

Building Information Modelling (BIM) and Energy Performance of Building - A Review

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Abstract: Nowadays, the advancement of technologies in the building industry may give a significant impact to the environment. The building sector contributes to the greenhouse gas emissions which may harm the environment and the high consumption of energy required high demand in burning the fossil fuel. These may effects the environment where, the carbon dioxide (CO₂) has been significantly released to the atmosphere and harm the environment which may lead to global warming. In order to reduce the impact of greenhouse gas emissions and energy consumption, there is a need to develop a solution which may account these environmental problems. Conserving the energy of the building is one of the strategies to reduce the impact of greenhouse gas emissions to the environment. Recently, linking the building information modelling (BIM) to analyse the energy performance of the building has been spread widely. BIM has been recognized as a suitable tool to perform a building analysis in the early design stage which helps to model the energy use, flow of thermal, patterns of lighting and many more sustainable measures. BIM is believed able to help a designer to choose the best building design due to its concept of parametric change that assist the AEC industry to implement the sustainable design in an effective way and significantly improve the energy efficiency of building.

Keywords: Building Information Modelling (BIM), Energy Consumption, Energy Efficiency, Sustainable Building

1. Introduction

At the First World Conference on Sustainable Construction in 1994, Charles Kibert offered the first concept of sustainable construction (Florida). He defined it as the “*responsible creation and management of a healthy building environment, considering the ecological principles and the efficient use of resources*” [1].

Currently, in response to the increased focusing on sustainable development, experts in the construction sector are emphasising sustainability. The goal of sustainable development is to improve the current quality of life without jeopardising the capacity of the future generation to meet their demands in all areas, particularly social, economic, and environmental [2]. Building sustainability is among the sustainable development initiatives that include building performance as well as the building industry's triple bottom line (social, financial, and environmental) [3]. The philosophy of green building design must be applied in the construction sector to lessen

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environmental effect [4]. In the construction industry, sustainable development defines green design as structures that are efficient in terms of energy and have a lower environmental impact, and this word often indicates the advantages of the material or approach that will improve sustainable development [5]. [6], Green building is defined as an approach to ensure sustainability that engages a building and its site to the climatic changes, site condition, and lifestyle, as well as the society, to decrease the consumption of resources while improving the quality of life that will indirectly contribute, the neighbourhood, and the builder's bottom line. It should be assured that the environment will persist for a long time, retaining its coherence, proper functioning, and self-sufficiency, while also assuring the wellbeing for its residents, as well as its resilience and adaptive ability [7, 8].

The need for sustainability and its evaluation of buildings is now increasing owing to widespread environmental issues and high energy costs [7]. On the basis of environmental protection and urban enhancement, as well as other diverse resources and activities, many corporations make choices based on the principles of sustainable development features in urban centres in order to achieve a developed city sustainability [8]. Nations throughout the world are working to promote sustainable design and avoid environmental deterioration by creating their own sustainable policies and standard [9]. Malaysia has implemented a sustainable strategy known as the Green Building Index (GBI), which was created by Pertubuhan Arkitek Malaysia and the Association of Consulting Engineers Malaysia and gives criteria for developers to design and build green structures [10]. GBI evaluates sustainability through six critical aspects: efficient energy, indoor air quality, sustainable site design and management, material and resource efficiency, water efficiency, and invention. These characteristics are severely impacted by the architectural design of the building, the architecture of the site, the layout of the infrastructure projects, and the design of the structural systems themselves [11].

The construction sector highlights sustainability, which necessitates the incorporation of an incorporated workflow at the early phases of design and has become a prominent movement in pushing process improvements within the sector [12]. Buildings are built to last for several years as an environmental physical characteristic as well as to satisfy human requirements, and contemporary technology allows for the creation of a contemporary and appealing green building while saving money. The demand for environmentally friendly and energy-efficient construction is increasing [13]. Building contributes significantly to energy consumption in each industrialized nation and is one of the sources of carbon dioxide emissions that have consequences on the environment [14]. According to [15], the construction sector accounts estimates around 19% of worldwide yearly greenhouse gas emissions and up to 32% of total global energy consumption, and this figure is expected to more than double over the next 50 years. s [15].

