D) representation of a constructed facility. BIM facilitates collaboration and integration of information between construction stakeholders such as architects, engineers, contractors, and subcontractors, leading to improved construction documentation performance in terms of cost, time, quality and safety [58]. With BIM, project processes are not only limited to the design phase but also allow the management of information throughout the building life cycle [59]. This makes it possible to create a digital model of buildings and to assess their energy efficiency.

In general, the energy consumption of a building refers to the amount of energy consumed directly [60], but the energy consumed by the building during the use phase, in other words, during its life cycle, is considerable [49]. The building life cycle covers the planning, design, construction, use, occupancy, and demolition processes [46, 61] (Figure 4). However, considering the energy required for the building demolition phase, the emergence of CO_2 embedded because of building destruction, and the environmental and economic impacts, it can be said that it is more helpful to strengthen the building rather than demolish it. BIM is seen as a new and effective technique for energy-efficient retrofit of existing buildings [50, 62].

In the building programming phase, the existing situation is modelled [63], project cost estimation is made [64-65], the stages of the process are programmed [61], and site analysis is performed through BIM [66-67]. In a building design, simulation of the site with BIM tools before the design starts, the appearance of various data of the site in the simulation will allow designs to be made in accordance with the spirit of the place. In addition, the determination of construction costs in advance allows process programming to be as close to accurate as possible. In this respect, compared to traditional methods, BIM processes offer many advantages in the planning phase, which precedes the design phase.

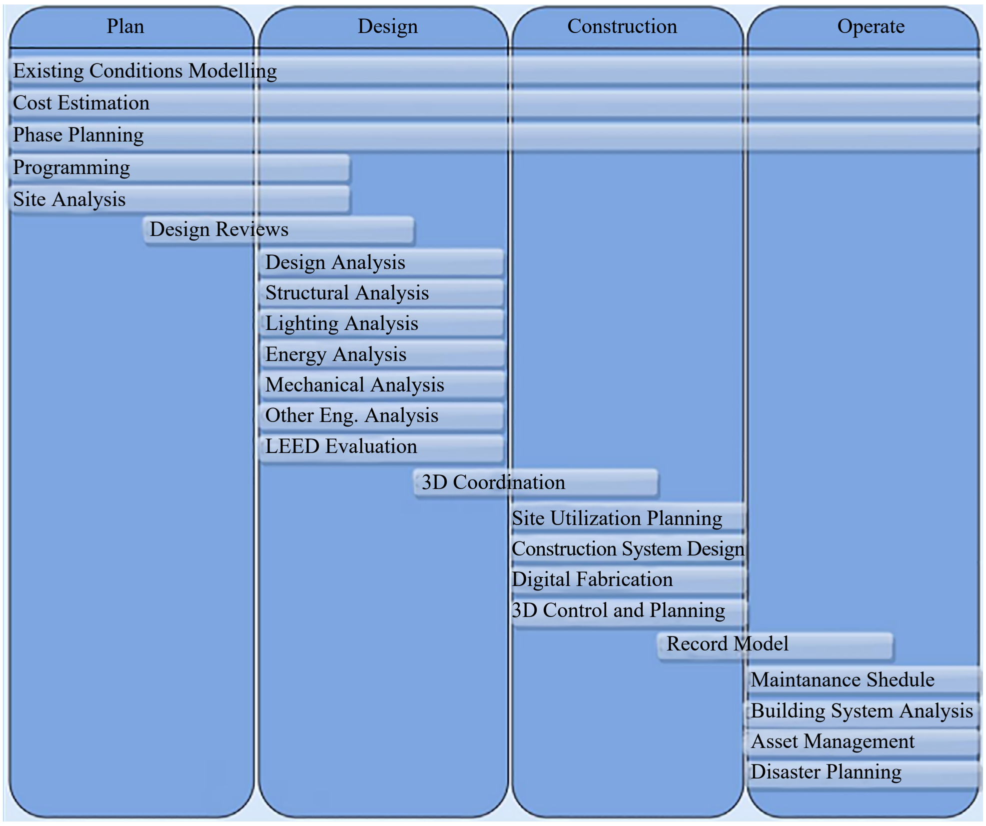

Figure 4. BIM capabilities

The building design phase is a critical stage where ideas about the building, decisions about energy efficiency, and life cycle performance are determined [68]. The use of BIM-based programs in the design phase, which are greened for information sharing, increases collaboration between stakeholders [56] and thus reduces misunderstandings among stakeholders. The use of BIM-based programs at the design stage facilitates cost estimations [69-70], energy consumption analysis [60, 71-72], or critical assessment information on the static conditions [42] of the building. In addition, lighting analysis [71, 73], mechanical installation analysis [74-76] and many other engineering-based analyses [77-78] can be easily performed.

