Intelligence in Green Building: A Literature Review

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***Abstract*—Today's world environment is gradually deteriorating. Many industries are facing reform and innovation. The traditional construction of high consumption, and high pollution does not meet the needs of development. The development of technology has made great progress in artificial intelligence. The expansion of the construction sector is seeing a new trend in the fusion of artificial intelligence and new green building. The use of artificial intelligence in the construction industry can enhance the sustainable development of the green building. Although artificial intelligence has been studied in the industry, currently there is no analytical research on the use of artificial intelligence in the main areas of green buildings, so this study is mainly based on the integration of artificial intelligence into green building, to determine the role of artificial intelligence in green building, and to provide reference and help to the future development of green building now.**

***Keywords*—artificial intelligence, green building, review**

I. Introduction

The construction industry has a significant impact on the environment and human health. Among the industries that consume energy globally, the construction industry is a very large consumer. The construction industry consumes 40% of the world's total energy production, 12%-16% of available water resources, 32% of non-renewable resources and 25% of renewable resources in trees, and 40% of raw materials. In addition to this, 30-40% of waste is generated as well as 35-40% of CO_2 emissions (Green Building Council Australia, 2006), which causes considerable global trouble and has an impact on the future development of mankind. This confirms the need for sustainable development in the construction industry, and green building is the key to unlocking the revolution. Due to the need for innovation in the industry, there is a global trend to support and promote green building (Debrah *et al.* 2022).

The U.S. Environmental Protection Agency (US Environmental Protection Agency, Definition of Green Building, 2016) defines green building as the practice of creating processes that are less environmentally damaging and more resource efficient throughout the life cycle of a building. Green building also has a more specific definition. Green building typically refers to the entire life cycle of the building, considering the impact on the environment and humans, to achieve more environmentally friendly building materials with less energy consumption compared to non-green buildings. This typically results in a higher level of indoor air quality and considers the impact of various building types, various building materials, decorative finishes, and furniture choices (Yudelson, 2009). According to the World Green Building Council (GBC), Green building is a way to improve people's quality of life (World GBC, 2021). If a building is constructed according to green building standards, throughout its whole life cycle, it can reduce construction costs and provide a quality environment. It reduces energy consumption and can enhance carbon neutrality to mitigate the greenhouse effect. When a building is built under green building guidelines, it can lower construction costs and create a quality environment. Due to the advantages of green buildings, which are receiving increasing attention from researchers worldwide, many review studies have emerged (Zuo & Zhao, 2014; Darko & Chan, 2016; Debrah et al., 2022). These studies cover a wide range of topics, including emphasizing the state of the art and future needs in the field of green building, researching certain parts of green building-related difficulties in a specific nation, and researching certain aspects of green building financing. There is no doubt that these studies are useful, but they are also flawed in that they do not look deeper into the direction of architecture and artificial intelligence. This research presents and discusses the concept of artificial intelligence(AI) in green construction.

AI is a new technical science that studies and develops theories, methods, technologies, and application systems for simulating, extending, and expanding human intelligence. Intelligent electronics and software systems serve as examples of artificial intelligence in architecture (Adunadepo& Sunday, 2016). Software systems in the early stages of the design of the building through Building Information Modeling technology to model the building simulation collision, etc., and intelligent devices can detect changes in the spatial environment, and in this case adjust and optimize the building's energy consumption, etc. AI technology is continuously evolving, and its application to green building-related problems can provide many creative solutions.

In this paper, AI and Green building were searched in Google Scholar as keywords, and representative related

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papers were selected for review, mainly from the following four aspects: fuzzy rules and knowledge discovery, big data and data mining, intelligent optimization, and building automation systems.

II. Fuzzy Rules and Knowledge Discovery

The most important manifestation of artificial intelligence in green buildings is fuzzy rules and knowledge discovery (Nilashi et al., 2016). The sustainability rating of green buildings and the performance rating of green buildings can be rated by an expert system formed from the expert knowledge collected from Likert's questionnaire. For the question of the influence of various factors on sustainable building development, the complexity of the construction industry in a fuzzy decision environment makes green buildings subject to multiple uncertainties. Through fuzzy set theory (FST) (Zadeh, 1996), answers to complex questions about green buildings can be provided (Mu *et al*., 2014). In recent years, FST has been studied in more detail, generating many application parts such as the fuzzy synthetic evaluation(FSE), fuzzy clustering, FAHP, Fuzzy analytical network process (FANP)-DEMATEL, and the Fuzzy-VIKOR-TOPSIS(Technique for Order of Preference by to Similarity to Ideal Solution) available from Table I. Fuzzy comprehensive evaluation (FSE) establishes a fuzzy comprehensive evaluation system by building a risk assessment model, collecting survey data, and determining risk factors. Mathematical calculations are used in the modeling, and questionnaires are used in the survey data to make various types of risks and send them to professionals in the field to determine the impact of various risk factors on the target problem (Zhao *et al*., 2016).

