Proceedings of the 5th International Conference on Materials Chemistry and Environmental Engineering
DOI: 10.54254/2755-2721/127/2025.20192

The Analysis of the Application of Intelligent Energy Management System Based on BIM Technology

Hesen Gong[1,a,*]

[1]*School of Architecture and Engineering, Maanshan College, Maanshan, Anhui, 243000, China*
a. ghs1614802191@163.com
**corresponding author*

Abstract: With the increase in building scale and complexity, traditional energy management methods are difficult to meet the requirements of modern buildings for energy conservation, efficiency and sustainability. Based on BIM (Building Information Modeling) technology and intelligent energy management systems, this paper explores ways to improve the accuracy and effectiveness of building energy management using data collection, energy consumption prediction, optimal control and 3D visualisation. This study also analyses the systematic integration of Internet of Things (IoT) and Artificial Intelligence (AI) related technologies, which are also elaborated to achieve dynamic monitoring and automated management of energy consumption. This paper refers to the relevant literature, reviews and analyses it with the aim of exploring smart energy management methods for the whole life cycle of buildings. After analysing, this thesis finds that the intelligent energy management system based on BIM technology has good feasibility and applicability in the field of intelligent energy management, providing efficient solutions for the energy management of buildings.

Keywords: building information modelling (BIM), smart energy management, internet of things (IoT), energy consumption optimisation, 3D visualisation.

1. Introduction

With the increasing global concern for environmental protection, reducing energy consumption and greenhouse gas emissions has become an important task. Energy management can help enterprises and the architectural industry to better control energy use and reduce carbon and pollutant emissions, which is important for mitigating climate change and environmental pollution. At the same time, good energy management can provide people with a more comfortable and safe living and working environment. However, traditional energy management methods have problems such as information silos, inaccurate data, and low efficiency, which make it difficult to adapt to the complex and changing requirements of modern buildings and industries. Therefore, the development of an efficient and intelligent energy management system is of great significance to improve energy use efficiency and reduce energy waste.

Building Information Modelling (BIM), as an advanced digital design and management tool, integrates the whole life cycle information of a building into one model through 3D modelling technology. In a nutshell, BIM technology has many application advantages in engineering and technology: such as visual presentation, data integration and sharing, collaborative work optimisation, effective cost control, and quality control enhancement.

BIM technology, as the main means of building information integration, provides strong support for the whole life cycle management of buildings. Azhar et al. showed that BIM technology has significant advantages in building design and construction management, especially in improving data transparency and collaborative efficiency [1]. Matarneh and Hamed emphasised that BIM, by integrating building information, is able to share data in and collaboration to improve efficiency [2]. These studies show that BIM has been widely accepted in the architectural industry and provides a basis for the development of smart energy management systems.

This paper investigates the application of BIM visualisation features in buildings, simulation of energy consumption by BIM models, optimisation of information sharing among different professionals by BIM models and research and learning of post-maintenance management applications. The intelligent energy management system based on BIM is of great significance in enhancing the intelligence of building facilities from the design stage to the maintenance stage and promoting the sustainable new development of the architectural industry.

2. Overview of BIM technology and intelligent energy management system

2.1. Introduction to BIM technology

2.1.1. Characteristics of BIM

BIM is a digital model that integrates the information of the whole life cycle of a building, and is characterised by a high degree of information integration, good visualisation and strong collaborative design capability. The BIM model can visually display the building's structure, equipment, pipelines and other information, providing comprehensive and accurate data support for project management. BIM technology supports the integrated management environment of construction projects, which can significantly enhance project productivity, improve building quality, shorten the construction period, and reduce construction costs.

2.1.2. Main functions of BIM technology

The main functions of BIM technology mainly include the following aspects

(1) 3D visualisation function

The visualisation function based on the BIM model can visually combine the energy consumption data with the 3D building model, which helps to improve the clarity and comprehension of the data presentation. Motawa and Carter proposed a BIM-based building sustainability evaluation method, which utilises visual displays to assist in the management of building energy efficiency [3]. This idea is widely used in intelligent energy management systems, where a 3D visualisation interface allows managers to intuitively understand the energy consumption of each area within a building, forming decision-making support. The study by Alwan et al. also points out that BIM-based visual analysis can significantly improve the operability and user experience of the system [4].

(2) Parametric design function

Model parametric modification: the components in the BIM model have parametric characteristics, which means that the model can be quickly adjusted by modifying the parameters of the components (e.g., dimensions, materials, properties, etc.).