With BIM, actions can be organised during the building construction phase, site utilisation [66, 79] can be planned, system design of the building [56, 80] can be arranged, digital production is possible [80], and the stage of the production planning process [81] can be continuously controlled. In this way, strategic plans [82] can be easily developed if needed by checking how far behind or ahead of the program.

In the building operation phase, a program for the maintenance of the building can be prepared [46, 83-84], analyses of mechanical [76] or electrical systems [85-86] can be checked during use, management of the building is possible, and finally, if the building needs to be demolished [87], a demolition plan can be prepared [88].

In 2015, the importance of BIM processes for energy control of buildings has increased within the scope of the 11th article of the global development plan "Inclusive, safe and sustainable structuring of cities". This situation has made it critical to evaluate the energy efficiency of existing buildings and then retrofit the current situation. It is a difficult and time-consuming process to figure out the energy efficiency of existing buildings using traditional methods and to provide recommendations. However, BIM processes are seen as more advantageous than traditional information management processes in the context of energy efficiency and sustainability. BIM processes have the potential to optimise resources, improve sustainability, and enhance the quality of buildings [46]. There are numerous chances to lower world energy consumption and greenhouse gas emissions by retrofitting existing structures [41].

4.1 *Role of BIM in the retrofit of existing buildings*

The goal of retrofitting is to improve a structural component or feature that is not included in the original design and construction of the structure [39]. Considering the general framework and capabilities of BIM systems, the idea that it can be used in retrofitting is overwhelming as it has a nature that integrates heterogeneous information networks such as semantic and geometric information.

BIM is a tool that can facilitate energy-oriented retrofits and achieve a high-quality sustainability rating in a short time. Whilst BIM is widely used for new construction, the process is a bit more challenging when it comes to retrofit projects [40]. Digital information assets, or "digital twins", are created and managed using BIM throughout their entire lifecycle, from planning and design to construction and operation. BIM offers the chance to improve the durability, energy efficiency, adaptability, and well-being of existing structures [42]. There is no standardisation for building retrofitting using BIM-based programs. For this reason, retrofit studies have been developed using different methods and techniques in literature studies.

Yildirim and Polat carried out the retrofitting of an existing building by using BIM-based programs. In this study, BIM tools have been used for energy optimisation in material selection and selection of the most accurate materials in the retrofitting phase. As a result of the study, it has been determined that the annual fuel and electricity consumption is reduced by approximately 60% by retrofitting the building [43].

D'Angelo et al. have modelled the workflow processes in BIM retrofit processes in Figure 5. According to this study, the first step is to check whether the building to be retrofitted has a BIM model. If not, the BIM model is produced, if available, the model is checked and updated. Then, the data required for energy analysis are added to the digital model of the building created with BIM-based programs. Then, elements, materials, or systems that can be used during retrofitting are tested, and the most suitable retrofitting model is obtained [40].