Because of increased demand for energy and the associated GHGs and the imminent effect on climate change, there is a significant and continuing necessity to improve energy efficiency and decarbonise construction sectors [16] where the designers must take into account the performance of energy in the design by developing alternative plans that conserve the energy in the early conception phase [17]. Building information modelling (BIM) integration enables designers to assess performance of buildings at the conceptual design phase, and they will utilise the information provided by the BIM to assess design options and make the best choices to develop a greener design [12]. BIM is an integrated process which is employed to ease the design exchange and construction information to project participants and extending the model developed by BIM will provides energy performance data including power consumption, temperature, CO₂ emissions, occupancy and humidity [18]. BIM contains a lot of data needed for analysing the performance of energy and the

appropriate use of BIM significantly save the time and effort as well as reduce the mismatches and errors [13]. In addition, extending BIM into analysis helps to recognise the solution for lessening the consumption of resources, increasing the opportunities of on-site renewable and meet the requirements for sustainable design and energy efficiency. The optimization of building performance for sustainability has become an integral part of mainstream practise in the architectural and design industry, thanks to BIM-based simulation. Unlike traditional practise, which demands a separate model for building performance generated by different experts, BIM technology allows for the direct input of building geometry to the analysis programme [19].

2. Use of Energy in Building

Our civilization is now facing one of the most critical problems in terms of lowering greenhouse gas emissions and maximising energy efficiency [20]. The building industry is more responsible for greenhouse gas emissions (GHGs) and energy consumption than the industrial and transportation sectors [21]. As a consequence, increased energy usage tends to degrade the ecosystem where energy is generated by the combustion of fossil fuels [22]. According to the United Nations Environment Programme [22], the construction industry accounts for around 30% of worldwide yearly greenhouse gas emissions and up to 40% of total energy consumption. Carbon dioxide (CO₂), methane (CH₄), nitrogen oxide (N₂O), and fluorocarbons are examples of greenhouse gases [23]. Moreover, CO₂ emissions into the atmosphere have the ability to boost global temperatures [24], and studies discovered that buildings account for around 40% of CO₂ emissions [24, 25]. Global warming is melting the polar ice caps, which will ultimately rise sea levels, leaving insufficient land for an expanding population [26]. With growing fears about global warming and carbon, the construction industry is always working to reduce emissions [27] by lowering building energy usage [22]. In order to meet the CO₂ emission goal, customers and industries must play a significant role in the construction of low-carbon buildings [28]. If no effort is taken to solve this problem, the construction industry's GHG emissions will increase over the next two decades [27]. Hence, it is a challenge for architects and stakeholders to meet the goal of reducing greenhouse gas emissions for a healthier environment.

Building specialists have addressed the importance of sustainability and energy performance in designing design in response to environmental consciousness concerns and the growing cost of energy, since structure a sustainable building involves specialised labour and a costly procedure [13]. As a consequence of the environmental effect of buildings, designers must offset this influence by enhancing or optimising energy efficiency early in the design process [13, 17]. The advantages of saving energy include lower energy costs and long term economic development, which drives innovation in the process [29].

Low net energy in buildings is essential, which may be achieved via inventive design. Several methodologies and technologies have been created recently to minimise building energy use. Building Information Modelling is one of the most recognized and rapidly increasing technologies in recent years [19]. Recently, linking the building information modelling (BIM) to analyse the energy performance of the building has been spread widely. BIM has been recognised as a suitable tool to perform a building analysis in the early design stage [30] which helps to model the energy use, flow of thermal, patterns of lighting and many more sustainable measures [28]. To analyse the energy performance of building, BIM analysis tools help to analyse heating and cooling requirements, identify the opportunities of day lighting as well as choose the main building component that have the potential to decrease the use of energy consumed by the building and by

integrating data of weather and electrical grid, the energy consumption and carbon emission released by the building can be well estimated [31].

