Pakistan Journal of Life and Social Sciences
www.pjlss.edu.pk
https://doi.org/10.57239/PJLSS-2024-22.2.00387

RESEARCH ARTICLE

Adaptive design of traditional residential buildings based on digital intelligence system under self-organization theory

Xin Gan[1,2], Thirayu Jumsai na Ayudhya[1*]

[1]School of Architecture, Art and Design, King Mongkut's Institute of Technology Ladkrabang. No.1 Chalongkrung alley, Ladkrabang district, Bangkok 10520

[2]College of Design, Yunnan Arts University, Kunming 650500, Yunnan, China

ARTICLE INFO

Received: Jul 10, 2024

Accepted: Sep 15, 2024

Keywords

Digital intelligence system

Generative adversarial network

Self-organization theory

Residential building.

***Corresponding Author:**

thirayu.ju@kmitl.ac.th

ABSTRACT

Adaptive design of traditional residential buildings that change in response to their surroundings, occupants, and things, as well as those that rely only on internal information, are the focus of adaptable construction, a multifaceted field. The primary problem with architectural design is the disparity between control and execution regarding cost comparisons. Another issue is that it is impossible to anticipate humans or conventional computer programs to analyze big datasets and identify trends using rule-driven approaches. The article proposed a Digital intelligence-based adaptive design of residential buildings under self-organization theory (DI-RB-SOT) for residential structures throughout their lifecycle, including conceptual, design, construction, operational, and maintenance stages. The DI simulate various design possibilities and estimates their impact on the structure's productivity, convenience, and security using data on the building's use, arrangement, operations, and environment. A crucial phase in the design process is using Artificial Intelligence (AI) algorithms to sift through this heap of data in search of trends and patterns. These models would assess potential improvements to the building's performance, user comfort, energy efficiency, and alternative design possibilities. The research examines the inner workings and motivating reasons underlying the emergence of home adaptive design by using self-organization theory as a framework. The study confirms the usefulness of Graph Converter generative adversarial network (GCGAN) computational models that facilitate the development of intelligent building design elements, which in turn permit the establishment of intelligent structures based on Digital intelligence. Managers and practitioners may be able to use solutions involving proactive thinking, improved efficiency, self-management, and satisfaction in residential buildings as a result of this work.

1. INTRODUCTION

The most common type of housing in urban areas is cooperative accommodation, which consists of shared spaces and amenities used by all residents in addition to individual homes (Xia et al., 2023). The efficient and everlasting utilization of urban social housing has emerged as a critical issue in residential policy formulation in light of recent societal and economic shifts (Wang et al., 2021). The design and development of residential buildings should adhere to user demands through feasible, adaptable, and efficient techniques. It will help prolong a structure's service life, especially when residents face distinguished living needs at different stages, such as changes in family makeup and form (Wang, Hong, 2020). Mission oversight is needlessly laborious and complicated due to the absence of technological advances and the organization's heavy reliance on conventional methods (Chang et al., 2021). Low efficiency, ineffective decision-making, insufficient execution quality, and project delays are all symptoms of the construction branch's inadequate digital expertise and implantation of technology (Bui et al., 2020). The construction sector must swiftly improve its technical capacity and intensely use DI approaches in the coming years due to the existing difficulties of labour shortages, the need to maintain environmentally friendly building rates, and global financial crises (Somu et al., 2021). The construction industry has a greater prevalence of non-fatal mutilation. Implementing effective construction oversight to boost productivity is prudent, as the construction industry contributes significantly to societal development through its economic activities (Wang et al., 2020).

The construction and building sector is gradually embracing new technologies such as Smart Vision, AI, Building Information Modeling (BIM), and Digital Twins (DT) to enhance the efficiency, productivity, accuracy, and safety of built environments (Wang et al., 2023). The fourth industrial revolution replaces antiquated building and manufacturing techniques with cutting-edge digital technologies that enable independent, intelligent systems (Lu et al., 2021). Similarly, cutting-edge cyber-physical systems, digital and computing technologies, and state-of-the-art manufacturing processes all come together in developing and constructing industries to reimagine the planning, building, use, and upkeep of buildings and infrastructure, focusing on circularity (Hu et al., 2022). The digital age is producing vast quantities of data, which, when analyzed systematically and used in conjunction with predictive modelling, can lead to novel structural and architectural designs, improve functioning and building safety, decrease operational and embodied energy specifications, lower functioning and development costs; increase construction speeds; improve payback periods; and enhance long-term viability (Sepasgozar et al., 2020).

The built environment's effectiveness, efficacy, precision, and security are steadily improving due to the building and architecture industry's gradual adoption of new technologies like digital intelligence (DI) and AI (Li et al., 2023). Graph modifications and self-attention in a Conversion are two novel features of the proposed generator that rely on graph converters; one of these features is an encoding that simulates local and global exchanges among linked and non-connected graph nodes (Guo et al., 2020). Figure 1 illustrates the modules for smart homes that use digital intelligence and self-organization theory. Rethinking the planning, constructing, maintaining, and upkeep of buildings and infrastructure with a focus on circularity is possible through the integration of cutting-edge cyber-physical.

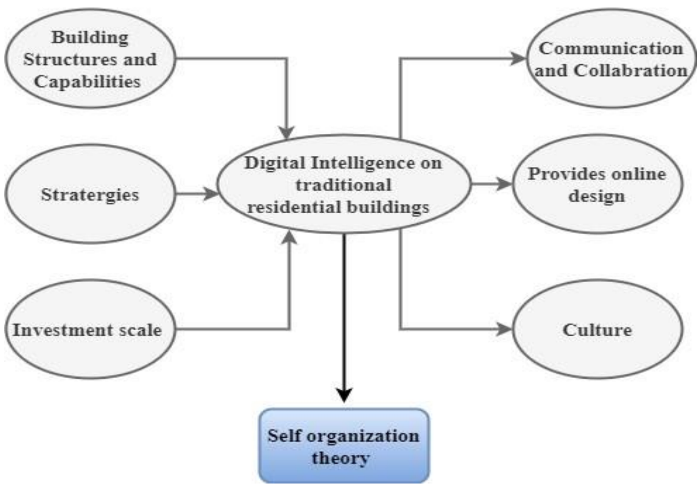

Fig.1 Digitally intelligent residential building blocks based on self-organization theory

systems, digital and computing technologies, and cutting-edge industrial production systems in the construction and building industry (Richarz et al., 2022). It is believed that DI based on SOT is a computer's capacity to learn, make judgments, and execute activities like human intelligence, which could increase construction productivity (Pallonetto et al., 2020). The digital transformation is producing vast quantities of data, which, when analyzed systematically and used in conjunction with predictive modelling, can lead to novel fundamental and construction designs, boost functioning and safety during construction, decrease operational and embodied energy requirements, lower overall costs; shorten repayment periods; and boost long-term viability.