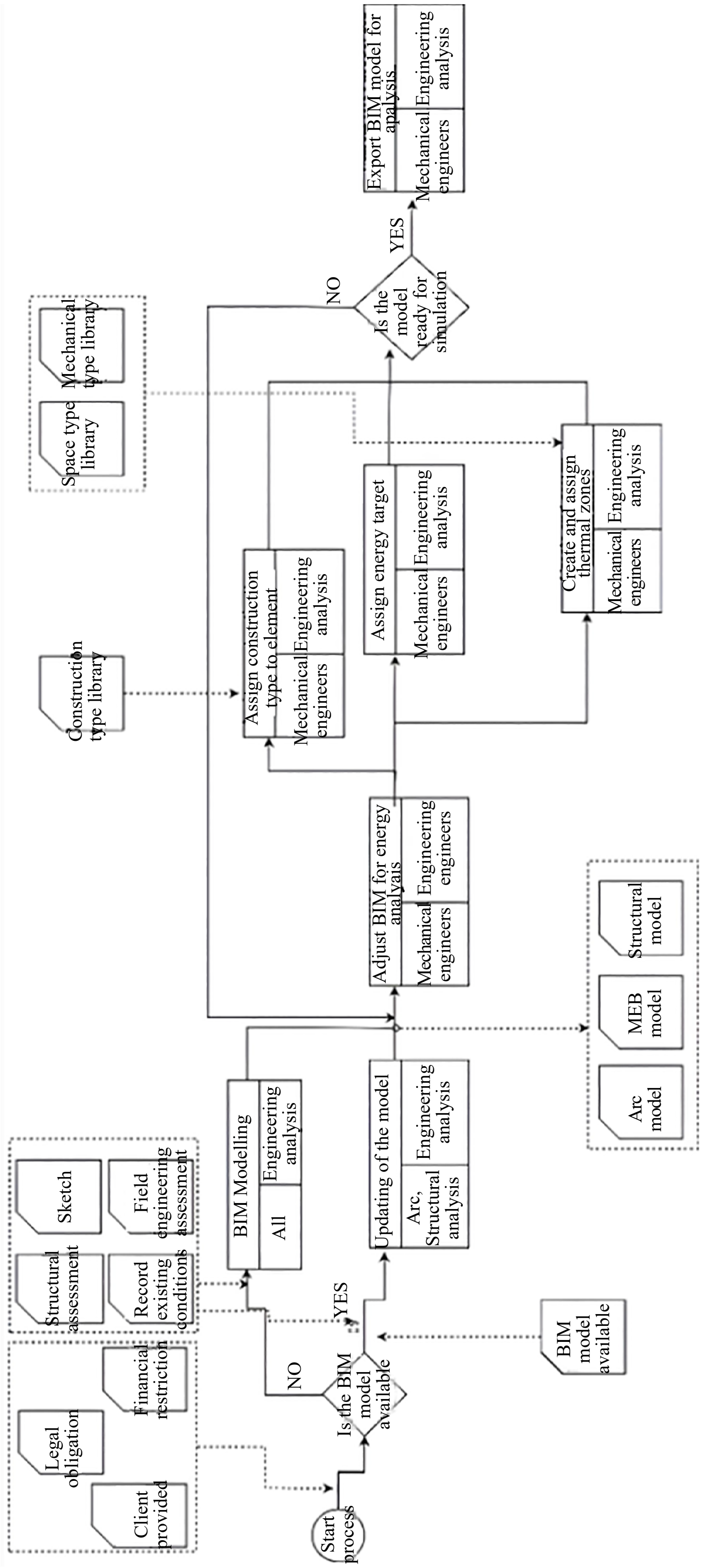

Figure 5. An example of a BIM retrofit process [40]

Sermarini et al. developed innovative solutions for retrofitting existing buildings by integrating Augmented reality (AR) and BIM. This study concluded that AR + BIM technology has the potential for retrofitting in the future [86]. All these studies show that the use of BIM tools in the retrofitting of structures has significant advantages in terms of design, visualisation, assessment of environmental impacts, economic evaluation of retrofitting and technically accurate results.

Although lifecycle Building Process Modelling (BPM) techniques have been used to deploy BIM in new construction projects, there is a dearth of BIM-based BPM designed explicitly for retrofitting existing buildings, according to a literature assessment carried out as part of this research [40]. One of the challenges has been maintaining the level of detail in a general enough way not to standardise it but to keep it suitable for different requirements, as suggested by Berard et al. [89]. In addition, the data structure of BIM-based projects is different from that of traditional construction systems, which complicates the process. Clarification of the file structure in project design with BIM-based programs would facilitate retrofit processes.

5. Data properties

Building elements created in BIM have various parametric data and properties. For example, a column element has properties such as material, size, type, cost, etc. Likewise, a wall element needs thickness, height and material data.

5.1 *Geometric data*

Geometric data in BIM studies includes detailed information about the geometric configuration and technical parameters of the building elements, materials, and building dimensions necessary for the definition of the structure [90]. In building retrofitting studies, first of all, the correct preparation of the geometric data of the BIM model prepared will directly affect the energy analyses to be performed. However, the BIM model does not only contain geometric information, but geometric information is also only part of the BIM model. The scope of geometric information in the BIM model varies according to the BIM detail level. The level of development (LoD) determines the accuracy of the 3D elements and the amount of geometric and non-graphical information included in each element [91].

As can be seen in Figure 6, BIM processes are used at every stage of modelling the building. According to the objectives of the BIM planner, any of the detailing levels mentioned in Figure 3 can be used. In this context, in building retrofitting studies, each element needs the highest level of detailing because the width-length-thickness of the element will affect the energy performance.