Material, weight, resistance of thermal and the physical properties of the building are digital models representing the elements and the characteristic of the building which contribute to the performance of the building [31]. The use of BIM application tools such as Revit Architecture as core of the rapid energy modelling workflow allows to develop a basic model in faster and easier way in order to help simulating the performance as well as the cost. Normally, to practice sustainable design for modelling the building, the computer aided design (CAD) which is a traditional tools is used and to analyse the performance of building by entering the design data into an energy simulation tool [28]. However, by directly importing the BIM into energy performance analysis at a design stage, the design scheme can easily be obtained and adjusted [32]. EnergyPlus, Ecotect and IES Virtual Environment are some of the energy simulation tools that take into account the design features of building such as climate response, glazing, thermal insulation, solar gain, natural and mechanical ventilation, HVAC system and many more. The integration between BIM and these simulation tools help to develop a powerful decision making tools in designing a high energy performance of buildings [33]. The designers can alter the BIM accordingly and retest the model for many times until the best results are achieved.

3. Literature Review

The problem of green building is a major topic of discussion among the Architect, Engineer, and Construction (AEC) business since the construction industry is the greatest contributor of greenhouse emissions, using one-third of world energy [34]. In the United States (US), the amount of greenhouse gases emissions, CO₂ released by the building sector is 38% and consumed for almost The quantity of greenhouse emissions, CO₂ emitted by the construction industry in the United States (US), is 38 percent and consumes about 50 % of the overall energy consumption [35]. Construction industries in Hong Kong utilise over 92 percent power and emit 60 percent of greenhouse gas emissions, which is higher than global norms [36]. In China, the Ministry of Public works supposed that the amount of energy released by a construction is 40% of energy consumed, with high demand for energy increasing to 72 billion square metres in 2020, and when compared to other developed countries, China accounts for greater overall energy consumption in a building [32]. Due to the strong demand for energy, the construction industry in Australia, which includes residential and commercial structures, contributes around 23 percent of total carbon emissions, with commercial offices covering 21 million square metres distributed over 3980 buildings. Malaysia's construction industry contributes for over 40% of worldwide greenhouse gas emissions as a consequence of using fossil fuels for either energy generation or building activities [37].

Because of high emissions and energy consumption, several countries throughout the world have established their own targets to reduce emissions and fuel consumption. The United Kingdom aims to establish a zero-energy home by 2016, Germany will construct a passive house after 2015, France will reduce energy requirements by 30% by 2020, Denmark will reduce the power consumption by 50% from 2015 to 2016, and the United States will establish a building with zero emission by 2030 [33]. Malaysia has also promised to participate in decreasing emissions of greenhouse gases by 2020 [37]. Considerable efforts have been made to reduce the use of energy sources over the next 20 years to accomplish the objective of net-zero energy usage in 2030 by implementing industry best practices, strict building standards, and implementing green building certification systems such as Leadership in Energy and Environmental Design (LEED) [38].

Most academics have concentrated on promoting energy performance of the building in order to minimise greenhouse gas emissions from power plants. Several variables influence the energy in a structure, including the built environment, construction materials, user behaviour, building orientation, building scale, and building form [39]. Shoubi et al. [30] performed a research on lowering functional energy consumption in buildings at the planning phase of construction utilising building information modelling techniques and sustainability methods. A standard bungalow of 400 m² was analysed to evaluate the substance mixture utilising BIM to lower the operating energy usage of a home. A variety of bungalows elements, including the sidewalls, window door, roof, and inside heat, have been adjusted. The BIM tools Revit Architecture was utilised to model the structure, and the study was carried out utilising Autodesk Ecotect Analysis software. The scientists discovered that components like double brickwork, reverse brick veneers, wood, gypsum insulating, and glasses were more energy efficient than other components. Furthermore, by adopting these components, they discovered that the yearly energy consumption of the building was lowered with this alternate design. The products employed are also ecologically beneficial, as they concluded that the usage of alternative materials including bamboo shades and single wind deflectors decreased the windows area to 15% of the overall space This study could be deemed a success in terms of process energy sustainability [30].