The main contributions of the article include

1. This paper suggested the digital intelligence-based adaptive design of residential buildings under self-organization theory (DI-RB-SOT) for imaginative, planning, building, operational, and maintenance stages.
2. For the complex graph-constrained residence construction problem, this study employs a DI method that develops appropriate graph node connections end-to-end with the help of a one-of-a-kind Graph Converter generative adversarial network (GCGAN).
3. This research uses self-organization theory to examine the emergence of adaptive design for residential buildings and its motivations.
4. The research may help residential building managers and practitioners employ proactive thinking, efficiency, self-management, and self-adaption.

The following is the outline of the paper. Section 2 conducted a comprehensive evaluation and comparison by discussing the most recent research. Following an explanation of the fundamentals of a DI-RB-SOT system in a conventional building in Section 3, to examine self-organization theory in demand side management as it pertains to the execution of demand response programs. Section 4 delves into the experimental findings, whereas Section 5 presents the final verdict.

2. LITERATURE SURVEY

Farzaneh et al. (Farzaneh et al., 2021) present an evaluation framework for evaluating recent research in this area across several key AI domains, including power, ease, architecture, and maintenance. Additionally, it delves deeper into the concepts and uses of AI-powered modelling methods for anticipating building energy consumption (AI-PBE). Using the BMS and DRP ideas, this paper seeks to present a thorough review of recent studies on AI applications in intelligent buildings. The essay wraps up with a summary of what is known so far and an outlook on future directions for research into smart buildings' use of AI.

Baduge et al. (Baduge et al., 2022) presented a cutting-edge examination of AI, ML, and DL utilization in the construction and building sector 4.0. This article discusses constructing buildings and representation, material scheduling and enhancement, essential growth and assessment, offsite production plants and technology, construction management, monitoring progress and safety, qualified to work, developing oversight and health monitoring, resilience, life cycle assessment, and circular economy. This study presents a new perspective on using AI, DL, and ML in various fields, from building conception to disassembly. This section also suggests future study directions.

Merabet et al. (Merabet et al., 2021) conducted a thorough and in-depth organized review of Artificial Intelligence (AI) methods used for building control systems. It also investigates their abilities to enhance energy conservation and preserve comfortable temperature conditions. With the help of AI and customized comfort models, to reduce energy consumption by an average of 21.81-24.36% and increase comfort by an average of 21.67-85.77%. Lastly, this study delves into the difficulties encountered when implementing AI to boost energy efficiency and comfort, and it lays out the critical areas for future research on AI-based building control systems for managing energy efficiency and human comfort.

Li et al. (Li et al., 2022) introduce the Semi-tensor product, a matrix operation that simplifies calculations and simplifies calculations by alleviating self-organizing problems in remote building automation logic control. However, the core logic control problem that supports system implementation is seldom the focus of research, while distributed optimization problems are more commonly studied. Studying distributed control systems' setup and programming paradigm suggested a logic control method based on semi-tensor products that can achieve controller plug-and-play. The results validate the viability of the proposed method for autonomously producing control logic.

Li et al. (Li et al., 2022) present a new multi-camera joint spatial self-organization (MC- JSSO) method that incorporates various camera types, a complicated spatial architecture, and a significant quantity of sensors into a single imaging environment. Instead of back-end data association, front-end data calibration revolutionizes surveillance data linkage. The approach ensures resilience in the face of dynamic changes and noise in scenes by utilizing sequence features' complementarity and redundancy. Extensive experimental evaluations conducted in a campus setting prove that the strategy generates outstanding outcomes.

Himeur et al. (Himeur et al., 2023) examine the systematic integration of AI and big data analysis into building automation and management systems (AI-BD-BAMS). AI functions include forecasting load, water management, population identification, indoor quality of the environment monitoring, and more. This study contains three instances demonstrating how AI-big data analytics may improve BAMSs. The first two case studies include residential and office energy consumption identification of anomalies, sports facilities energy, and operating enhancement. Finally, critical next steps and suggestions for enhancing the functionality and dependability of BAMSs in IBs are highlighted.

Zhang et al. (Zhang et al., 2021) propose a Deep Believer Network (DBN)-Recurrent LSTM Neural Network to forecast massive data obtained from Internet of Things (IoT) smart cities. Additionally, the suggested model indicates the fire threat values collected from intelligent towns through the Internet of Things. When tested against other methods already in use, the simulation results reveal that the suggested method outperforms them all in terms of F-1 score, recall, accuracy, and precision. With an approximate error rate of just 0.14 percent, the presented model is 98.4 percent accurate in detecting fire outbreaks. In addition, smart cities can employ the proposed model for various predicting challenges.

Jiang et al. (Jiang et al., 2023) offer an adaptive control system for building fire prevention (DT-ACBFP) that uses digital twins and semantic web technologies in the case of a fire. Building Forms Ontology (BFP) provides a semantic model and basis for integrating geometric data about static buildings with data from dynamic sensors. Like a physical space map, the above details comprise DT data models. Developing rule and process models allows the DT data model to accomplish physical space-syncing and intelligent control mechanisms. A case study was conducted utilizing a fire accident simulation to verify that DTs and semantic web technologies are feasible.

3. SYSTEM METHODOLOGY

3.1 Structure of DI-RB-SOT

New economic gains may be available to firms through the use of DI. At this time, cutting-edge technological developments are the key to any country's economic modernization and defining resources. Figure 2 shows the architectural design process begins with the designer making broad assumptions about potential issues that develop during development, developing procedures to address these assumptions, developing a plan, and submitting drawings and documents. On the surface, architectural design is the application of DI technology in various fields, including home planning and architectural design. Positively impacting the project is that everything is proceeding as planned and within budget, in addition to purchasing completed goods that meet consumers' diverse needs and preferences. The study focused on improving the construction process by applying DI and self-organization theory.