TABLE I. References for Fuzzy Rules

Method	Purpose	Studies
FSE	GB Risk Control and Forecasting	Nguyen& Macchion,2022
FAHP	GB multi-angle performance evaluation	Nilashi et al, 2015; Wang et al. ,2019; Bhatt & Macwan, 2016
Fuzzy clustering	Rating ecological construction requirements GB multi-angle performance evaluation	Lu et al., 2021; Seo et al. 2004; Vakili-Ardebili & Boussabaine , 2017
Fuzzy-VIKOR-TOPSIS	GB risk avoidance and improved decision rationalization	Yin & Li, 2019
FANP-DEMATEL	Health and safety risk assessment Evaluation of GB material sustainability grading Abandoned building demolition and green building development	Mohandes & Zhang, 2021; Khoshnava et al. ,2018; Negash et al. ,2021
Fuzzy-Delphi method	Abandoned building demolition and green building development	Negash et al. ,2021
Non-dominated fuzzy decision support system	Judgment on green construction	Tam et al. , 2004

In Table I we can learn that the FSE research has been relatively comprehensive and can assist in proposing solutions for various types of problems in the field of green building. In the research process, hierarchical analysis (AHP) was proposed and used in combination with fuzzy logic so that the combination is relevant for the performative judging of alternatives (Nilashi *et al.*, 2015). AHP is a systematic procedure to conclude by comparing key factors and covariates in a hierarchical way to the structure of things (Ahmadi *et al.* ,2014; Ahmadi *et al.*, 2015; Roudsar & Malaysia, 2011; Nilashi *et al.*, 2014; Saaty, 2018). So, using the fuzzy-AHP in the complex selection problem of green building can cope with the diversification of material selection, the diversification of construction indexes in different regions, the combination of personnel and machinery deployment, and the problem of multi-leadership decision making when it can carry out structural comparison analysis, and can cope with the sixth sense, rational and emotional (Akadiri *et al.*, 2013; Figueiredo *et al.* , 2021). After solving the above problems, the fuzzy-AHP derives a performance evaluation system for green buildings during site layout (Wang *et al.* , 2019). Khoshnavaet al. The ranking of materials for green buildings is ranked through a combination of FANP and DEMATLE (Khoshnava *et al*., 2013). Based on APH, ANP is its upgrade, which uses a more advanced network structure. In one aspect, it is a more logical model to show the relationship between various elements by becoming three-dimensional and intuitive from a flat surface (Gabus & Fontela, 1972). In the study, fuzzy prospect theory has been coupled with other multi-criteria decision making (MCDM) methodologies, like TOPSIS (Hwang & Yoon, 1981). and VIKOR (Opricovic, 1998), to tackle the decision problem in GB (Yin & Li, 2019). The MCDM method is known to be a method of weighing the pros and cons in decision making and is very helpful for feasibility, which makes it effective in making decisions. The development of technology has made it easy and fast to collect information, and a large amount of data is available to analyze a variety of issues, such as the role of artificial intelligence and big data in green building.