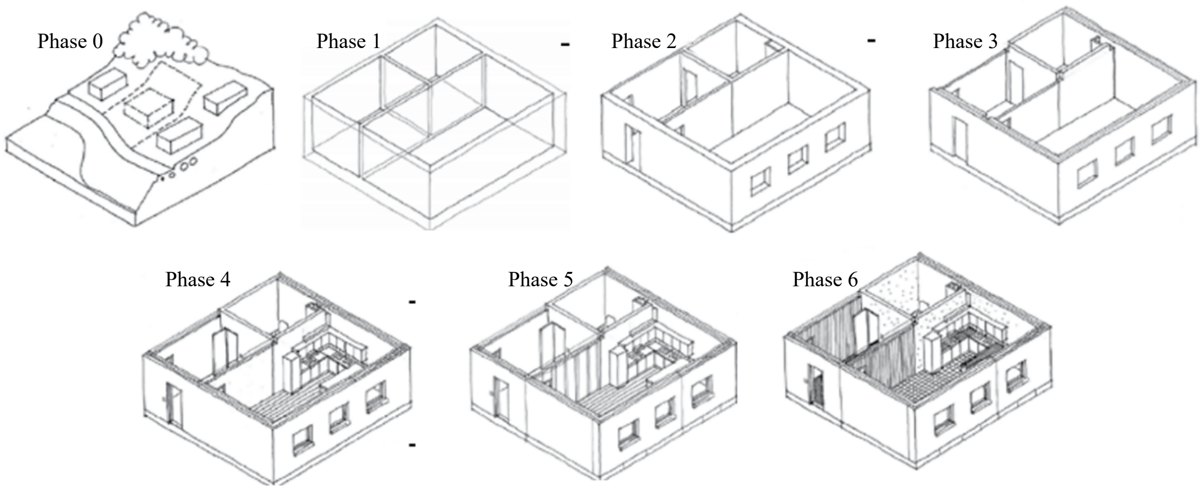

Figure 6. BIM project geometric information detail phases

5.2 *Semantic data*

The fact that various information about a building cannot be represented geometrically but coded in a way that computer software can understand is called semantic data [92]. As a result, parametric objects are created by combining semantic and geometric information. By storing the BIM model created from parametric objects in a single file [93-94], a process that can be accessed, evaluated and worked in cooperation with different stakeholders will be obtained. In the process of transferring this digital model to different programs, semantic information formats must be compatible with each other; the data must carry semantic meaning and be interconnected in terms of interoperability [95]. To explain the scope of semantic information with examples: wall-window, door-window connections and embedded elements coded in a way that can be read by computer programs, door frame sash connection information, embedded properties of tiles, the relationship of brick elements with other elements, etc. It refers to relationships. It is recommended to encode semantic information in Industry Foundation Classes (IFC) format to make it readable in different programs.

5.3 *Energy related data*

In order to investigate and manage the energy performance of buildings, it is necessary to integrate the architectural (semantic, geometric features) as well as the mechanical design and mechanical elements of the building into BIM-based programs [72]. Determining the current condition of the building, assessing the climatic conditions, and integrating the resources used in heating and cooling into BIM-based programs involves a complex process. Building Energy Modelling (BEM) delivers an optimised building design by allowing stakeholders involved in the process to evaluate the environmental impacts of various design options during the design or repair phase of the buildings [96]. This is a crucial stage to achieve the goals of global development plans. The energy data required for the BEM tool to perform an in-depth analysis include zone loads [46]; building envelope, natural lighting and solar energy [97]; infiltration, ventilation and multi-zone airflow; renewable energy systems; electrical systems and equipment [85]; HVAC systems; HVAC equipment [98]; environmental emissions [99]; economic assessment [100]; climate data (Figure 7).

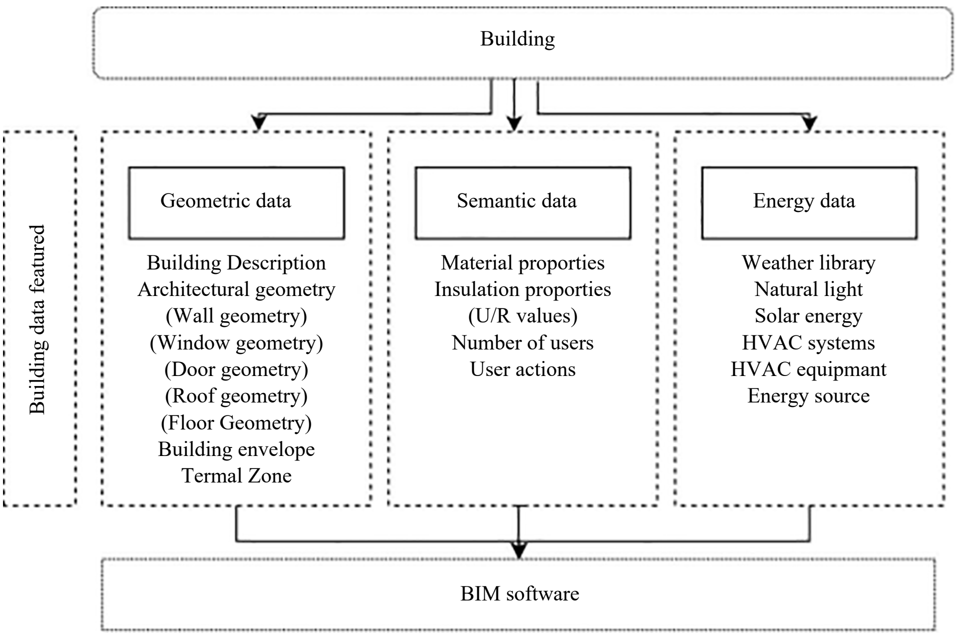

Figure 7. Building data features

Some previous research investigations have explored and contrasted the capabilities of commonly used BEM tools.