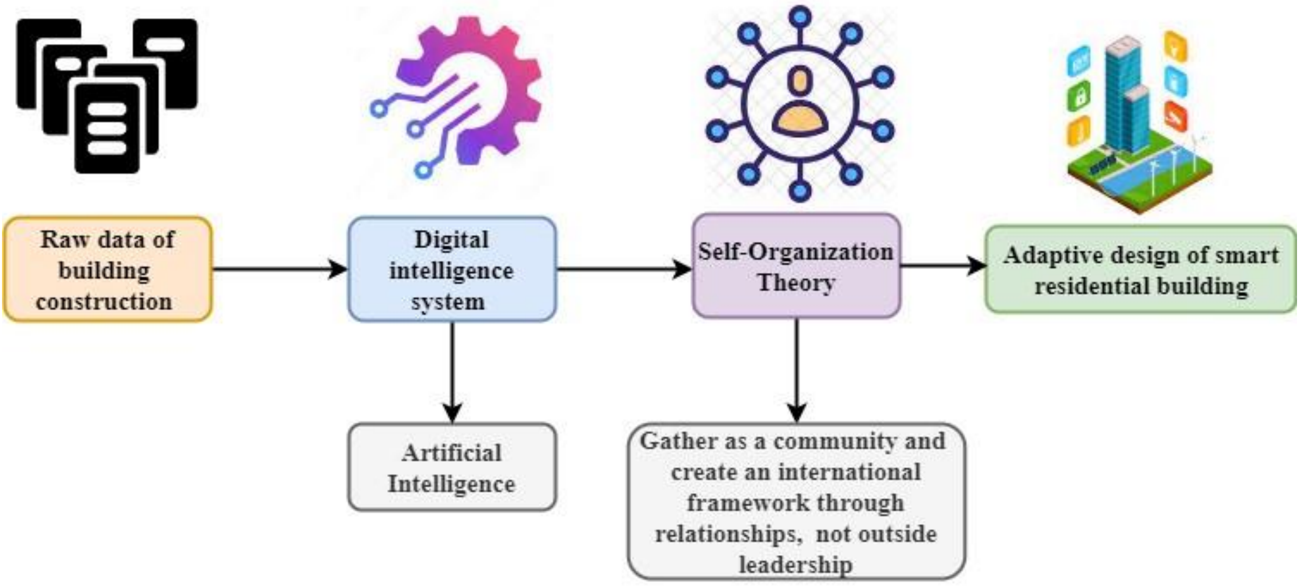

Fig 2 Overview of DI-RB-SOT

First, the raw data for constructing residential buildings is given as the input. Automated architectural design is made possible using computational technologies such as algorithms, self-organizing processes, and parametric linkages. DI can elevate building presentation and design by spotting patterns in pre-existing data. Creating two- and three-dimensional architectural plans, classifying different building kinds and styles, and identifying areas and drawings related to architecture. The knowledgeable systems are integrated with the DI technique, greatly enhancing the potential for simulating human expertise and experience. The inability to incorporate knowledge gained from actual project execution into the planning process is a significant shortcoming of conventional planning methodologies. DI-RB-SOT technologies present the possibilities to develop plans, validate data stored, and derive conclusions from them. Insufficient solutions to complicated real-world project planning issues are produced when self-organization theory is applied to a small amount of topic domain knowledge for organizing. An overarching process for developing novel systemic patterns is the hypothesis of self-organization theory. An arrangement is a data activity that explains relationships, architecture, organizing methods, and structural order. From the perspectives of environmental data function, preservation and establishment of the general data structure of the system, and investigation of novel data modes, the features of self-organization behaviour—including transparency, nonlinear behaviour, inner inconsistency, inner feedback, networked information, and holographic construction—provide equivalent circumstances and the foundation for the self-organizing growth of the system. Work tasks are defined, resources and time needed are assessed, and costs are estimated as part of construction planning. Sophisticated DI systems, AI data processing, and SOT have contributed to the emergence of intelligent buildings, which in turn have facilitated the development of contemporary infrastructure. Building managers, proprietors, and occupants reap the rewards of intelligent buildings' increased efficiency, decreased operational and upkeep costs, reduced energy usage, and improved security and comfort.

3.2 Graph Converter Generative Adversarial Network (GCGAN)

The paper utilizes a new Graph Converter generative adversarial network (GCGAN) with two primary components: generators based on graph converters and discriminators based on a categorization of nodes. The objective of the proposed generator is to create an authentic representation of a house based on the source graph. Figure 3 displays the general structure of the GCGAN for generating residential design. The system comprises an original generator called G, based on a graph converter, and a novel discriminator called D, based on graph classification. Generator G is provided with a disturbance vector and the bubble diagram as parameters for each room. Subsequently, it produces a house blueprint, depicting each room as a square aligned with the axes. The creator takes graph nodes as input and utilizes the proposed graphs-building block and multiple node accumulation to express global relationships among linked and non-connected nodes, respectively. The input bubble (I_b) equation 1 is represented by

$$I_b = (N(0,1): x_r) \tag{1}$$

Where x_r The room index vector corresponds with noise vector N. The generator comprises three main components: a convolutional data-transferring network of neurons (Conv-DTN), a Graph Converting Encoder (GCE), and a generation head. Conv-DTN is designed to take nodes in the network as inputs, and its main objective is to extract distinctive node properties. Subsequently, the embedded nodes are inputted into GCE, where the linked node concentration and non-connected node concentration modules carry out distant and universal relation reasoning. After that, the recommended graph map block (GMB) receives the results from both focus modules. It uses them to record the connections around the residence and its immediate vicinity based on the structure of the design. The final step in using GCE to create a home's blueprint or roof is to feed the data into the generating head. To solve the issue of creating residences with networking limitations, pioneers utilized a graph transformer to depict both the local and global interconnections among graph nodes.

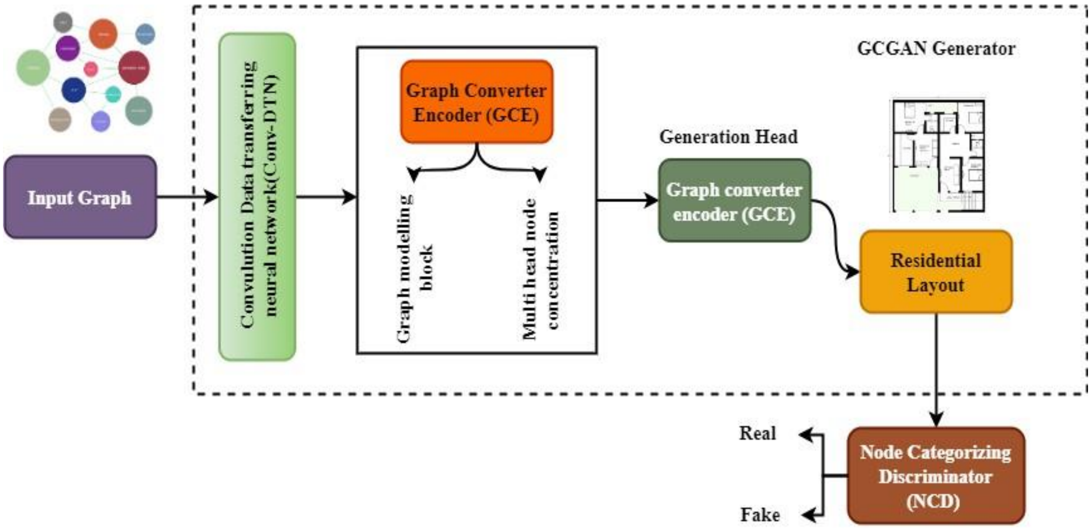

Fig. 3 Structure of GCGAN

A graph of feature volumes broken down by room is kept up-to-date by the Conv-DTN layer through convolutional message forwarding. Specifically, after doing the following procedures, xr equals 1. GCE to get the added correlations between connected rooms in the input graph. 2) Apply a new GCE to the input graph to capture the extensive dependencies between rooms that are not connected. Step three: merge a sum-pooled feature from the input graph's linked rooms. 4) Merge a sum-pooled characteristic from each of the disconnected spaces. 5). Run the merged feature via a CNN. The DTN based on CNN is represented in Equation 2