III. Big Data and Data Mining

Big data is also known as a huge amount of information because of its five characteristics: volume, velocity, variety, value, and veracity. At the same time, it is useful data beyond what conventional databases can carry and can classify and solve. With the development of technology, big data analysis is made possible using artificial intelligence, which can analyze structured, semi-structured, and unstructured data in big data (IBM, 2021), and the process of analysis is called data mining. Data mining is an algorithm based on artificial intelligence and computer science to count, retrieve, analyze, classify, and summarize the hidden information in big data. Therefore, data mining is a kind of decision support process, and the results obtained can be predicted for the future and can be applied to future decisions (Briga-Sá *et al.*, 2021; Cheng & Ma, 2015). In recent years, the speed of interconnection has increased, the price of computers and the cost of data storage have decreased (Mehmood, 2019). With the combination of big data and artificial intelligence becoming more sophisticated, green buildings have been equipped with sensors and electricity and water flow meters that can accurately control the data. Managers or tenants can use artificial intelligence technology to analyze this data and learn from the results to improve the efficiency of resource management and reduce energy consumption to achieve low consumption, high efficiency, and green (Palensky & Dietrich, 2011). As an example: the light sensor is used to control the movement of awnings and window shades. The sensor continuously collects data from the sunlight, and AI analyzes the light intensity through algorithms to determine whether the next action is to open the shade or turn on the light to fill in the light. But through the collection of a large amount of data for data mining, the formation of a law that can be automatically adjusted, which in turn can reduce the use of sensors, for more extreme energy saving (Mehmood, 2019). Kim et al. (2021) used data mining techniques to extract internal relationships and patterns of interest from a large database. The case study conducted in their paper shows that data mining-based energy modeling can help project teams discover useful patterns during the design phase to improve the energy efficiency of building designs.

What methods can be used to determine if a building meets the criteria for a green building? Over time, big data mining has developed many applications for green building rating, building energy projection, green building modeling, and cost prediction and control. As shown in Table II, there are artificial neural networks (ANN), convolutional neural nets (CNN), K-Nearest Neighbors (KNN), multiple linear regression (MLR), support vector machines (SVM) or regression (SVR), ensemble methods, association rule mining (ARM), cluster analysis and logistic regression, and back propagation neural networks, respectively. ANN is a complex network structure formed by many interconnected neurons, an algorithm that simulates the organizational structure and operational functions of the human brain. It can be applied to the cost calculation of green buildings by forming a neural net of various factors to build a model. This allows for estimating the cost of green buildings, measuring the performance of green building and rating green buildings (Lu *et al.*, 2021; Tatari & Kucukvar, 2021; Son & Kim, 2015; Juan *et al.*, 2017). Gonzalez and Zamarreno use an ANN model to predict the short-term electrical load consumption of buildings. The greatest advantage of this model is that it uses minimal resources, but its simplicity and accuracy are like other forecasting methods. Among various methods of neural network configuration, back propagation neural network (BPNN) is the most mature and widely used, which combines feedforward multilayer perceptron with BP algorithm (Lu *et al*., 2021; Gardner & Dorling, 1998) and is mostly used for performance prediction of green buildings to calculate compressive strength of concrete and energy consumption. It also shows the role of data mining in green building as a key decision-making algorithm that no longer needs to go through trial and error to arrive at the result by analyzing large amounts of data (Debrah, 2002). In addition to this, there is a method of combining multiple models and voting to reach a final decision (Pan & Zhang, 2021). As an example, Ma & Cheng (2017) used BIM technology combined with random forest to predict the environmental impact of buildings. BIM technology enables digital modeling and provides shared data and relevant information to facilitate the combination and analysis of multiple models to arrive at final decisions. Data mining is only part of the embodiment of artificial intelligence in green building, while intelligent optimization is a more obvious reflection of how artificial intelligence can help the development of the construction industry.

TABLE II. REFERENCES FOR BIG DATA AND DATA MINING

Method	Purpose	Studies
ANN	GB energy consumption forecasting and cost control GB Performance Rating Construction progress analysis Measuring concrete strength Clarify GB impact factors	Lu et al., 2021; Tatari & Kucukvar, 2021; Son & Kim, 2015; Juan et al. ,2017; Son & Kim, 2015; Ganes & Muthukannan, 2021; Shahmansouri et al. , 2021; Wang et al. , 2021
CNN	The value of BIM technology in GB Indoor temperature modeling related tests	Wen et al. , 2020; Elmaz et al. , 2021
KNN	Connecting BIM and LEED Technologies for Green Buildings	Jalaei et al. , 2021
MLR	Complete LEED credits GB price budget and cost control	Cheng & Ma, 2015; Juan, 2017
SVM/SVR	GB Performance Rating GB design perfection Selecting target LEED points through project information and climate factors	Son & Kim, 2015; Wen et al. ,2020; Chen & Yang, 2017; Jun & Cheng, 2017
NLP	Attention and emotion analysis of GBs Organize and categorize GB material information Determining occupant satisfaction with LEED-certified buildings	Liu & Hu, 2019; Hong et al. , 2019; Guo et al. ,2021
CBR	Complete LEED credits Support GB retrofit decision	Cheng & Ma, 2015; Zhao et al. , 2019