6. Integrated energy analysis with BIM-based tools

Integrated Energy Analysis (IEA) has become increasingly crucial within sustainable building design and energy efficiency. By leveraging BIM-based tools, professionals now possess the capability to conduct comprehensive evaluations of energy performance across all stages of a building's life cycle. This integration empowers architects, engineers, and stakeholders to make informed decisions early in the design phase, optimising energy usage and mitigating environmental impacts. The scholarly discourse surrounding IEA with BIM-based tools underscores its profound relevance within contemporary architectural and engineering domains. Numerous studies have explored various aspects of this approach, ranging from its effectiveness in predicting energy consumption to its role in enhancing building performance and fostering collaborative efforts among project teams.

Several BIM-based tools have garnered recognition for their pivotal role in facilitating IEA. According to the annual report by the National Building Specification (NBS), Autodesk Revit emerges as a leading platform that is widely embraced for its extensive features in building design and modelling. Its robust capabilities extend to energy simulation and performance analysis, making it indispensable for professionals evaluating energy efficiency within architectural projects. Similarly, Design Builder has earned acclaim for its advanced energy modelling functionalities, enabling users to analyse diverse design scenarios and implement energy-saving strategies with precision. Furthermore, Ecotech, Autodesk Insight, and OpenStudio have emerged as indispensable resources in the realm of IEA, each offering specialised features tailored to the nuanced requirements of energy simulation, daylight assessment, and environmental performance evaluation. These tools equip designers with the means to comprehensively assess various energy efficiency measures, simulate diverse climatic conditions, and optimise building systems to achieve sustainable outcomes.

Accurately estimating and quantifying energy benefits is crucial for creating a dependable decision-making framework to prioritise retrofit measures. Typically, these measures undergo a process of adjustment and simulation, followed by a comprehensive analysis and comparison of simulation outcomes. Numerous tools for analysing building performance are accessible, offering features like whole-building energy analysis, thermal performance assessment, water consumption evaluation, artificial lighting and daylight inspection, solar radiation analysis, HVAC system comparison, acoustic and airflow assessment, weather data collection, cost analysis, and more [101]. Put plainly, numerous energy analysis tools facilitate simple intervention and assessment of the energy efficiency of an entire building [102-103].

Prior to talking about the literature studies of energy analysis with BIM, back in 2020, a comprehensive forecast emerged from a survey orchestrated by NBS, delving into BIM trends over the following decade. The findings revealed a striking shift: a notable decline in the number of individuals unfamiliar with the program juxtaposed against a remarkable surge in recognition and utilisation [104]. These pivotal insights are vividly illustrated in Figure 8 below.

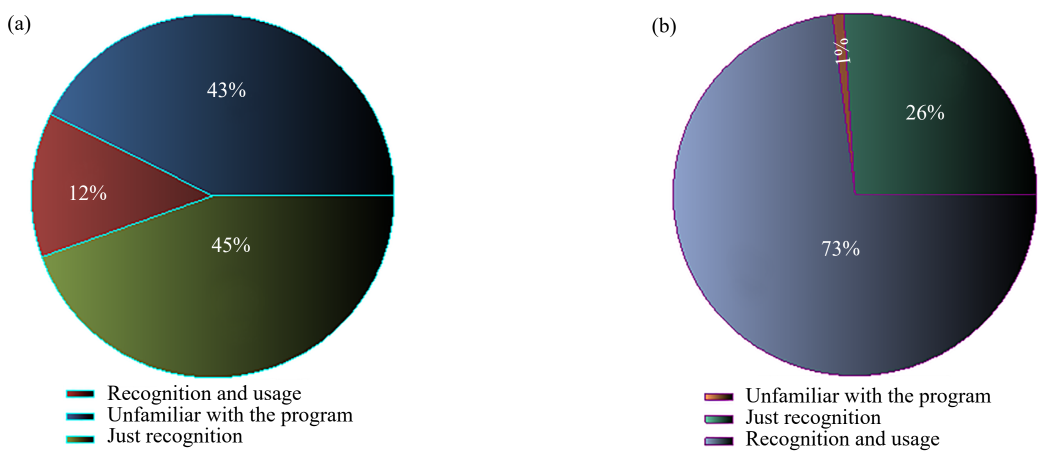

Figure 8. (a) BIM recognition and usage percentage value compared to 2011 (b) BIM awareness percentage value in 2020 [104]

As a result of, using BIM together with an energy analysis tool provides advantages in terms of going beyond a building design, providing detailed and accurate results of energy-efficient building designs, accelerating the process in the computer environment, and predicting possible problems [104]. Such positive features play an essential role in expanding awareness of the use of BIM. BIM continues to develop daily; for example, between 2012 and 2016, software that can be used with BIM was developed in the UK instead of CAD software. These are Autodesk Revit, ArchiCAD, Sketchup and so on [105]. In addition to this software, there are a few other software and a study on the areas in which this software can be used [106]. The information obtained from this study is included in Table 1.