$$I_b \leftarrow CNN\{{I_b}^l + GCE\left(pool_{N\in s(b)}\, {I_s}^l {I_b}^l\right) + +GCE(pool_{N\in \overrightarrow{s(b)}}\, {I_s}^l {I_b}^l) \tag{2}$$

with "+" representing additive on a per-pixel basis and ";" denotes when combining channels individually, and N(r) representing sets of linked and not-linked spaces, accordingly. GCE captures global correlations using self-awareness in transformer networks and localized connections using graph convolution networks. The objective is to produce node locations in the produced residential plan, hence not utilizing location insertions in the system. To convert a characteristic volume into a 1×33×33room recognition mask using three layers of a convolutional neural network (CNN). The number of convolutional channels varies between 257, 129 and 2. Feed the segmentation mask graph into the proposed discriminator D during training. Finally, each room is fitted with the narrowest axis-aligned rectangular to produce the residence's layout.

Remember that the positional node information in the house plan that was developed is not based on position embeddings. The discriminator D has the dual objective of differentiating between authentic and synthesized layouts while categorizing the designed house layouts based on their respective room categories. Furthermore, the proposed Node Categorizing Discriminator (NCD) aims to differentiate between authentic and counterfeit residential plans, hence guaranteeing the authenticity of our created residential patterns or roofing. Simultaneously, the discriminator categorizes the designed rooms based on their genuine labels, maintaining the distinguishing and meaningful characteristics of various elements within the house. A graph-based loss calculus for cycles is utilized to sustain the configuration at the graph level to safeguard the relative spatial links between the surface of truth and predicted graphs.

3.3 Digital Intelligence for Adaptive Design

A digitally intelligent system for residential adaptive design is summarized in Figure 4. It is ideal for the project administrator to work for a competent organization that uses digital technologies. For the project manager to zero down on the eight domains of digital intelligence, the five foundational components must be in operation. Ideally, businesses would employ digitally competent project managers to oversee and execute projects connected to this field. Figure shows the residential building models' operations, arrangement, and operations. DI-based models are system-based models that incorporate AI simulations. During the decision-making stage of building oversight and servicing, typical buildings do not have sensors, meaning critical data is unavailable. Data collection and the design of an integrated building administration system present formidable obstacles owing to the wide variety of construction elements, massive volumes of data, unpredictable structure motion, extreme weather, and inevitable inconsistencies. The DI provides the infrastructure for modern construction to gather this data efficiently and subsequently analyze it using tools. DI in functional and construction executives, the word innovative structure" inevitably comes up. It describes an efficient environment thanks to optimized frameworks, offerings, structures, and relationships among these components. A building with intelligence integrates multiple technologies. Variance-driven structural equation modelling examines the regions and building's raw data. Planning the structure's shape, considering the framework's attractiveness (including colours, texture, and materials), and generating structural layouts with architectural details are the key elements of architectural design. Residential security, water management, networking and communication, intelligent energy control and management, and smart sensors and control devices are all part of the traditional buildings proposed paradigm.

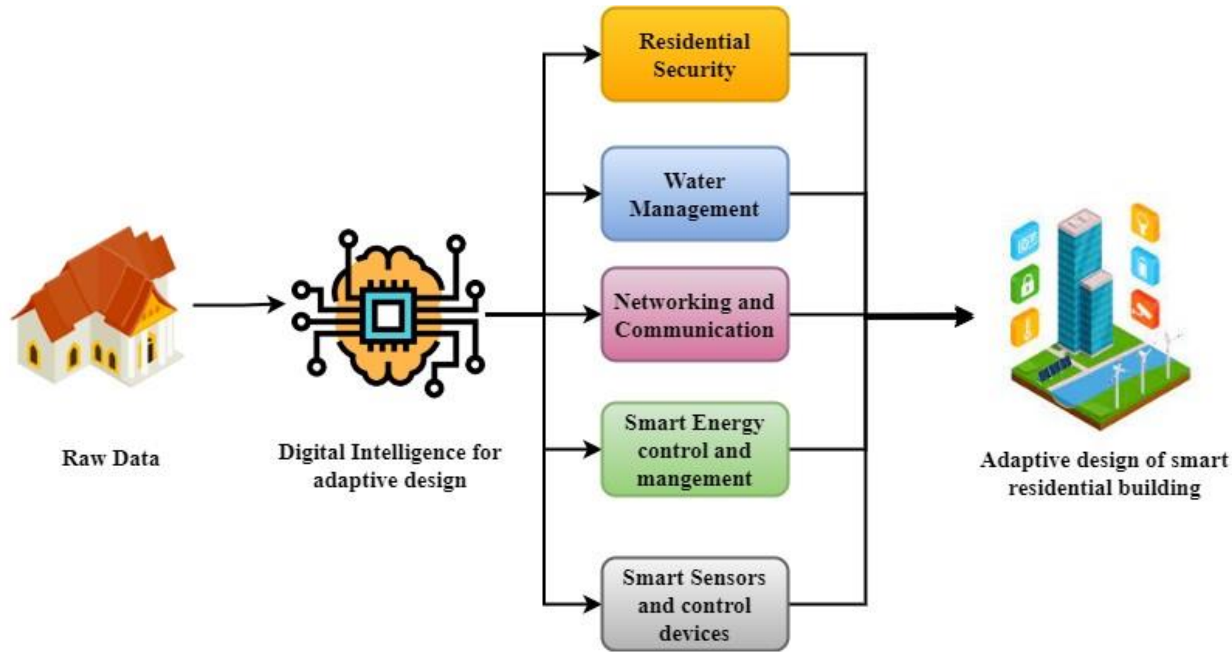

Fig.4 Digital Intelligence system for adaptive design of residential building

Table 1 shows the Traditional residential building design using digital intelligence. Graph Planning is another technique that considers the user-inputted layout while generating floor plans using GCNs and CNNs. Using the technique, it was feasible to introduce layout limitations, such as room adjacencies, in greater detail. Making architecture floor plans with vectors instead of deep learning has also been the subject of much research. Employing rasterized photos of varied complexity, numerous researchers have employed deep learning algorithms like GANs, ResNET, and CNN to produce highly accurate vectorized floor layouts.

