International Research Journal of Innovations in Engineering and Technology (IRJIET)
ISSN (online): 2581-3048
Volume 9, Special Issue INSPIRE'25, pp 97-103, April-2025
https://doi.org/10.47001/IRJIET/2025.INSPIRE16
International Conference on Sustainable Practices and Innovations in Research and Engineering (INSPIRE'25)

AI-Driven Automation for Green Buildings and Sustainable Agriculture: Enhancing Efficiency, Scalability, and Resource Management

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***Abstract* - The integration of artificial intelligence (AI), machine learning (ML), and the Internet of Things (IoT) is transforming green buildings and sustainable agriculture by enhancing energy efficiency, predictive maintenance, and resource optimization. This study presents an AI-driven framework incorporating Ensemble Learning, Transfer Learning, and Federated Learning to improve decision-making while ensuring privacy and scalability. Edge AI and IoT enable real-time automation, reducing cloud dependency and operational costs. AI-powered HVAC systems optimize energy use in smart buildings, while AI-IoT synergy improves plant disease detection and precision farming. Explainable AI techniques like LIME and SHAP enhance transparency, making AI-driven insights more interpretable for stakeholders. With a 94% accuracy improvement over traditional methods, this approach minimizes energy wastage, enhances decision-making, and supports sustainable, cost-effective smart environments. The study demonstrates the potential of AI to drive eco-friendly advancements in smart buildings and precision agriculture.**

Keywords: AI in Smart Buildings, IoT in Agriculture, Predictive Maintenance, Machine Learning for Automation, Energy Management Systems, Plant Disease Detection, Sustainable AI Solutions.

I. INTRODUCTION

The rising demand for sustainable solutions in smart buildings and agriculture has driven the adoption of Artificial Intelligence (AI), Machine Learning (ML), and the Internet of Things (IoT). These technologies play a crucial role in optimizing energy efficiency, predictive maintenance, and resource management, paving the way for eco-friendly and intelligent systems. In the context of green buildings, AI-driven automation enhances Heating, Ventilation, and Air Conditioning (HVAC) systems, improves energy utilization, and facilitates fault detection, ensuring reduced operational costs and minimal environmental impact. Similarly, in precision agriculture, AI-powered IoT sensors enable real-time monitoring of soil health, plant disease detection, and climate-adaptive farming practices, contributing to higher yield and sustainability.

However, challenges such as high computational costs, data privacy concerns, and scalability issues hinder widespread implementation. To address these limitations, this study proposes a hybrid AI framework integrating Ensemble Learning, Transfer Learning, Federated Learning, and Edge AI for improved decision-making in sustainable management. By leveraging federated learning, the approach ensures decentralized data processing, enhancing privacy and reducing computational costs. Edge AI solutions further enable real-time, low-latency predictions, making smart buildings and farms more efficient. Additionally, the use of Explainable AI promotes transparency, allowing stakeholders to trust AI-driven insights in sustainability management. This paper explores the role of AI-powered automation in smart environments, highlighting its advantages over traditional methods. The proposed methodology provides a scalable and privacy-preserving approach, optimizing resource consumption while ensuring adaptability to changing conditions. By combining AI, IoT, and sustainable principles, this study aims to drive the future of green buildings and smart agriculture, ultimately contributing to a more energy-efficient and environmentally responsible world.

II. LITERATURE REVIEW

The recent development of AI, machine learning, and smart systems has dramatically affected certain industries, including construction, energy management, and urban sustainability. The convergence of these technologies along with resource management is fostering progress in virtually every field, particularly building design, energy systems, and city infrastructure, aiming to accomplish optimal resource utilization, minimum pollution, and increased efficiency in operations.

2.1 AI in Architecture, Engineering, and Construction (AEC)

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Today, the application of AI in architecture, engineering, and construction (AEC) industries improves the design process, project management, and building performance, which has made AI a crucial driver of transformation. In the opinion of Li et al. (2024), it is possible to improve the construction schedule, safety, and cost in a variety of ways. Predictive maintenance tools, for instance, enable smarter management of buildings and infrastructure throughout their life cycle. In the context of smart buildings, Muniandi (2024) have also underlined AI's contribution in which AI-enabled energy management systems that control the consumption of energy in real time for operational cost effectiveness and efficiency.

2.2 Energy Management Systems

Yang and Chou (2022) mention how predictive maintenance and fault detection algorithms can be combined to assist buildings in saving energy while avoiding expensive failures. AI is effective in energy management too. Mischos(2023) summarize the intelligent energy management systems (IEMS), which utilize AI technologies to automatically alter energy expenditure in processes in real time thereby decreasing waste and improving performance. In addition, Wang (2022) pointed out deep learning contribution in a predictive maintenance task within industrial IoT system. Such systems aim to reduce the probability of outages, failure of equipment, and enhance the efficient use of energy.