Table 1. Usage area in accordance with the software [106]

Software	Energy	Carbon emissions	Natural ventilation	Solar and daylighting	Acoustic
e-QUEST	✓		✓	✓	
Energy plus	✓	✓		✓	
Odeon room acoustic software					✓
Design builder	✓	✓	✓	✓	
Autodesk green building studio	✓	✓	✓	✓	

Researchers use basic BIM processes related to energy and sustainability performance [106-107], use BIM tools for many analyses such as sunlight exposure, natural ventilation, daylight efficiency, acoustic performance, etc. [108], green roof energy potential evaluation [109] conduct many studies such as using Eco Designer in energy evaluation [110] and determining the way to minimise energy consumption [111]. Additionally, researchers have introduced the application of BIM-based energy analysis to the literature on various topics, as summarised in Table 2 below.

Table 2. Some literature summaries about the BIM-based energy analysis.

Ref	Country	Building	Programme	Usage goals	Findings
[112]	Greece	University	Revit Green Building Studio Ecotect CFD Flex	Building energy assessment Building energy analysis Research climatic conditions Passive heating-cooling techniques	It is revealed that the most appropriate energy-efficient building design would be possible by quickly changing the building envelope and window design.
[113]	Thailand	University	BIM/e-QUEST	Building redesign and energy consumption analysis	It has been shown that energy analysis can be obtained quickly and accurately after the building envelope is easily replaced.
[114]	China	Public	e-QUEST	Design and energy analysis of public buildings	It is explained that air conditioning and lighting systems, as well as the building envelope, are seriously responsible for energy consumption.
[115]	Saudi Arabia	Mosque	e-QUEST	Energy analysis simulation	Although they are complex structures, a good job has been done in energy analysis, thus preventing time and cost burdens by predicting them in advance.
[116]	Egypt	Education	Autodesk Revit Green Building	3D modelling Energy analysis	The cumulative outcome elucidates a remarkable 22% improvement in the suggested building parameters compared to the initial design, thereby facilitating the creation of autonomous, energy-efficient buildings.

Table 2. (cont.)

Ref	Country	Building	Programme	Usage goals	Findings
[117]	China	Prefabricated concrete	BIM + Chenxi	Carbon emission analysis	The use of BIM technology verifies the energy efficiency and carbon emission reduction of prefabricated concrete.
[118]	China	Prefabricated project	BIM	Carbon emission analysis	BIM is a proficient and potent approach for gauging carbon emissions during the construction phase of new buildings, while prefabrication diminishes carbon emissions.
[119]	Iran	Office	EnergyPlus + NSGA-II	Carbon emission analysis	It provides insights into optimising and measuring costs and carbon emissions for long-term calculations.
[120]	Midwest	University	Ecotect + BIM	CO_2 emission analysis	The curtain wall with brick walls and the maintained interior temperature comfort have been discovered to be efficacious in decreasing CO_2 emissions.
[121]	Turkey	Residential	Autodesk Revit + Green Building Studio	CO_2 emission analysis	Annual CO_2 emissions released from the system used for energy have been mitigated from 6.2 Mg to 3.3 Mg.
[122]	Hong Kong	Residential flat	BIM + CFD	Natural ventilation	The outcome shows that thermal comfort cannot always be achieved with natural ventilation and that cold air is carried into the system around April, which means that energy use in terms of mechanical ventilation can be reduced.
[123]	Hong Kong	Forty-floor residential	BIM + CFD	Natural ventilation	Wind-driven ventilation system shows that buildings can preserve up to 25% of electricity consumption compared to conventional ventilation.
[124]	China	University Faculty	BIM + Ecotect	Natural lighting	It is seen in the outputs that there is an increment in the coefficient of lighting as the window as well as floor are enlarged, and this increase starts to decrease after a while (≥ 3.6).
[125]	Brazil	Prefabricated metal construction	Autodesk Revit	Construction design	This multi-region study highlights that ventilation openings should vary depending on each area, and designs need to be tailored to the region's conditions.
			Autodesk Green Building Studio	Ventilation	
[126]	China	University	Autodesk Revit + Ecotect	Ventilation	The water supply and drainage system, along with the HVAC system, can collaborate with passive energy-saving technologies to create a comfortable indoor environment while conserving energy.
[117]	China	Prefabricated concrete	BIM + Chenxi	Carbon emission analysis	The use of BIM technology verifies the energy efficiency and carbon emission reduction of prefabricated concrete.
[118]	China	Prefabricated project	BIM	Carbon emission analysis	BIM is a proficient and potent approach for gauging carbon emissions during the construction phase of new buildings, while prefabrication diminishes carbon emissions.