Table 1: Adaptive design of traditional residential buildings based on digital intelligence system

Application	Technique used
Create floor plans	FloorNet
Three-dimensional interior plans	Duelnet
Synthesizing indoor scenes	CNN
Automatic room identification in a building blueprint	ANN
Creation of preliminary architectural design drawings	Sparse GAN
Making construction aesthetic components	Evolutionary Algorithm
Residence fashion identification	CNN

Completing the complex building design and representation process requires designers' expertise, background, and inspiration. AI can aid in presenting architectural and design projects by examining patterns in past design information. Representation and design in architecture have significantly benefited from several applications based on deep learning. Synthesizing interior sceneries, identifying construction plans and areas, creating 3D design concepts, and classifying different kinds of buildings and styles are all part of this. The measurement framework for structural, discriminant, convergent, and latent variable validity and normalized load factors is to be considered. DI technology during the design phase of complex structures and managerial systems allows for more efficient consideration of critical elements, leading to faster system performance.

Residential Security

The frequent occurrence of accidents during construction demonstrates a lack of focus on safety and security. The construction industry continuously implements new DI method technologies to enhance building operations and increase worker safety. One real-time platform that can detect and warn of accidents results from intelligent sensors and control devices. Consequently, alerts are sent mechanically whenever a danger manifests.

Water Management

While construction automation and water supply systems have existed for a considerable period, their primary emphasis has been monitoring and offering alarm functionalities. Given the growing integration of residential buildings, creating a centralized analytics platform that can provide enhanced insights based on the aggregated data is highly beneficial. DI oversees, gathers, regulates, assesses, and manages building water usage. The system governs energy use and decreases it during periods of high demand, recognizes and alerts to issues, and anticipates equipment malfunctions in advance.

Intelligent energy control and management

As time goes on, DI develops into a fully autonomous intelligent assistant that can highlight the benefits of the building industry in areas like budget control, funding, drawing, managing automated equipment and processes, organizing the project, interaction management, and the security and precision of production.

Intelligent sensors and control devices

According to the results of the experiments, the level of construction safety management issues, ineffective safety supervision, and a lack of safety knowledge among construction personnel are all mitigated when DI technology and computer vision are used to manage the safety of civil construction. Businesses have had some success evaluating resource use and performance with the deployment of DI in the building and sensors for data collecting. Mounted on the ceiling are tiny sensors that make up the neurological system. Platforms like MindSphere, Siemens, or Schneider Electric EcoStruxure take data, move it to the cloud, and then analysts analyze it to help engineers manage utility costs and usage.

While DI has much potential in the residential building design field, several critical considerations and obstacles must be overcome before these algorithms can reach their maximum potential; obtaining an excellent data set appropriate for the problem under investigation is an essential factor to consider. Data preparation for using these algorithms is an additional critical consideration that requires time and energy. Data pre-processing is necessary to get a highly accurate ML model. On the other hand, several methods call for substantial data pre-processing before model input. Developing more robust techniques, such as self-organization theory, for automating the laborious early data processing step should be prioritized, which should be considered while developing data-gathering processes.

3.4 Self-organization Theory for Residential Analysis

Self-organizing, as a concept, applies to several forms of entities. "Aside from organizations" refers to administrative expertise and abilities not naturally present within the system. Figure 5 illustrates the concept of self-organization theory, which offers an alternate explanation for observable occurrences. According to this theory, a system's internally organized residential subsystems can autonomously arrange themselves into a specified structure or function, following predetermined rules, without any external effects. The system can generate a novel structure organized in terms of time, place, or function through the collaboration of multiple subsystems. This phenomenon is clarified by the principle of self-organization, which involves the movement of external energy, knowledge, and materials. Constant changes happen in conventional residential building designs' internal and external surroundings based on digital intelligence systems. These designs are sophisticated and open systems. There is a continual flow of data, energy, and materials between the system's components and the outside environment. Everything in an ecosystem constantly changes internally and externally; under certain circumstances, species compete. Creatures within the system adapt when their traits are maintained or eradicated. As a result of emergence and adaptation working together, the system undergoes coevolution, growing in complexity and enhancing its functional capacity. Below is a figure that shows how the traditional residential buildings based on digital intelligence self-organization evolve.