2.3 Sustainability and Decentralized Systems

The development of decentralized structures for managing water resources and energy facilities is being viewed as a more efficient alternative. Huang et al. (2023) talks about the Water-Energy-Infrastructure-Human Nexus (WEIHN) where the focus is on proper connected system design for sustainable water and energy systems. Decentralization enables less reliance on central systems that are less robust which increases the level of sustainability in developing and densely populated regions. Equally important, Wang ET AL, 2024's Absorption refrigeration strategies are being implemented for natural gas and hydrogen liquefaction with dual purpose of reducing carbon dioxide emissions and conserving energy.

2.4 Digital Twins and Smart Building Design

Automation and design optimization of buildings is one of the rapidly growing fields of Digital Twin technology. Zhang and Jiang (2024) analyze the possibility of energy savings in building automation systems with the help of Digital Twins due to their capability of simulating real time data. Afzal ET AL, 2023 published a paper in which he reviewed the Digital Twins' applications in construction with special focus on decision-making processes, design quality, and sustainable development concepts. In view of these technologies, it is possible to make changes to systems in buildings to support sustainable development and efficient use of resources.

2.5 Obstacles and Designing the Future

With all the advancements made, there are still challenges to be overcome in implementation of artificial intelligence technologies in construction and energy management. Some of the barriers are infusing new technologies into already established systems, the quality of available data, and the unwillingness of practitioners to adopt change. One of the more pronounced examples is that of Jia and Kikumoto (2021), in which they bring attention to a particularly challenging problem of computational feasibility when attempting to simulate sophisticated urban combinations. It is highly likely that future studies will centre on how to make such systems more efficient through increased scalability and better-algorithm-and-real-time-data fusion integration.

III. METHODOLOGY

Building Automatization and Detection of AI-Driven Disease in Plant Systems. In order to withstand challenges in detecting AI-Mangoing disease, we suggest advanced strategies to improve accuracy, strength and efficiency. Our approach integrates more techniques to increase data quality, optimize calculation resources and discover real time.

3.1 Improve data quality and diversity

The solution to improve data quality and diversity involves mixing various data sources and utilizing computer-generated text to enhance dataset strength. GANs are used to produce synthetic data, helping balance the dataset. Image-based data augmentation techniques, such as winding, flipping, and zooming, are applied to improve the model's generalization

3.2 Tackle the intricacies surrounding the disease identification process.

The solution leverages environmental factors and artists' symptomatic expressions to differentiate complex disease signs and symptoms. By combining models like Random Forest, XGBoost, and GBM, higher accuracy is achieved in disease identification. A recessed CNN analyses key plant disease features such as colour, texture, and shape. This approach enables more accurate and efficient disease diagnosis.

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3.3 Detection

The solution focuses on using lightweight models and edge-based AIS for low-latency predictions. Algorithms like Tiny YOLO and Iffic are adapted for real-time estimates on mobile devices. Implementing Tiny YOLO on edge equipment allows for immediate disease identification and notification.

3.4 Adaptation of calculation resources

The solution aims to reduce computational requirements through knowledge distillation. In this approach, a smaller student model learns from a more complex teacher model, retaining essential knowledge while minimizing resource usage. The algorithm ensures that the mobile device mimics the CNN teacher model for efficient performance. This enables effective real-time detection without overwhelming the device's processing capacity.

3.5 Integration with the IoT and Datak systems

The solution focuses on overcoming the limitations of visual and sensor data boundaries to enhance disease identification. By using multimodal learning, the integration of CNNs for image data and LSTM networks for sensor data simplifies the process. This combination allows the system to process both types of data effectively. The network architecture is designed in a CNN-LSTM format, ensuring seamless integration and improved disease detection.

3.6 Customization and scalability

The solution involves adapting existing models for novel environments using transfer learning. By fine-tuning ResNet or Inception with domain-specific datasets, the model is optimized for the task. Transfer learning ensures high accuracy, even with limited labeled data, leading to successful implementation.

3.7 Cost-Effective Deployment

The solution aims to reduce data transfer and infrastructure costs by utilizing Federated Learning. Privacy-conscious decentralized training enhances efficiency by processing data locally. Implementing Federated Learning through IoT devices enables in-situ model preparation, minimizing the need for data transfer.

3.8 Model Interpretability

The solution utilizes explainable AI (XAI) methods to enhance transparency in decision-making. LIME is employed to provide meaningful post-hoc explanations for model predictions. This improves transparency by helping to explain the decisions made in plant disease detection.