Osello et al. [40] analyses the energy efficiency of a single-story structure with one entrance, many windows on every wall, a base, and a ceiling during. Various window orientations and window sizes have been tested. The research is carried out at the planning phase of construction, and decision-making is also properly considered while executing the building's overall modelling. The scientists created a model by evaluating kinds of software, Power Plus and IES Digital Environment, in order to identify the most appropriate and successful software as BIM-based simulations tools for evaluating the power performance of building performance models. The findings reveal that when the Energy Plus programme is used, the orientation of the windows at 0 degrees and 180o depicts the least energy use, including cooling and heating. The bigger screens are seen to boost overall energy usage. Therefore, despite bigger screens may significantly enhance lighting conditions, the HVAC system uses more energy to heat and cool the structure. As a result, wider windows are not regarded to guarantee a superior design. The simulation using IES Virtual Environment, on the other side, yields no meaningful differences between these two models, leading the scientists to conclude that all these two programs can be utilised to predict energy performance since they are frequently utilised as energy simulation alternatives. Energy Plus is versatile in terms of HVAC system definition and can simulate numerous HVAC systems for a single zone, but an IES Virtual Environment is simple to set design parameters, user-friendly in terms of user interface and reporting, and suitable of doing a Life Cycle Cost Assessment.

Abanda and Byers [39] did a research at Oxford Brooke University to evaluate the influence of building orientation on energy usage, and Green Building Studio software was utilised to model a three-story home in Hertfordshire, UK. A set of simulations with varying orientations were created. Following a survey at the selected site, the authors simulated the design in Revit and saved it to a gbXML file that Green Building Studio could understand. The authors found that the energy required for a structure is determined by elements such as the external walls, construction materials, building orientation, occupant conduct, and the scale and design of the building. A well-oriented structure might save power all through life span, and the findings reveal that the orientation of the building relation to the sun's path affects the solar gain to warm the built environment. The poorest orientation is 45o, which installs windows pointing down and generates 10822 kWh of yearly electricity while using 86489 Mj of fuel energy. The optimal orientation is 180 degrees, which install three sets of

bay windows facing south, with overall yearly fuel and electricity energy consumption of 10475 kWh and 86883 Mj, accordingly.

4. Executive Problems of Energy

The construction industry is the largest contributor to greenhouse gas emissions and consumes a lot of energy. In Malaysia, the building industry accounted for around 80-90 percent of greenhouse gas emissions throughout the operating period, which requires energy for cooling and heating, lighting, ventilating, and powering devices [29]. According to [37], residential buildings account for around 65 percent of total world emissions, whereas commercial buildings account for approximately 35 percent. Therefore, it is critical to create sustainable building designs in order to decrease greenhouse gas emissions and excessive energy usage. Green construction is a philosophy that highlights the necessity of designing with natural and sustainable resources and supports the usage of renewable resources to produce buildings that are environmentally friendly [41]. Furthermore, it has been observed that the optimal selection of sustainable products to suit project needs is a barrier in analysing sustainable construction [42]. Therefore, efficient techniques to model the structure depending on the material choice are required to determine the suitable design options.

The building life cycle covers the entire life from its design, conception, occupancy, and demolition; thus, it needs an effective design of energy performance for long-term duration to be served in the buildings [43]. Mostly, the construction companies use complex energy simulation and energy packages which lead in difficulty of handling, increase the cost and the characteristic of energy efficient strategies building could not be assessed [44]. Efficiently use of energy can significantly reduce the electrical bills for both households and businesses as well as enhance the economy for future development, leading to innovation in the process and to achieve the goal of less energy can create the opportunity [45]. However, the governments have paid less concern that the reduction of energy demand play an important role in managing the energy system as the good management of energy will result in more cost-effective and also achieve the climate goals [45]. Due to the environmental issues and the increase of energy cost, the building experts emphasize the sustainability and performance of energy in their designs [46]. However, in spite of the approval of the green building rules, commercial buildings often do not achieve the designed energy conservation objectives and consume as much as 3 times the expected energy consumption, representing a considerable gap in building energy performance [34].