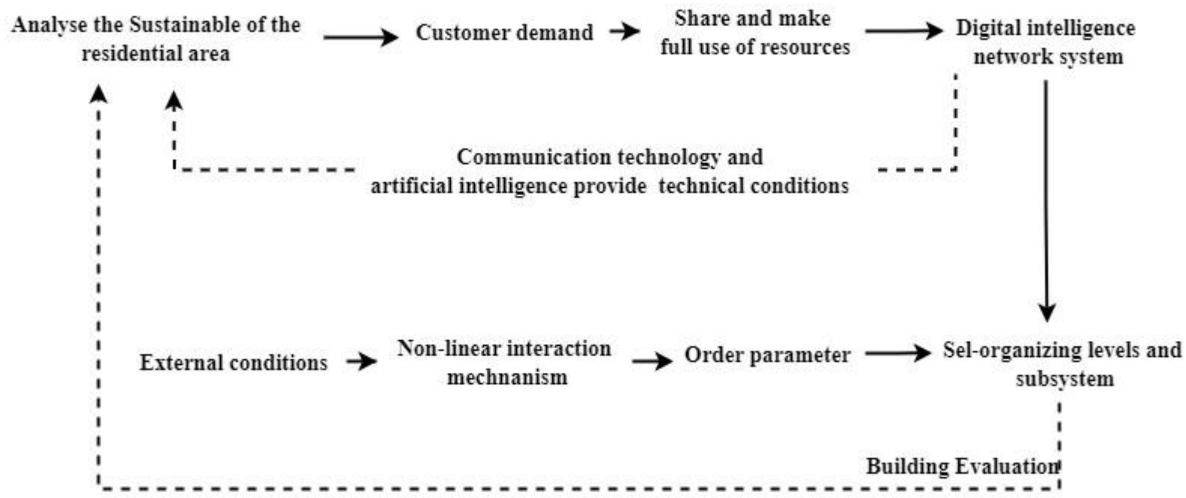

Fig.5 Flow of Self-organization Theory

The key to organizing the traditional residential structure is a nonlinear interaction between subsystems, regardless of their proximity to a stable equilibrium state. The future trajectory of evolution for the steady equilibrium state of the residential building is uncertain, as it can transition into a volatile or novel equilibrium state based on the conditions outside. The stability of the building's structure is jeopardized when the variables of the balanced system fall within a defined and wide range of values. As a result of alterations in the system's motion, the unstable equilibrium gradually transitions into a state of more excellent stability. Conversely, in the nonlinear zone distant from a state of balance, a synchronized endeavour might amplify a minor unpredictable disruption in the structure's blueprint, safety protocols, and management systems, resulting in large-scale fluctuation. This disturbance leads to the ecosystem transitioning from an unstable state to a secure and organized state. The self-organizing features of adaptive design allow it to achieve a state of order via coordination. As a result, the evolution of residential design depends on both external factors and the adaptable design itself. Self-organization is crucial to the ecosystem's growth, which facilitates cross-border e-commerce. The objective of the self-organization principle in synergetic theory is to elucidate the process by which systems transition from a state of disorder to one of order. This phenomenon is essentially the system's inherent ability to organize itself, and synergy is the mechanism via which this occurs. Hence, it is logical to infer that self-organization is the predominant mechanism for the residential community to transition from an unstable and chaotic state to a stable and organized one while also achieving self-enhancement and advancement.

4. EXPERIMENTAL ANALYSIS

The proposed methodology utilizes the ReCo dataset for Residential Community Layout Planning. https://www.kaggle.com/datasets/fdudsde/reco-dataset [24]. Regarding publicly accessible vector files about real-life communities, the Resident Communities Layout Planning (ReCo) Dataset stands out as the first and most prominent. Presented in various forms, the ReCo Dataset contains 37,648 plans for residential communities and 599,728 individual structures' heights. Generative layout design, morphology pattern recognition, and spatial evaluation are examples of how ReCo can be easily customized for urban design tasks related to residential community planning. Moreover, two generative models based on Generative Adversarial Networks (GANs) are applied to the dataset to confirm that ReCo is helpful for computerized residential community layout planning. With any luck, the ReCo Dataset will spark new ideas and initiatives in intelligent design and beyond.

Architectural design Efficiency comparison based on shortcomings

The section analyses and contrasts the occurrence rate and magnitude of numerous significant issues. Figure 6 highlights that the fundamental concern among the four architectural plans is the insufficient emphasis on cost management. When strategizing and allocating resources, schedules, and financial investments for the construction project, it is advisable to employ segmented management. The design department often handles the initial building plans and budgets but cannot provide a cost estimate for managing and modifying the project. Excessive expenditure on architectural design is unavoidable due to poor financial planning, leading to a decrease in the overall quality of the finished product. While talent shortages, innovation gaps, and poor technical and economic integration contribute to the issue, the skill shortages have a relatively minor impact. The efficiency level is compared with the other methods, such as AI-PBE, MC-JSSO, AI-BD-BAMS and DBN-RLSTM.

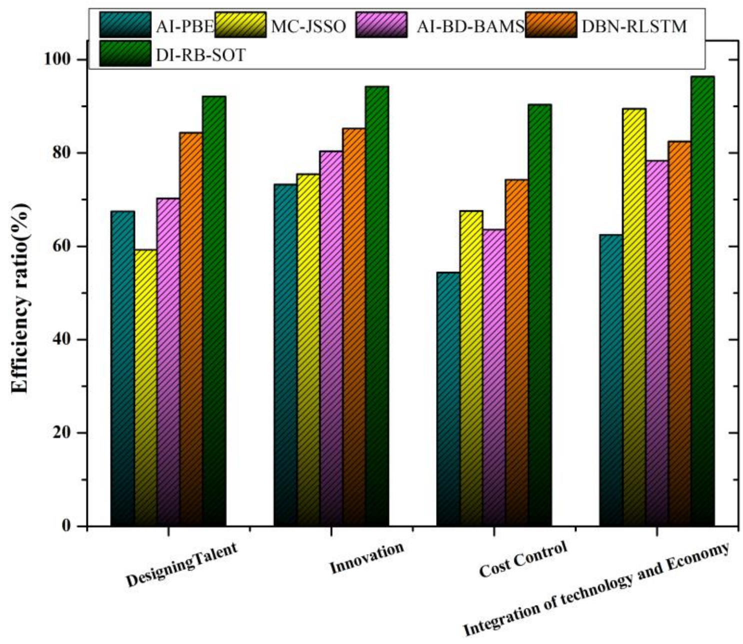

Fig.6 Architectural design Efficiency comparison

Design satisfaction score

For many designs in architecture methodologies, Figure 7 presents customer evaluations following the self-organization theory of the DI methods. Because DI technology enhances simple architectural designs, improving them can make them easier to control. The efficiency degree of attracting talents is the lowest of the four methods; increasing innovation has the highest optimization happiness of cost control; increasing on-site inspection has the best average of attracting talents; and acquiring skills has the lowest enhancement degree overall. The figure shows the satisfaction scores for architectural designs before and following optimization using various methods. Before DI technology, the satisfaction scores were the lowest. Still, after efficiency, there is a significant improvement, with the addition of the the optimization scheme for on-site inspection being one of them. On average, 0.9 is the level of satisfaction with the architectural design, making it the highest. Other approaches to architectural design likewise achieve satisfaction levels of about 0.2.

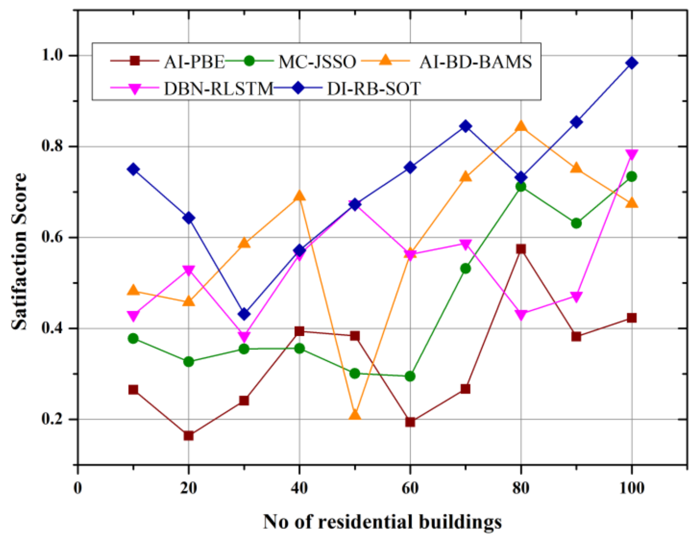

Fig.7 Design satisfaction score

Qualitative comparison of GAN network in residential building design

Figure 8 compares GCGAN to three residential-leading methods—Floor-Net, Sparse GAN, and RoofGAN—to help analyze its performance on pattern creation. To avoid roof duplication, the Roof GAN network divides the sets for training and testing according to the number of primitives. GCGAN with DI is the most effective method in the suggested model by beating the other three rival techniques in both measures. Regarding the comparison of GCGAN and RoofGAN, it is the most relevant approach. Figure 8 shows the visualization results. GCGAN produces floor and roof architectures that are more rational and realistic than the leading approach, RoofGAN and FloorGAN. For example, the sparseGAN technique makes tooting building layout plans that are excessively long, too high, or isolated.