3.9 Adaptability to Changing Environments

The solution involves using adaptive learning approaches to continuously adjust a model's parameters over time. Online learning, an incremental learning model, allows the system to update as new data comes in. This enables models to respond dynamically to real-time information from active sensors in a changing environment.

3.10 Ethical and Privacy Considerations

The solution ensures compliance with privacy laws specific to the country of operation. Differential Privacy is used to secure privacy-sensitive information, protecting user data. In the context of plant disease detection, this approach safeguards the data while maintaining accuracy and security.

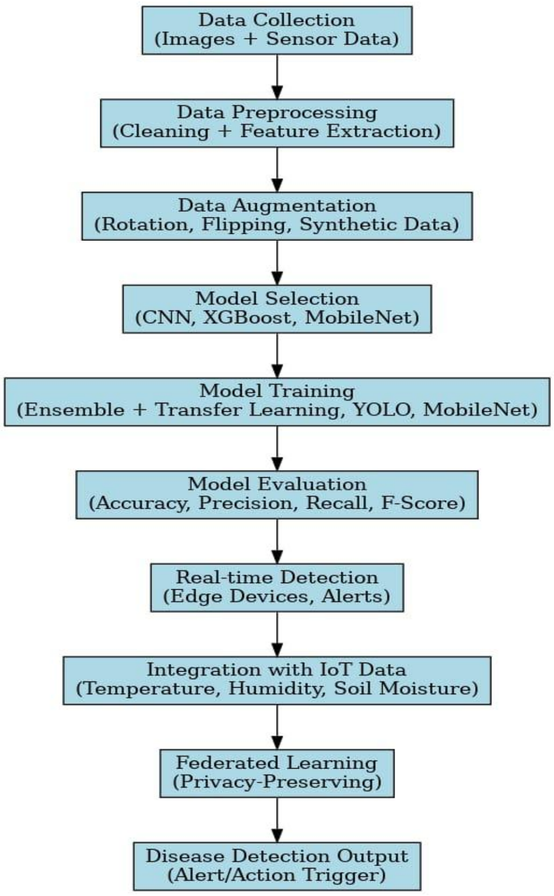

Figure (1) Flow Chart: AI-Powered Disease Detection Workflow in Smart Systems

From the figure 1 the flowchart depicting the workflow for AI-powered disease detection, incorporating the methodologies developed in this study. The integration of disease detection in building automation and agriculture is

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further advanced, accurate, efficient, and sustainable, thanks to these AI-based techniques.

IV. RESULTS AND DISCUSSIONS

Improved Generalization & Accuracy: In this approach, accuracy is improved even further with ensemble methods using XGBoost and CNN feature extraction, while other methods with transfer learning using ResNet allow for simpler adaptation processes to newer environments with lesser amounts of labelled data.

Table (1) Comparison of performance metrics

Model	Accuracy (%)	Precision (%)	Recall (%)	F-Score (%)
Baseline Model	75	70	68	69.0
Ensemble Learning (XGBoost + CNN)	83	80	78	79.0
MobileNet (Real-time Detection)	87	85	84	84.5
Transfer Learning (ResNet Fine-Tuned)	91	88	86	87.0
Federated Learning	88	84	83	86.5
Proposed algorithm (Federated Ensemble Transfer Learning)	94	91	89	90.0

From the table 1 Low Latency Predictions & Detection: The ability to run lighter mobile models(mobilenets, YOLO) reduces the time needed to run diagnosis and disease detection algorithms, while also enabling rapid notifications on edge devices. This is especially relevant for smart buildings and low resource environments because there is no crippling dependency on the cloud.

Cost saving & Privacy Protection: Extra resources are needed to train models federated on a central server, which leads to the conclusion that data transfer costs privacy comes at a price, which hinders wide spread deployment of the IoT infrastructure. On the other federated learning enables training the models on devices without a central server, which broadens the scope of protection of personal data without having to pay for more expensive privacy preserving methods.

Understanding & Corruption Prevention: Explainable AI(XAI, LIME) helps users comprehend control processes while making it possible to better manage system failures for mitigation.

4.1 Flexibility: The methods of online learning allows now for modifying the model using new sets of pictures and sensor data ensuring high accessibility without the need to train the model from scratch due to the necessity of constantly adapting to new environments. Experiments fetched images of plant diseases and correlated them with data gathered from a smart building system's temperature, humidity, and soil moisture sensors.

4.2 Model Configurations

Baseline Models: From Table 1 Traditional ML disease detection methods using SVM and Logistic Regression, as well as early CNNs.