IV. INTELLIGENT OPTIMIZATION

Pareto-optimal solutions are extremely helpful for decision problems in the construction industry, and it means that the solution to a problem is not influenced by other solutions in the functional space (Wang *et al.* ,2006). In locating Pareto optimal solutions in green buildings, intelligent optimization is more in line with the future development of the construction industry than traditional methods whose use of artificial intelligence technology enhances the ability to locate. Intelligent optimization is performed by finding the optimal solution to a problem with maximum and minimum probability under a limited set of constraints (Pan & Zhang, 2021). In general, there are two types of optimizations: single-objective optimization and multi-objective simultaneous optimization. Single-objective optimization is a simple problem that requires only finding an optimal alternative to the existing solution. Multi-objective optimization, on the other hand, is a complex problem that requires the simultaneous analysis and comparison of multiple methods for a combined optimal solution. Since optimization of problems in the green building industry is usually a complex problem with time constraints and other factors, multi-objective optimization is the most preferred method in the construction industry. With the continuous advancement of artificial intelligence, it has also been identified as the better or even optimal solution for the constrained problems related to green building because of its fast and effective optimization.

There are many issues in the whole life cycle of green buildings that require multi-objective optimization, such as the following three areas (Pan & Zhang, 2021). The first is in the optimization of the structural design of the building, in the green building, a good structure can save resource consumption and achieve internal air optimization to improve air quality. Through intelligent optimization can be limited constraints on the building structure, on this basis with minimal energy consumption to achieve maximum structural benefits. We optimize the shape of the building structure, the distribution of steel reinforcement, and the selection of materials for the outer layer of the building to ensure the strength of the building while reducing resource consumption and increasing the service life (Bureerat & Pholdee, 2016). Secondly, rationalization of resource deployment and cost-effectiveness are also helpful for green buildings, eliminating unnecessary waste. Intelligent optimization can also be used in the problem of allocating people or resources under limited conditions (El-Abbasy *et al.*, 2017). Its main role is to balance the relationship between time, cost, and quality in the construction plan, to find the optimal duration, to improve efficiency, to improve flexibility while ensuring quality, and finally to complete the construction successfully (Arashpour *et al*., 2018). Thirdly, it is about the constraint of site layout apparatus construction. In this case, through BIM technology to simulate the construction site situation, after the use of intelligent optimization to meet the construction site personnel equipment placement and use requirements, as far as possible to reduce costs and ensure efficiency. The advantages of intelligent optimization will be amplified in the future, and the scope will increase, like greenhouse gas emissions, indoor air quality, the energy consumption of building materials, resource regeneration, etc. Finally, there are also good effects of building upgrading and renovation (Pan & Zhang, 2021).

V. Building Automation System

Building automation system, a comprehensive system controlled, managed, and monitored by a computer, is an automatic management system in which building electromechanical systems are self-monitored, self-controlled, and self-regulated. Electricity, lighting, air conditioning, water supply and drainage, firefighting, broadcasting, and communication in the building are all part of the automation system. A large amount of data can be collected through centralized management and monitoring, and data mining and analysis can be used to better optimize building energy consumption and realize green buildings. Research over the years has focused on reducing the energy consumption of buildings, much of which is in the automatic regulation of lighting, HVAC, and other systems (O'Grady *et al.*, 2021). While BAS manages the equipment in a building, the automation system ensures the operation of the equipment and improves the comfort and safety of the occupants (Lazim *et al*., 2015). Different sensors are used in different locations, and sometimes multiple sensors are used together to control energy consumption.

Some places that are less visited or do not need to stay, such as restrooms, roomy storage rooms, and some special function rooms, will use passive infrared sensors to reduce the energy consumption of lighting and HVAC. The study determined that total energy consumption could be reduced by 7% after use, and HVAC energy consumption by 1.2% (Gomes *et al*., 2019; Lin et al., 2019; Abdallah *et al.* , 2016; Chan *et al.*, 2017). However, the use of PIR sensors alone can lead to some unnecessary waste of resources because of their noise. Therefore, there is a combination of sensor use methods. For example, Mataloto *et al.* (2019) integrated motion detection sensors with RIP sensors and modified the detection circumstances so that motion could be detected more accurately, as well as controlling lighting systems and HVAC to reduce energy consumption.