(3) Data integration and sharing

Multi-disciplinary data integration: BIM is an information integration platform that integrates data from all phases and disciplines in the whole life cycle of a building. Data sharing and collaboration: Different parties involved (e.g., investor, design team, construction team, operation team, etc.) can share data through the BIM platform. All parties can access and modify relevant data within the scope of authority to achieve collaborative work.

2.1.3. Future research direction

Future research can be further improved and optimised: firstly, to promote the further unification of BIM data standards to facilitate cross-platform data integration and sharing [5]; secondly, to develop an energy optimisation algorithm framework applicable to different building types to improve the adaptability and universality of smart energy management systems [6].

2.2. Definition and role of intelligent energy management system

Intelligent energy management system is a system that comprehensively monitors, analyses, controls and optimizes the production, transmission, distribution and use of energy by comprehensively utilizing modern information technology (e.g. Internet of Things, big data, artificial intelligence, etc.). It digitally integrates energy-related data, including data from the energy supply side (e.g., power plants, substations, etc.) and the energy consumption side (e.g., factories, buildings, households, etc.). By establishing energy models and algorithms, the system is able to sense the state of the energy system in real time, automatically process and analyse energy information, and automatically or semi-automatically control and regulate energy equipment and systems according to pre-set rules or optimisation strategies, in order to realise the efficient use and rational allocation of energy.

The role of intelligent energy management system is mainly in the following aspects:

(1) to improve the efficiency of energy use; (2) to reduce energy costs; (3) to guarantee the stability and reliability of energy supply; and (4) to achieve sustainable development of energy and environmental protection.

2.3. Feasibility analysis of the application of BIM technology in intelligent energy management

BIM model has good compatibility with IoT, big data and other technologies, and can achieve seamless data docking and integration through API (Application Programming Interface) interfaces and other means. This provides a technical basis for realising the application of BIM technology in intelligent energy management systems.

BIM technology can realise the integration and sharing of information of the whole life cycle of the building and provide comprehensive and accurate energy data support for the intelligent energy management system. This helps to improve the system's data analysis capability and decision support effect.

Through the combination of BIM model and intelligent energy management system, real-time monitoring and optimal control of energy data can be achieved, significantly improving energy management efficiency and reducing energy costs. At the same time, BIM technology can also provide strong support for intelligent transformation and upgrading of building facilities.

3. BIM-based intelligent energy management system function module application

BIM-based intelligent energy management system is an interdisciplinary, multi-module collaboration of complex systems. To achieve real-time monitoring of building energy consumption, intelligent prediction, optimised decision-making and other functions, it needs to rely on a number of key technologies. These technologies include BIM data modelling, energy management data acquisition and processing, energy consumption prediction and optimisation algorithms, and system visualisation and decision support. These key technologies and specific implementation methods are discussed in detail below.

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3.1. BIM data modelling

BIM data modelling is one of the core technologies of intelligent energy management system. Its main role is to create a 3D visual building model, laying the foundation for the integration and sharing of building information. BIM data modelling involves data acquisition, information entry, 3D construction and data format conversion, the main steps are as follows:

3.1.1. Data acquisition and input

Laser scanning, drone aerial photography and other methods are used to obtain the actual terrain and structural data of the building. This information is entered into the BIM model through software tools (e.g. Revit, ArchiCAD). The information on each building component such as material, size, location and other data needs to be entered accurately.

3.1.2. Creation of 3D building model

Based on the collected data, the BIM software is used to construct the 3D model and add all kinds of building information step by step in a hierarchical manner to form a detailed 3D structure of the building. Taking Revit as an example, the process of constructing the BIM model includes establishing the basic structural framework of the building, components, and setting building materials. Each component can be given thermal physical properties such as thermal resistance and thermal conductivity according to requirements.

3.1.3. Data format conversion and standardization

In order to achieve cross-platform sharing and integration of building information, BIM data needs to be converted into compatible formats such as IFC (Industry Foundation Classes) and gbXML (Green Building XML). These standardised data formats support data exchange between BIM models and other systems, ensuring model data integrity and consistency.

Through BIM data modelling, the intelligent energy management system can call up building information in real time, realise the synchronous integration of building information and energy consumption data, and form a unified management platform.

3.2. Collection and processing of energy management data

The intelligent energy management system collects building energy consumption data through IoT devices and sensor networks. These data provide real-time information for the system's prediction and optimisation algorithms. The process of energy management data collection and processing mainly includes the following aspects:

3.2.1. Deployment of sensor networks

Multiple sensors for temperature, humidity, light, carbon dioxide concentration, etc., as well as energy consumption metering devices, are set up inside and outside the building. The environmental parameters and energy consumption of each area are monitored in real time through the sensor network. Sensor data is delivered to the system through a low-power, low-latency transmission protocol.