Additionally, it causes incorrect geometrical forms and topology by generating weak relationships between different elements. But GCGAN makes things better by creating more intricate and lifelike mixtures of roof primitives, which helps with all these issues. Another benefit of GCGAN is that it establishes roofs with more diversity.

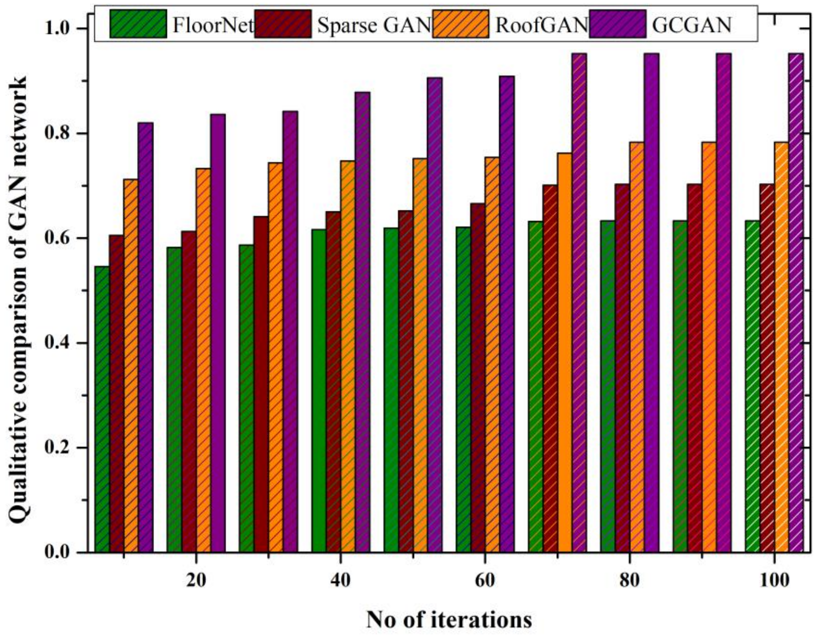

Fig.8 Qualitative comparison of the GAN network

Performance Evaluation of DI-RB-SOT

Incorporate more factors like a relative error and mean comparative error to conduct a performance evaluation for architecture design improvement based on equation 3. Figure 9 illustrates the performance evaluation findings of the proposed modes compared to traditional residential buildings. Distributed intelligence (DI) in intelligent buildings, driven by the self-organization theory, utilizes generative convolutional generative adversarial network (GCGAN) technology to maximize building operations and management efficiency. Buildings consume excessive power; however, implementing DI can significantly reduce this consumption by enhancing systems' automation, control, and reliability. Moreover, these technologies can augment the security and convenience of structures. The study of residential building design involves many necessary artificial intelligence (AI) topics, including recognizing patterns, neural networks, computer vision, and trained systems. The study suggests that academics should prioritize GAN above disciplines, such as recognizing pattern accuracy in design and energy management. The graph unequivocally illustrates the superior performance of the proposed methodology compared to the others.

$$a = \frac{Design\ energy\ cosumption - forecast\ energy\ consumption\ of\ traditional\ bulding}{Design\ energy\ consumpetion} * 100 \quad (3)$$

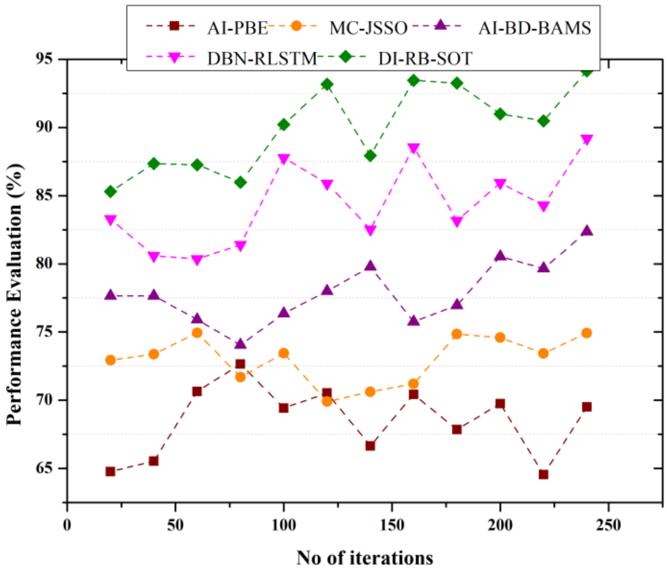

Fig.9 Performance Evaluation of DI-RB-SOT

RMSE

Figure 10 shows the suggested model's root mean square error (RMSE) calculated using Equation 4. Two popular statistical measures, the forecasting coefficient and the mean squared errors, were employed to assess the models' prediction capabilities. One of the most common loss functions used in first-year ML classes is RMSE. Take a weighted average across the entire dataset to get RMSE, which is the square of the difference between your model's predictions and the truth. When the training error values are zero, the model performs as efficiently as possible in the evaluation. The coefficient of determination indicates that the water management index significantly improves the economic strength of areas with congested design. The management system's components, on the other hand, severely restrict it. The proposed method's RMSE has a lower error rate than the other approaches. Compared to approaches like AI-PBE, MC-JSSO, AI-BD-BAMS, and DBN-RLSTM, the suggested model has a lower error rate based on the RMSE.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} a^2}{N}} \quad (4)$$