In addition, automation in a green building generates a lot of data, through which it is easy to distinguish where improvements are needed and where anomalies occur. Building automation systems provide two functions for green buildings. The energy consumption for a certain period is first predicted, after which the actual data is compared with the predicted value to determine whether there are any anomalies. Simply put, it is to determine whether an abnormality occurs at a certain point in time or stage, and this function is called “point abnormality detection”. The presence of anomalies is determined by the larger context, such as weather (Zhu, 2019). Machinery will inevitably break down, so building automation systems cannot do without the help of artificial intelligence, just like many smartwatches nowadays, which can detect the state of the human body. Some sensors may develop defects over time, or people may inadvertently damage them, which can lead to unnecessary energy consumption. As a result, numerous artificial intelligences are being used in building automation systems to assure proper machinery performance and to reduce unnecessary or inefficient energy usage. Table III lists some relevant information on building automation systems.

TABLE III. REFERENCES FOR BUILDING AUTOMATION SYSTEM

Method	**Purpose**	**Studies**
Light sensors	Balance natural lighting and electric lighting to reduce energy consumption in buildings	Iwata et al. , 2017
Thermostats	Detects relative humidity, air velocity and temperature to adjust temperature to reduce energy consumption	Homod et al. , 2018
Expert system	Detection and control of outdoor lighting systems; diagnosis of faults	Atis & Ekren, 2016
Deep learning model	Estimating the efficiency of GB natural ventilation system Energy consumption of budget buildings	Park & Park, 2021; Ding et al., 2021
Machine learning model	Optimize building energy structure	Briga-Sá, 2021; Yang et al., 2015; Gonçalves et al. , 2020
Bluetooth Wi-Fi	Intelligent control from a distance for wireless connection	Mataloto et al. , 2019

VI. DISCUSSION

Through previous research on fuzzy rules and knowledge discovery, this method has matured, and many new methods have been derived. It also forms as an independent expert system, which can provide better advice for problems in green building. In addition, after continuous research and development of multi-method combinations to make the problem more three-dimensional, the model clearly shows the analysis of the advantages and disadvantages of decision-making, in the green building multi-criteria and multiple constraints to assist in making the best decision. Green building is the goal of the future, and there will certainly be many issues yet to be solved. Fuzzy rules and knowledge discovery can only be analyzed in the context of existing experience, which can be of assistance to the actual situation.

Today is the era of big data, and the data presented is generally the most objective, coupled with the growing development of artificial intelligence technology, the future of green building must be inseparable from artificial intelligence. According to the study, the algorithm of data mining can obtain information on various aspects of green buildings. For example, we analyze and rank the energy consumption of various materials in green buildings, count the emission of exhaust gases in a certain period, check the brightness of the room and calculate the consumption of electricity, etc. Through the processing of some data comparison, it can be better to identify problems and better optimization. Combined with artificial intelligence, with the use of intelligent electronic devices for data monitoring or the formation of regularity, to do intelligent optimization to achieve green building. Building automation system, simply put, is a housekeeper-like system, which is a very advanced artificial intelligence technology to bring this feature of automation into play. In fact, in life, artificial intelligence has been slowly integrated into the building, and smart home appliances are good examples. In addition to the impact of artificial intelligence, it should also be concerned about the impact of a range of artificial intelligence devices themselves on green buildings.

The existing research has been able to gradually clarify that the use of artificial intelligence in green buildings is a future trend in the construction industry. However, the research related to AI and green building is based on historical examples and experiences, and both are unknown to human civilization. In future research, we should pay attention to the more detailed and longer term, such as analysis based on the satisfaction of the occupants, analysis based on the future population, the pros, and cons of AI for green building, and even the question of whether human civilization will be destroyed. Layered analysis can better target existing problems in green buildings and reasonably use artificial intelligence to optimize and improve them so that future problems can be predicted and prevented.

VII. CONCLUSION

This study is to propose the use of artificial intelligence in green buildings for the future development of the construction industry, to reduce energy consumption, and enable the transformation and development of the construction industry. A literature review is conducted to analyze the role of artificial intelligence in green building and its help to the development of the construction industry through four perspectives. Research on fuzzy rules and knowledge discovery, big data and data mining, intelligent optimization, and building automation systems has solved some decision-making problems in green building, provided concrete insights into green building-related information, and confirmed that the use of artificial intelligence technology in green buildings is a trend that has strong support for the development direction of the construction industry. As the issue of the green building continues to be raised, and AI technology matures, in the future attention should be paid to the question of whether AI technology itself has a greater impact on green building and how this is to be optimized.

CONFLICT OF INTEREST

The author declares no conflict of interest.

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