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A Guiding Approach to Make Sustainable Design Decisions by Building Information Modeling (BIM)

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Abstract

Building information modelling provides clear and specific requirements to promote sustainable construction in an integrated manner. Accordingly, this paper reviews the current state of the literature on sustainable construction and BIM. A review approach was adopted to analyze two main sources of literature, namely, the main criteria of sustainability and the elements that can be applied in BIM, and to implement practical support from case study experiences. Use BIM for Sustainable Design Analysis to determine the impact of the application on sustainable construction. Using BIM to Make Sustainable Design Decisions Through BIM simulation and analysis It was observed that a method of sustainable design analysis and the determinants of engineering and management data were used to analyze sustainable alternatives during the early stages of the project. The research has led to steps for a sustainable building guiding approach through BIM, where design decisions can be adopted to achieve sustainable benefits.

Key words: BIM, Sustainability, sustainable construction, design Software, sustainable design.

1. Introduction

The building industry is becoming digital and based on software and modern technologies. Measurement and analysis tools are becoming increasingly high-tech. Software, especially BIM, has contributed to enabling sustainable design by allowing architects and engineers to use more advanced technology tools in integrating and analysing some things in their designs, such as heat gain, solar energy, ventilation, and energy efficiency[1]. Thus, the BIM programme is considered a new tool that allows architects and engineers, in real-time, to digitally design different elements of a building, such as form, structure, heating and cooling, cost, materials, etc., and understand how specific changes in design or construction models will affect other variables such as the environment, energy efficiency, and financial minimum.

2. Research Methods

The research methods were reviewed for theoretical interpretation, to develop a correct understanding of the relevant theoretical and practical issues, and to implement practical support from case studies using BIM for sustainable design analysis.

3. Sustainable Architecture

The Sustainable Architecture has emerged as a result of the negative impact of buildings on the environment. It is not just about using energy, but also about using materials and wasting water. The international systems for green and sustainable buildings such as LEED, BREAM have the same objectives as follows:

- Effectively using all resources such as energy and water.
- Conserving nature through rationalization of energy consumption.
- Reducing waste through reuse and recycling.
- Balancing between performance efficiency, environment, and total cost.
- Providing a healthy environment for future generations.

3.1 Sustainable building design

In the sustainable building design range, environmental factors, such as global warming, pollution, and rapid consumption of energy resources, were taken into account; as the buildings consume resources, they consume 40% of energy consumption and 12% of water consumption. It also harms the environment, as it produces 40% of waste and 38% of greenhouse emissions [2], so we need sustainable design for:

- Reducing power requirements.
- Reducing water consumption.
- Reducing carbon emissions
- Reducing perishable materials
- Preserving the natural environment
- Maintaining human health and well-being
- Using materials with low environmental impact

Sustainable buildings can be complex and require coordination across different project phases, from design to operation. Using BIM facilitates the design and implementation process; BIM is the basis for performance analysis and simulation by monitoring performance and verifying the efficiency of use, integrated design, and performance-based standards for sustainable construction [3]. The results of several studies show that software is an essential tool for sustainable design. Companies are also looking for the best way to integrate BIM technology with sustainable design and analysis tools [4].

3.2. Sustainable Design Analysis

The sustainable design analysis can be defined as a "quick and measurable reaction to the various sustainable alternatives proposed by the design team and customers during the early stages of the The sustainable design analysis can be defined as a "quick and measurable reaction to the various sustainable alternatives proposed by the design team and customers during the early stages of the project" [5]. Its main purpose is to understand the challenges of sustainability, convenience, safety, and project cost through options based on information taken from data entered, such as building materials and construction specifications, energy consumption and generation, carbon dioxide emissions, water use and collection, and waste and pollution management. The building model simulation capabilities help to analyse sustainable design to achieve sustainability goals for energy-efficient buildings through design, analysis, and evaluation through BIM models. The virtual building model provides access to building-related information in order to manage facilities and build systems and components through the development of BIM models in Revit and Autodesk BDS [6].