Literature reviews highlight that Autodesk Revit stands out as a powerful 3D software tool that offers seamless integration with numerous programs for BIM. This versatility allows for comprehensive pre-project preparations, including adjustments to drawings and material selections, cost assessments and energy analyses, among others, with ease of export to other programs. Analysis programs that work with Revit are valuable tools that facilitate a wide range of analyses before the start of the project, allowing even the most negligible errors in design and analysis to be identified and corrected. It also provides significant flexibility in adapting designs.

7. File sharing process for energy analysis in BIM

The interoperability of stakeholders from various areas of expertise is essential in strengthening a structure [56]. BIM offers a systematic approach to facilitate the understanding of architectural projects with heterogeneous information structures by the stakeholders involved in the retrofitting process [127]. Although BIM-based programs have many advantages, most serve a single business function and have functional and organisational boundaries. Additionally, information flow between programs does not provide full performance, and data loss may occur [76].

7.1 *IFC*

When different data sources in an architecture project are stored in heterogeneous data formats, computers cannot easily integrate the data; (1) the schemas of the data sources are local and cannot be shared between computer applications on the Internet, (2) different data sources may use different terms to refer to the same entity or an entity word may have different meanings in two databases (3) database schemas are not easy to change dynamically because data schemas match the object models of the computer programs that use them. In other words, each domain develops its own schema to represent the domain properties of the same objects [127]. As a result, a user of a BIM platform is limited to the platform schema and is not able to define information that falls out of the platform schema. To solve this problem, a new industry foundation class, the IFC data standard for interoperability, was created by The Industry Alliance for Interoperability (IAI) in 1997 [55]. IFC is a standard, object-oriented data model developed in the EXPRESS language, independent of any software, and is supported by BIM-based programs. IFC provides users with comprehensive information and specifications about a building project. It also represents internationally standardised object definitions. The information about the building elements in the IFC file can be read by other experts in the building industry and can be easily transferred between different software [128]. When the digital model of a building is modelled in BIM-based programs and then converted to IFC format, all information about the building elements can be translated into IFC concepts. This would make it a convertible model accessible to other stakeholders in the retrofitting of the building [129]. IFC definitions are constantly being updated and improved by BuildingSMART, and in some cases, older formats are not supported.

Choi et al. [130] present a plan to generate alternatives and evaluate energy performance by analysing the shape of the shell of amorphous buildings through IFC. They developed an evaluation system based on IFC and compared and examined it through building energy analysis. In the study, the IFC2X3 version is used in the field of energy analysis. Politecnico et al. [123], on the other hand, found from tests on models made within the scope of energy analysis that the IFC2X3 and IFC4 versions were successful; the IFC4 versions worked slightly better and had fewer errors. This shows that the IFC is open to improvement and can still be improved.

BIM models created for building energy performance analysis through IFC information models are hardly used in the energy field because the information required for the transformation of format data such as gbXML (IES/Ecotect), IDF (EnergyPlus), IFC (Riuska), etc. have been eliminated or modified for energy analysis. IFC adopts a relational approach to represent a whole building project, resulting in a complex data representation scheme. It is therefore recommended that a Model View Definition (MVD) format be developed to filter data according to needs [131].

7.2 *IDM/MVD development processes*

In organising the exchange of information about a building, the use of IDM and MVD should be evaluated using the IFC format [84]. While IDM organises the process through which stakeholders' information about the building is exchanged, MVD is a term related to the content of the exchanged data. The process of developing building energy performance simulation (BEPS) models includes repetitive processes that often lead to data losses and errors. As a consequence, BEPS model inputs can vary widely from this time-consuming, non-standardized and subjective process [132]. To avoid these data losses, researchers and organisations began to develop their MVDs to support and streamline internal processes based on the IFC schema. MVDs are used for the aimed exchange of specialised models, considering the required graphic and contextual information needed by the developer [133]. This means that MVDs vary and are unique according to the needs of the user, the nature of the structure, and the intended process.