To design a sustainable building is a difficult task, requires an extensive labour and also expensive in process, thus this complexity will create mistakes in design and also mismatches exist between the prediction and actual performance of the building [13]. Even though the energy simulation tools that help in designing the energy efficient of the building is available for decades, the building analysis usually is performed later in design stage and the changes of building features cannot be amended, in the meantime, by performing traditional CAD to analysis the energy efficient will produce difficulties in process [18]. On the other hand, very few design alternatives has been created and explored by the designers before selecting the final design which turn to underperforming designs due to the lack of effective parametrical tools to explore the design alternatives and realize their effects on energy performance of building based on automatic process that assists the designers to have an options to explore and choose the best design alternative [13]. Realizing the difficulties of the current designs, a decision support tools is essential to help in assessing the sustainability of the building, where the tools would be useful during the conceptual design stage and the solution for finding the sustainability design can be made at the design stage [47]. These tools can combine the

interactive design method based on BIM with dynamic architecture to suggest a systematic design decision process that allows buildings to respond to seasonal climate changes as well as the integration of new technologies [48]. BIM is used not only as a model, but also as a platform that incorporates all the building's characteristics, as well as the disciplines and systems that are involved [49]. During all phases of the project, it provides a suitable platform for collaboration between multidisciplinary and interdisciplinary efforts. Furthermore, because BIM saves necessary information about energy performance analysis, it can save a lot of time and effort while also reducing inconsistencies and mistakes [50]. As a result, this method becomes a motivating way for architects and engineers to achieve various design goals.

5. Conclusion

Currently, the advancement of technologies in the building industry may give a significant impact to the environment. The building sector contributes to the greenhouse gas emissions which may harm the environment and the high consumption of energy required high demand in burning the fossil fuel. These may affect the environment where, the carbon dioxide (CO₂) has been significantly released to the atmosphere and harm the environment which may lead to global warming. In order to reduce the impact of greenhouse gas emissions and energy consumption, there is a need to develop a solution which may account these environmental problems. Conserving the energy of the building is one of the strategies to reduce the impact of greenhouse gas emissions to the environment. The use of natural material resources can reduce the energy need in the building. It is first believed that the use of natural resources will conserve more energy compared to the other type of materials. The building envelope, building thermal, ventilation, HVAC system required high energy if not design appropriately. The unsuitable materials used to build a building may give uncomfortable conditions to the occupants. The concern about the environment has driven many countries around the globe to emphasize the sustainability in the design starting from the design stage, construction stage, in-use stage, and post-construction stage. By conserving the energy in the early design stage will helps in reducing a significant amount of energy required for a building.

The designers may develop a few design alternatives and then select the best alternative for their design. In order to choose the best design alternative, there is a tool needed to assist a designer during the design stage. Building information modelling is believed to help a designer to choose the best building design. BIM is the concept of parametric change that assist the AEC industry to implement the sustainable design in an effective way and significantly improve the energy efficiency of building. It is clear that, the design and specifically the material selection processes are greatly influence the energy consumption and carbon emissions of the building. Therefore, a designers should make a proper evaluation on each type of the materials used for conserving the natural environment and also beneficial to the building occupants with the assistance of parametrical performance-based tools.

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References

- [1] Carvalho J P, Bragança L and Mateus R 2019 Optimising building sustainability assessment using BIM *Automation in Construction* **102** 170-82