4. Using BIM to Make Sustainable Design Decisions

According to statistics from McGraw-Hill Construction's SmartMarket report, 78% of BIM users do not currently use BIM for sustainability, but it is expected to do so within three years, although 17% of them claim that it will happen in the next 12 months. Thus, in the near future, it is likely to see an increase in BIM companies adopting sustainable building [4]. BIM supports sustainable design decisions, which affect the efficiency and performance of building design. The sustainable analysis tools, such as Autodesk Ecotect Analysis, provide a lot of data that has the ability to be replicated to get optimal sustainable designs based on the size, type, and location of the building, determine appropriate materials, systems, and virtual equipment using accurate hourly weather data services as well as rainfall data, and also use regional building codes and standards to make smart assumptions. Architects can change these settings to determine specific aspects of their design, such as:

- Determining optimal location, shape, and direction.
- Determining openings in size, shape, and type of glass.

- Determining a suitable HVAC system.
- Assessing the impacts of buildings on the environment.
- Ensuring the use of the most sustainable materials.
- Making full energy, water, and carbon analyses to measure energy use and recommend potential savings regions.
- Designing shading elements and selecting materials based on environmental factors such as daylight, shadows, solar energy access, visual impact, available daylight, glare protection, and acoustic comfort.

4.1 BIM Applications

BIM is a representation of the physical and functional characteristics of the building in the form of a model built using a computer, which is considered the source of information shared during the life cycle of the building that can be relied on to make the necessary decisions [7]. It is digital software that simulates and characterises all building processes. It includes additional information about the project, including three-dimensional representation (3D), the realisation of the time factor (4D), the cost factor (5D), and the sixth factor, sustainability (6D).Using sixth-dimensional simulation allows modifying the designs to become more sustainable through the following items [9]:

- Following up on LEED and sustainable items
- Improving energy efficiency in the building for the users' convenience
- Optimal use of resources
- Energy simulation and analysis
- Analysing the HVAC system and performance improvement
- Assessing fire risk
- Completely analysing the building construction modelling and performance.

The relationship between the building and the surrounding site is assessed by local climate, surrounding surfaces, landscapes, topologies, clustering, orientation, form, building envelope, zoning, daylighting, heating and cooling, air change rate, users' behaviour, services, and thermal comfort.

The foregoing factors must be linked to a design process sensitive to environmental, social, and economic aspects [10]. Using the BIM model, an architect can simulate how the wind flows around the building and through it. The ventilation and wind can be changed if the building form or roof material changes. BIM helps save time in the design process by simplifying the communication process between different parties involved in building design, which increases efficiency in the design process, so it is a good choice for sustainable design[11]. The elements of sustainable design analysis are energy consumption, energy generation, CO_2 emissions, construction materials, water, and waste management. Some examples will be presented to illustrate BIM's applications for sustainable design [12].

4.2 BIM Simulation & Analysis

The information that can be modelled in BIM also includes details of components, specifications, materials, structural loads, airflow, water flow, spatial relationships, and tabulation and cost information. This can be done by exporting the simulation and analysis based on all design stages. Ecotect models can be directly integrated and imported in gbXML's analysis into Revit or Autodesk Ecotect Analysis once the basic design information has been generated. Autodesk Ecotect Analysis, along with Revit, combines a wide range of analysis functions, including shadows, shading, solar energy, lighting, heat, ventilation, and acoustics, in addition to a visual and interactive display showing direct analytical results in the context of the building model [18]. These visual observations enable the programme to effectively communicate complex concepts and a broad range of data. Moreover, it helps designers quickly resolve performance problems and change the design easily.

5. Case studies: Use BIM for Sustainable Design Analysis

The research methods employed were reviewed for theoretical interpretation, to develop a correct understanding of the relevant theoretical and practical issues, and to implement practical support from case study experiences.

5.1 Miami Science Museum

A cultural, educational, and research institution in Miami focused on environmental standards while contributing to the creation of a healthy regional economy and society, designed by Grimshaw Architects, explores various environmental issues during the design process(Figure 1).

Fig.1. Miami Science Museum

Using BIM in the design process helped to determine how solar strategies, water systems, and building shape affect ventilation through voids and how these elements can be maximised, not only reducing energy and external resource needs [13].