3.2.2. Data transmission and integration

Raw data collected by various types of sensors and monitoring devices are transmitted to the central database of the BIM system through IoT technology. To ensure the accuracy and security of data

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transmission, the system adopts encrypted transmission protocols and sets up multi-level data backups to ensure data integrity and reliability.

3.2.3. Data cleaning and processing

Before data integration, the raw data needs to be cleaned to remove outliers and deal with missing values to ensure the accuracy and consistency of the data. In addition, the system will perform data dimensionality reduction processing to reduce the amount of data and improve processing speed. The building energy consumption data after data collection and processing can be used for subsequent energy consumption analysis, optimisation and visualisation display, forming the real-time information base of the system.

3.3. Energy consumption prediction and optimisation algorithm

Energy consumption prediction and optimisation are core functions of the intelligent energy management system, which achieves energy saving and consumption reduction by predicting future energy consumption and optimising energy allocation.

3.3.1. Energy consumption prediction algorithm

Energy consumption prediction adopts machine learning-based algorithms, including SVM, which achieves energy consumption classification and regression by constructing high-dimensional spatial decision boundaries, and is suitable for prediction scenarios with a small amount of historical data; followed by LSTM, which demonstrates better prediction ability on multivariate long time series data sets through time series modelling, and is suitable for energy consumption prediction of large-scale building complexes.

3.3.2. Energy consumption optimisation algorithm

The optimisation module achieves dynamic energy allocation through multi-objective optimisation algorithms, such as Genetic Algorithm (GA) and Particle Swarm Optimisation (PSO). Based on the mechanism of natural selection and genetic variation, genetic algorithm (GA) can find the optimal solution in multi-dimensional space, which is used to optimize the energy consumption of lighting, air-conditioning and other equipment; PSO simulates the foraging behaviour of bird flocks, and optimizes through the exchange of information between individuals, which is suitable for real-time energy consumption regulation.

3.3.3. Intelligent control strategy

Based on the prediction and optimisation results, the system can implement energy consumption control strategies to achieve intelligent management of the building. The strategies include timer switching, temperature adjustment, light intensity adjustment, etc., in order to dynamically adapt to changes in the external environment and the requirements of use, and ensure optimal energy consumption.

3.4. System visualisation and decision support

The system visualization and decision support module uses the 3D visualization function of BIM to intuitively display the building energy consumption data in the 3D building model, providing users with clear energy consumption information. The core functions of this module include:

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3.4.1. 3D energy consumption data visualization

Through the BIM model, the energy consumption data is visualized and mapped to the building model, and the energy consumption of each area of the building is displayed in the form of heat maps, bar charts, line charts, etc. of temperature, humidity, light and other data, so that managers can intuitively understand the energy consumption distribution and changing trends.

3.4.2. Real-time energy consumption monitoring panel

The system provides an energy consumption monitoring panel, which displays real-time information such as energy consumption data and environmental parameters of each area, and allows users to switch to different viewpoints, such as floors and functional areas, according to requirements. The real-time monitoring function also automatically triggers alarms based on set thresholds to facilitate timely intervention in case of abnormal energy consumption.

3.4.3. Decision support and energy consumption report generation

The system generates decision-support suggestions based on energy consumption prediction and optimisation analysis, while the system supports the generation of energy consumption reports, providing detailed reports including energy consumption trends, energy-saving effects, etc., to support decision-making by management personnel.

In summary, the intelligent energy management system based on BIM technology achieves intelligent management of building energy consumption through BIM data modelling, energy consumption data acquisition and processing, energy consumption prediction and optimisation algorithms, as well as visual display and decision support. The mutual collaboration of these key technologies enables building energy consumption information to be effectively integrated and managed within the system, providing technical support for the realisation of intelligent energy saving and resource optimisation.

4. Conclusion

This study analyses and reviews an intelligent energy management system based on BIM technology, which can establish a real-time data collection and transmission network by integrating the BIM model and energy consumption data, using Internet of Things (IoT) technology and combining environmental sensors. This thesis also analyses the real-time monitoring, prediction and optimal regulation of building energy consumption, visually displaying the real-time energy consumption data and environmental parameters of the building, which facilitates managers to make quick adjustment decisions and provides a new solution for the energy management of the whole life cycle of the building.

Although this research has achieved certain results in system design and application effect, after learning and exploring, it still has some limitations, which need to be further improved and optimised, and in the future, we will mainly focus on the following aspects of the research: a. Developing the energy optimisation algorithmic framework applicable to different building types, to improve the adaptability and universality of the intelligent energy management system; b. Strengthening the combination of BIM with IoT and AI, in order to achieve more accurate energy consumption prediction and dynamic optimisation.

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