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- [2] Scarlat N and Dallemand J-F 2019 *The Role of Bioenergy in the Bioeconomy*, ed C Lago, et al.: Academic Press) pp 435-547
- [3] Luo Y and Wu W 2015 Sustainable design with BIM facilitation in project-based learning *Procedia engineering* **118** 819-26
- [4] Jalaei F 2015 Integrate building information modeling (BIM) and sustainable design at the conceptual stage of building projects. Université d'Ottawa/University of Ottawa)
- [5] Moore S A 2015 Adapting building information modeling (BIM) for affordable & sustainable housing. Master's Thesis. University of Texas, Austin)
- [6] Karolides A 2010 Introduction to Green Building Materials & Systems *Green Building: Project Planning & Cost Estimating* 27-68
- [7] Chel A and Kaushik G 2018 Renewable energy technologies for sustainable development of energy efficient building *Alexandria Engineering Journal* **57** 655-69
- [8] Jalaei F, Jalaei F and Mohammadi S 2020 An integrated BIM-LEED application to automate sustainable design assessment framework at the conceptual stage of building projects *Sustainable Cities and Society* **53** 101979
- [9] Wong K d and Fan Q 2013 Building information modelling (BIM) for sustainable building design *Facilities*
- [10] SALEHUDDIN M Y 2010 GREEN BUILDING INDEX MALAYSIA: DRIVERS AND BARRIERS OF IMPLEMENTING IT IN THE MALAYSIAN CONSTRUCTION INDUSTRY. Universiti Teknologi PETRONAS)
- [11] Yusoff W Z W and Wen W R 2014 Analysis of the international sustainable building rating systems (SBRSS) for sustainable development with special focused on green building index (GBI) malaysia *Journal of Environmental Conservation Research* **11** 11-26
- [12] Middlebrooks R E 2005 Realizing the future of sustainable design through BIM and analysis *Autodesk document*
- [13] Rahmani Asl M, Zarrinmehr S and Yan W 2013 Towards BIM-based parametric building energy performance optimization
- [14] Junnila S, Horvath A and Guggemos A A 2006 Life-cycle assessment of office buildings in Europe and the United States *Journal of infrastructure systems* **12** 10-7
- [15] Van Dronkelaar C, Dowson M, Burman E, Spataru C and Mumovic D 2016 A review of the energy performance gap and its underlying causes in non-domestic buildings *Frontiers in Mechanical Engineering* **1** 17
- [16] Herrando M, Cambra D, Navarro M, de la Cruz L, Millán G and Zabalza I 2016 Energy Performance Certification of Faculty Buildings in Spain: The gap between estimated and real energy consumption *Energy Conversion and Management* **125** 141-53
- [17] Azhar S, Brown J and Sattineni A 2010 A case study of building performance analyses using building information modeling. In: *Proceedings of the 27th international symposium on automation and robotics in construction (ISARC-27), Bratislava, Slovakia*, pp 25-7
- [18] Moakher P E and Pimplikar S 2012 Building information modeling (BIM) and sustainability—using design technology in energy efficient modeling *IOSR Journal of Mechanical and Civil Engineering* **1** 10-21
- [19] Tantawy D A 2015 Using building information modeling for green interior simulation and analysis *Int J Contemp Appl Sci* **2** 262-79p
- [20] Alkhatib F, Kasim N, Goh W I, Shafiq N, Amran M, Kotov E V and Albaom M A 2022 Computational Aerodynamic Optimization of Wind-Sensitive Irregular Tall Buildings *Buildings* **12** 939
- [21] Acquaye A A and Duffy A P 2010 Input–output analysis of Irish construction sector greenhouse gas emissions *Building and Environment* **45** 784-91
- [22] Ham Y 2015 Vision-based building energy diagnostics and retrofit analysis using 3D thermography and building information modeling. University of Illinois at Urbana-Champaign)
- [23] Sagheb A, Vafaeihosseini E and Ramancharla P K 2011 The role of building construction materials on global warming: lessons for architects. In: *National Conference on Recent Trends in Civil Mechanical Engineering*. Available at: [www. researchgate. net% 2Fprofile% 2FPradeep_Ramancharla%](http://www.researchgate.net/profile/Pradeep_Ramancharla)