An MVD model developed for energy analysis should include the following frameworks for data exchange:

building construction (e.g. spatial, broad and comprehensive), definitions of space type and function (e.g. internal loads and air conditioning limits), construction of building elements (e.g. thermal properties and internal structures), space (e.g. thermal properties and internal structures), area (e.g., e.g. level 2 space boundary), HVAC partitioning, natural lighting and use of photovoltaic devices.

8. Barriers to the use of BIM in retrofit works

Strengthening existing structures is one of the most far-reaching solutions proposed in the 2030 global development plan. BIM processes, on the other hand, can be managed for many reasons, including comprehensive analysis capabilities, semantic information, geometric information and energy information. However, it is still possible to encounter many difficulties in the process of modelling the existing building stock with BIM tools and making it energy efficient. These barriers are listed as follows in the literature;

As the scope and level of detailing of the structures increases, the complex network of data transfer between programs becomes more complex and errors in geometric and semantic information increase [131].

There is a need to have data compatibility between BIM tools and energy performance analysis programs, and a method for exchanging data over the IFC format is needed for the development of object-oriented modelling element technology [130].

One of the challenges of using BIM-based programs for retrofitting existing buildings is that BIM systems are new, and the existing building stock needs to be designed in BIM, which results in additional time and effort [40].

There are a number of limitations in current energy analysis, including the lack of transparency in model algorithms, the complexity of the issue of energy consumption and carbon emissions, the limited evidence to show for occupant-housing interactions, and the lack of capacity to accommodate qualitative data input [134-135].

A few of the issues with using BIM for energy analysis of existing buildings are inadequate data integration, faulty data transformation, and communication problems between energy simulation environments and BIM [136].

The deformation of the existing building stock over time, material damages, and element contents constitute semantic information. However, the integration of this semantic information into BIM-based programs increases the complexity of the process since it is not based on certain standards.

In the process of retrofitting existing structures with BIM tools, various problems arise due to the lack of technical knowledge of the stakeholders [41].

Although the architectural, aesthetic, technical and material uniqueness of existing buildings makes geometric and semantic information management in BIM processes difficult, it is possible to implement retrofit processes with BIM. In fact, the integration and standardisation of BIM processes is a vital requirement for making buildings more robust and less energy-analysed.

9. Discussion

Since the energy efficiency of buildings around the world has yet to be at the desired level, there is a constant increase in energy consumption, and sustainable building practices are still far away. In addition to taking new energy-efficient measures for buildings in the future, the need to strengthen existing buildings with energy-efficient practices rather than demolishing them and reconstructing them accordingly is prioritised. However, when making these reinforcements, factors such as the location of the building, the materials used, and the climatic conditions of the environment should be taken into consideration. Therefore, using a predictive tool can minimise financial and time losses. Nowadays, BIM is gaining importance with increased usage awareness and users. Thanks to this modelling, the design, material selection and layout of a building can be easily done, and applications such as the desired insulation method can be easily integrated. Additionally, by incorporating energy analysis tools into this model, energy analysis can be performed in advance, and possible problems can be predicted, which can ensure that the project progresses more efficiently and smoothly. However, BIM also has some disadvantages, and these require detailed examination. For example, problems such as incompatibilities between data, inadequacy of the program in complex designs, lack of a standard structure and lack of technical knowledge may occur. However, despite such problems, BIM and energy analyses based on it may increase its popularity in the future and become an inevitable necessity, especially in large projects.

10. Conclusion

This extensive review explores the application of BIM tools in retrofitting existing structures to enhance energy efficiency. It emphasises the benefits of BIM in optimising building performance through detailed analysis and management of parametric data. Despite its potential, there are significant gaps in understanding and utilisation of BIM's capabilities within retrofit contexts, which pose barriers to widespread adoption in the construction industry. The review aims to address these challenges by highlighting specific advantages of BIM in retrofitting, comparing its information structures, and outlining essential integration requirements for energy-efficient practices. Moreover, it identifies critical gaps in current literature and emphasises the transformative potential of BIM in achieving global energy efficiency goals.

BIM tools enhance energy efficiency, reduce costs, and improve sustainability in retrofit projects.

Incomplete understanding and underutilisation of BIM's information systems hinder its adoption in retrofit contexts.

Specific requirements like interoperability and standardised data formats are critical for integrating BIM into energy-efficient practices.

Critical gaps in current literature underscore the need for further research in advanced information-sharing methodologies and comprehensive understanding of BIM's capabilities in retrofitting.

Beyond energy savings, BIM supports broader objectives such as reducing carbon emissions and enhancing indoor environmental quality, contributing to sustainable development.

The transformative potential of BIM in retrofitting underscores the need for ongoing development and adoption of sustainable building practices globally.

Future research should focus on refining BIM methodologies for retrofit applications and integrating renewable energy technologies.

Conflict of interest

The authors declare there is no conflict of interest at any point with reference to research findings.

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