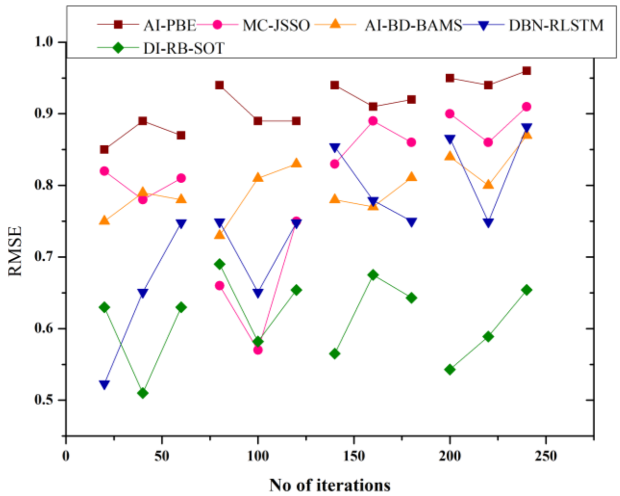

Fig.10 RMSE

5. CONCLUSION

This article used the DI-RB-SOT framework to describe a residential building approach incorporating intelligent technology into the building lifecycle stages of planning, building, operation, and servicing. With data about the building's function, layout, operations, and environment, the DI models possible designs and predicts how they might influence the building's safety, comfort, and efficiency. An integral aspect of the design method is using AI algorithms to search for patterns and trends in this massive data. In addition to evaluating possible design alternatives, these models would also consider ways to enhance the building's efficiency, user convenience, and energy efficiency. Through the prism of self-organization theory, this study investigates the processes and driving forces behind the evolution of adaptive design for residential buildings. This research lends credence to the practicality of computational models based on the Graph Converter generative adversarial network (GTGAN), which paves the way for creating AI-powered construction components and, ultimately, AI-powered structures. This work could lead to solutions that managers and practitioners can use in residential buildings that involve proactive thinking, increased efficiency, self-management, and satisfaction. The degree of contentment is elevated when contrasted with other approaches like AI-BD-BAMS, DBN-RLSTM, MC-JSSO, and AI-PBE. The proposed model is the most efficient and practical architectural design, with an average satisfaction level of 0.9 and an efficiency level of 0.9. Despite the low level of DI-based application acceptance in residential building and construction, self-organization theory predicts that the industrial sector will gradually adopt these approaches.

REFERENCES

Baduge, S. K., Thilakarathna, S., Perera, J. S., Arashpour, M., Sharafi, P., Teodosio, B., ... & Mendis, P. (2022). Artificial intelligence and smart vision for building and construction 4.0: Machine and deep learning methods and applications. Automation in Construction, 141, 104440.

Bui, D. K., Nguyen, T. N., Ngo, T. D., & Nguyen-Xuan, H. (2020). An artificial neural network (ANN) expert system enhanced with the electromagnetism-based firefly algorithm (EFA) for predicting the energy consumption in buildings. Energy, 190, 116370.

Chang, K. H., Cheng, C. Y., Luo, J., Murata, S., Nourbakhsh, M., & Tsuji, Y. (2021). Building-GAN: Graph-conditioned architectural volumetric design generation. In Proceedings of the IEEE/CVF International Conference on Computer Vision (pp. 11956-11965).

Farzaneh, H., Malehmirchegini, L., Bejan, A., Afolabi, T., Mulumba, A., & Daka, P. P. (2021). Artificial intelligence evolution in smart buildings for energy efficiency. Applied Sciences, 11(2), 763.

Guo, Z., Moayedi, H., Foong, L. K., & Bahiraei, M. (2020). Optimal modification of heating, ventilation, and air conditioning system performances in residential buildings using the integration of metaheuristic optimization and neural computing. Energy and Buildings, 214, 109866.

Himeur, Y., Elnour, M., Fadli, F., Meskin, N., Petri, I., Rezgui, Y., ... & Amira, A. (2023). AI-big data analytics for building automation and management systems: a survey, actual challenges and future perspectives. Artificial Intelligence Review, 56(6), 4929-5021.

Hu, Y., Cheng, X., Wang, S., Chen, J., Zhao, T., & Dai, E. (2022). Times series forecasting for urban building energy consumption based on graph convolutional network. Applied Energy, 307, 118231.

Jiang, L., Shi, J., Wang, C., & Pan, Z. (2023). Intelligent control of building fire protection system using digital twins and semantic web technologies. Automation in Construction, 147, 104728.

Lu, Z., Wang, T., Guo, J., Meng, W., Xiao, J., Zhang, W., & Zhang, X. (2021). Data-driven floor plan understanding in rural residential buildings via deep recognition. Information Sciences, 567, 58-74.

Li, X., Lin, S., Shan, K., Han, Z., & Wang, S. (2022). A self-organization method for logic control of distributed building automation system. Journal of Building Engineering, 54, 104688.

Li, C., Li, J., Xie, Y., Nie, J., Yang, T., & Lu, Z. (2022). Multi-camera joint spatial self-organization for intelligent interconnection surveillance. Engineering Applications of Artificial Intelligence, 107, 104533.

Li, J., Herdem, M. S., Nathwani, J., & Wen, J. Z. (2023). Methods and applications for Artificial Intelligence, Big Data, Internet of Things, and Blockchain in smart energy management. Energy and AI, 11, 100208.

Merabet, G. H., Essaaidi, M., Haddou, M. B., Qolomany, B., Qadir, J., Anan, M., ... & Benhaddou, D. (2021). Intelligent building control systems for thermal comfort and energy-efficiency: A systematic review of artificial intelligence-assisted techniques. Renewable and Sustainable Energy Reviews, 144, 110969.

Pallonetto, F., De Rosa, M., D'Ettorre, F., & Finn, D. P. (2020). On the assessment and control optimization of demand response programs in residential buildings. Renewable and Sustainable Energy Reviews, 127, 109861.

Richarz, J., Henn, S., Osterhage, T., & Müller, D. (2022). Optimal scheduling of modernization measures for typical non-residential buildings. Energy, 238, 121871.

Somu, N., MR, G. R., & Ramamritham, K. (2021). A deep learning framework for building energy consumption forecast. Renewable and Sustainable Energy Reviews, 137, 110591.

Sepasgozar, S., Karimi, R., Farahzadi, L., Moezzi, F., Shirowzhan, S., M. Ebrahimzadeh, S., ... & Aye, L. (2020). A systematic content review of artificial intelligence and the internet of things applications in smart home. Applied Sciences, 10(9), 3074.

Wang, Y., Zhang, N., & Chen, X. (2021). A short-term residential load forecasting model based on LSTM recurrent neural network considering weather features. Energies, 14(10), 2737.

Wang, Z., & Hong, T. (2020). Generating realistic building electrical load profiles through the Generative Adversarial Network (GAN). Energy and Buildings, 224, 110299.

Wang, Z., Hong, T., & Piette, M. A. (2020). Building thermal load prediction through shallow machine learning and deep learning. Applied Energy, 263, 114683.

Wang, Y., Rui, L., & Ma, J. (2023). A short-term residential load forecasting scheme based on the multiple correlation-temporal graph neural networks. Applied Soft Computing, 146, 110629.

Xia, L., Mi, S., Zhang, J., Luo, J., Shen, Z., & Cheng, Y. (2023). Dual-Stream Feature Extraction Network Based on CNN and Transformer for Building Extraction. Remote Sensing, 15(10), 2689.

Zhang, Y., Geng, P., Sivaparthipan, C. B., & Muthu, B. A. (2021). Big data and artificial intelligence based early risk warning system of fire hazard for smart cities. Sustainable Energy Technologies and Assessments, 45, 100986.