- 2Fpublication% 2F26 9031946_The_Role_of_Building_Construction_Materials_on_Global_Warming_Lessons_for_Architect,
- [24] De Lasso J, França J, Espirito Santo K and Haddad A 2016 Case study: LCA methodology applied to materials management in a Brazilian residential construction site *Journal of Engineering* **2016**
- [25] Jin R, Zhong B, Ma L, Hashemi A and Ding L 2019 Integrating BIM with building performance analysis in project life-cycle *Automation in Construction* **106** 102861
- [26] Hamzah M, Jamshidi A, Shahadan Z, Hasan M M and Yahaya A 2010 Evaluation of engineering properties and economic advantages of WMA using local materials *Journal of Applied Sciences(Faisalabad)* **10** 2433-9
- [27] Initiative C 2009 Buildings and climate change
- [28] Motawa I and Carter K 2013 Sustainable BIM-based evaluation of buildings *Procedia-Social and Behavioral Sciences* **74** 419-28
- [29] Zaid S and Graham P 2012 The need for energy efficiency legislation in Malaysian building sector. A comparative study of South East Asian policies
- [30] Shoubi M V, Shoubi M V, Bagchi A and Barough A S 2015 Reducing the operational energy demand in buildings using building information modeling tools and sustainability approaches *Ain Shams Engineering Journal* **6** 41-55
- [31] Carvalho J P, Bragança L and Mateus R 2021 Sustainable building design: Analysing the feasibility of BIM platforms to support practical building sustainability assessment *Computers in Industry* **127** 103400
- [32] Zhu H 2014 Practice on Green Design of Building Energy Efficiency Based on BIM *Comput Model New Tech* **18** 678-81
- [33] Ryu H-S and Park K-S 2016 A study on the LEED energy simulation process using BIM *Sustainability* **8** 138
- [34] Zou P X W and Alam M 2020 Closing the building energy performance gap through component level analysis and stakeholder collaborations *Energy and Buildings* **224** 110276
- [35] Parshall L, Gurney K, Hammer S A, Mendoza D, Zhou Y and Geethakumar S 2010 Modeling energy consumption and CO2 emissions at the urban scale: Methodological challenges and insights from the United States *Energy policy* **38** 4765-82
- [36] Pan W, Qin H and Zhao Y 2017 Challenges for energy and carbon modeling of high-rise buildings: The case of public housing in Hong Kong *Resources, Conservation and Recycling* **123** 208-18
- [37] Zaid S M, Myeda N E, Mahyuddin N and Sulaiman R 2015 Malaysia's rising GHG emissions and carbon 'lock-in' risk: A review of Malaysian building sector legislation and policy *Journal of Surveying, Construction and Property* **6** 1-13
- [38] Vierra S 2016 Green building standards and certification systems *National Institute of Building Sciences, Washington, DC*
- [39] Abanda F and Byers L 2016 An investigation of the impact of building orientation on energy consumption in a domestic building using emerging BIM (Building Information Modelling) *Energy* **97** 517-27
- [40] Osello A, Cangialosi G, Dalmaso D, Di Paolo A, Turco M L, Piumatti P and Vozzola M 2011 Architecture data and energy efficiency simulations: BIM and interoperability standards. In: *proceedings of Building Simulation*,
- [41] Sheth A Z and Malsane S M 2014 Building information modelling, a tool for green built environment
- [42] Jalaei F, Jrade A and Nassiri M 2015 Integrating decision support system (DSS) and building information modeling (BIM) to optimize the selection of sustainable building components *Journal of Information Technology in Construction (ITcon)* **20** 399-420
- [43] Altaf M, Alaloul W S, Khan S, Liew M, Musarat M A and Mohsen A A 2021 Value Analysis in Construction Projects with BIM implementation: A Systematic Review. In: *2021 International Conference on Decision Aid Sciences and Application (DASA)*: IEEE) pp 51-6
- [44] Garwood T L, Hughes B R, Oates M R, O'Connor D and Hughes R 2018 A review of energy simulation tools for the manufacturing sector *Renewable and Sustainable Energy Reviews* **81** 895-911
- [45] DECC 2012 The energy efficiency strategy: The energy efficiency opportunity in the UK. Department of Energy and Climate Change London, UK)

- [46] Alkhatib F, Kasim N, Goh W I and Al-Masudi A 2021 Multidisciplinary Computational Optimization: an Integrated Approach to Achieve Sustainability in Tall Building Design at Early Stage-Review. In: *2021 Third International Sustainability and Resilience Conference: Climate Change: IEEE*) pp 562-6
- [47] Oti A H and Tizani W 2015 BIM extension for the sustainability appraisal of conceptual steel design *Advanced Engineering Informatics* **29** 28-46
- [48] Utkucu D and Sözer H 2020 Interoperability and data exchange within BIM platform to evaluate building energy performance and indoor comfort *Automation in Construction* **116** 103225
- [49] Alkhatib F, Kasim N, Goh W and Al-masoodi A 2022 Performance-Driven Evaluation and Parametrical Design Approach for Sustainable Complex-Tall Building Design at Conceptual Stage. In: *IOP Conference Series: Earth and Environmental Science: IOP Publishing*) p 012047
- [50] Baarimah A O, Alaloul W S, Liew M, Kartika W, Al-Sharafi M A, Musarat M A, Alawag A M and Qureshi A H 2021 A bibliometric analysis and review of building information modelling for post-disaster reconstruction *Sustainability* **14** 393