Solar radiation and solar energy analysis

BIM has been used to model diverse solar energy conditions throughout the day and year. Solar panels cover areas of the museum facade. High-efficiency photovoltaic panels have been used in areas such as the inner courtyard and do not affect natural daylight. Passive solar strategies are well integrated into the design, providing a method for both heating and cooling, and photovoltaic panels provide direct shading of the building.

Air flow and ventilation analysis

Ventilation and air flow were carefully studied in relation to the building shape, and the evaluation of the various profiles was repeated using BIM. The south-west direction was chosen to take advantage of the wind.Using BIM early in the design process to determine the size of the building and windows for the balance of comfort and wind movement to ensure effective ventilation.Many iterations are designed to determine the optimal roof shape and current height.

5.2 Energy Plus House

Located in the Green Belt, UK (Figure2). The building design and performance were evaluated in terms of environmental sustainability by BIM using Softwers Autodesk © Revit, Green Building Studio, and Ecotect programs[14].

Fig.2. Energy Plus House

Thermal analysis

The initial calculations for thermal analysis and energy consumption were created based on a model defined by the predefined construction specifications, and viable alternatives were created and their performance evaluated early in the design process.

Solar radiation analysis

The model was used for shade and sun studies, the generation of sun trajectories and solar stress plots, calculations of the average daylight level and artificial light factors, including visibility studies and solar exposure analysis, and as the design progressed, the thermal zones of the building (walls, ceilings, floors, and interior partitions) were created. In the thermal models, the services, occupancy, and software used to produce thermal performance calculations were identified, including heating and cooling loads, negative gains and losses, and solar radiation. Based on these results, the areas, size, and shape of the openings were rearranged, including protection from solar thermal gain in the summer and the selection of specific materials. After analyzing the various alternatives, the final design began to be determined, and after completing the BIM model and drawing up the data for drawings and performance specifications, the model was exported to the IES program for the final energy analysis.

Passive ventilation and cooling analysis

The effectiveness of the underground pipe system as part of the passive ventilation and cooling strategy, taking into account the following variables (building size, required air change rate, pipe design, pipe depth, soil, climatic conditions, and groundwater level), was applied through the use of passive means of cooling by the underground pipe and taking advantage of the slope of the site. Analytical calculations and computational fluid dynamics (CFD) were made using Dassault Systèmes. © Solidworks[14].

5.3 Shanghai Tower

Shanghai Tower is a sustainable tower in the form of a glass spiral (Figure 3). BIM was used at the beginning of the project for integrated design to deal with the complexity of the structure and achieve the goals of designing a sustainable tower.BIM allowed the entire project team to share a vision to achieve sustainable construction according to LEED, as all team members, the customer, engineering groups, and the contractor were able to fully visualize the project using BIM [15].

Fig.3. Shanghai Tower

Shape and materials analysis

BIM allowed the design of the most efficient structures of the tower, through which wind impact measurement tests were carried out, and the rotation of the tower reduces the wind impact by about 24%. This reduction makes it possible to keep the building stable using less building materials, which saves energy as well as materials since building materials consume a lot of energy to produce them, and the design of the tower helped to reduce the glass in the facade by 14% of a square building with the same area.

energy analysis

BIM helped to achieve the goals of reducing energy use; the modelling provided the design team with feedback on energy performance and solar analysis, as the use of BIM helps to confirm the energy metrics of the target LEED points.

6. Results and discussion

The case studies provided applications for building information models and data analysis to sustainable building by incorporating BIM as a tool in the process, which in turn improved its design to achieve its sustainable goals, including the following:

- Analyze the building design and environmental conditions such as wind, sunlight, and water.
- Analyze the optimal use of energy and perform convection calculations to efficiently design heating, ventilation, and air conditioning systems and air flow through the building.
- Calculation of wind loads based on the principles of wind engineering, ventilation, air conditioning, equipment installation, and electronics Using BIM, it is possible to study various designs to reduce carbon emissions.
- Analyze the sun and shade to choose the best lighting design for buildings throughout the year, control the temperature, and find out which places need shading by conducting a simulation of the building.
- Analysis of the exterior facade of the building with various building materials and insulation to determine the most suitable throughout the year

The sustainable design analysis process can be developed through the following phases:

Phase 1: Identifying a set of elements for sustainable design that takes into account all the necessary design methods and serves a specific purpose to achieve sustainable aims, such as the following:

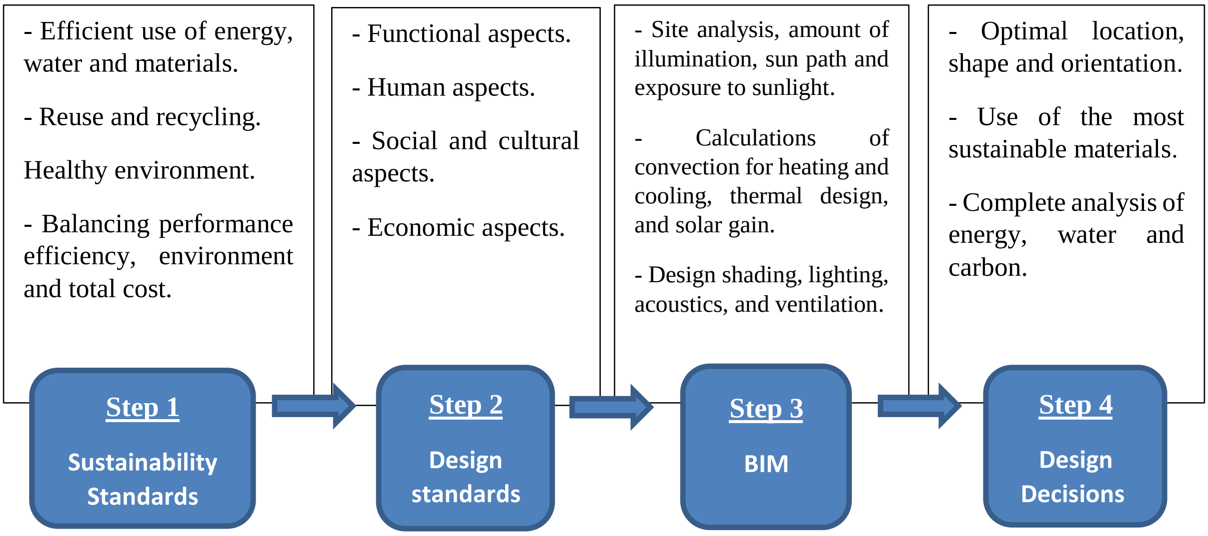
- Climatic, cultural, and social.
- Reduce resource consumption.
- Use local resources and natural systems.
- Use effective systems.
- Apply renewable energy generation systems.
- Reduce the negative effects.

Phase 2: This phase relates to solving the problem and understanding the level of design decisions in order to identify qualitative directional decisions and compare different design alternatives, such as:

- Functional, such as structural, technical, and operational.
- human such as safety, security, comfort, and well-being.
- social and cultural factors such as context, sense of place, and beauty
- Economic factors such as profits versus environmental impact and lifecycle costs analysis

Phase 3: Use BIM through these phases to analyse photovoltaic potentials, lighting amount, solar path, solar stress charts, sun exposure, thermal convection calculations for heating and cooling, thermal design, solar gain, shading design, lighting, acoustics, ventilation, computerised airflow dynamics, CFD analysis, etc. through software applications: Integrated Environmental Solutions© (IES), VE, Odes Autodesk© Revit, Ecotect, Ari Vasari, Building Green Building Studio, Graphisoft© EcoDesigner STAR, and EDSL© TAS Building Designer. The programmes vary depending on the accuracy of results, data representation, awareness required to work, the way in which they interpret the results, visual presentation, type of inputs and outputs, and compliance with building codes.

Phase 4: Use BIM through the design process for sustainable design analysis to support design decisions and performance analysis. Various sustainable alternatives can be assessed in the early phases of the design process to determine which are most useful in terms of the most sustainable and effective designs.



A guiding approach of sustainable design through BIM.

7. Conclusion

BIM's integration into the design process is an integral and crucial part of creating successful and sustainable buildings. It should be through specific approaches and steps. Sustainable design decisions are effective when BIM is integrated early by creating preliminary calculations for thermal analysis and energy use using a predetermined number of specifications, and this leads to less calculation effort through modelling in general. Facilitate early site sustainability verification through environmental soft wear to control the costs and effort required to make the most beneficial adjustments in the early stages of design.

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