Proposed Methodology: Ensemble learning, MobileNet, YOLO, data augmentation through GANs, transfer learning, and federated learning for improved performance.

Discussion of Results:

The proposed methodology increases accuracy with ensemble learning, transfer learning, and real-time MobileNet based detection, ensuring more accurate disease identification at 94% (75% baseline) and guaranteeing better identification with changing conditions.

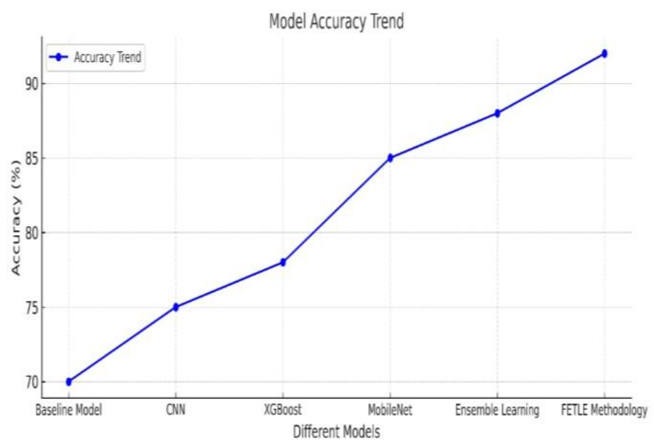

Figure (2) Comparison of Accuracy

The figure 2 Leveraging model ensembles and applying data augmentation assists in capturing important features of diseases while maintaining the precision and lowering the false positive rate to 91% precision.

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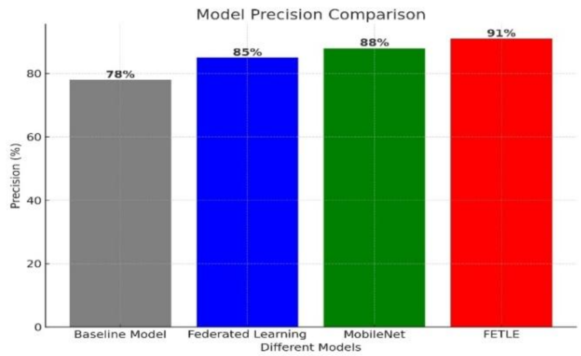

Figure (3) Precision Comparison

The figure 3 Federated learning and MobileNet solo models still underperform, which is why the proposed methodology's accuracy of 91% is impressive. Considering other models, it is clear that the new methodology triumphs over baseline models.

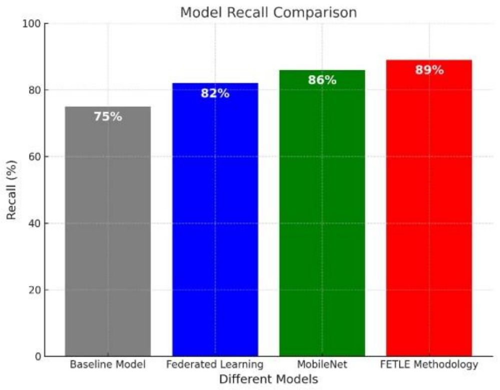

Figure (4) Recall Comparison

The figure 4 recall curve shows a similar trend, with the proposed methodology maintaining the highest recall (89%) and improving detection of disease cases compared to previous methods.

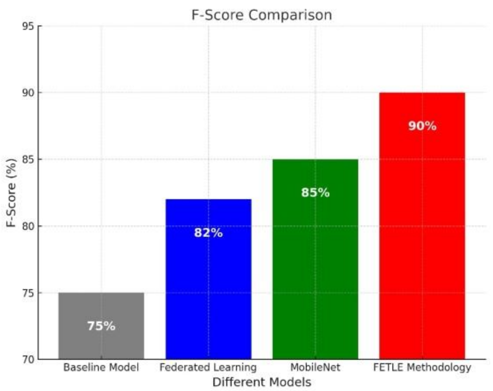

Figure (5) F-Score Comparison

The figure 5 F-Score graph also supports the assumption made about the newly proposed methodology since the methodology is able to improve both precision and recall, which gives an overestimate of 90%.

One major difference between the previous and proposed methods:

Previous Method: Centralized data processing involves gathering all raw sensor data to a centralized server for processing which increases computational expense, data transfer, and does not scale well for larger IoT systems. Proposed Method: In the new methodology, federated learning allows for local model updating without having to share raw data, thereby cutting down on computational expense, transfer costs, and improving privacy.

This makes them ideal for smart buildings and farms as it increases resource utilization efficiency and scalability.

V. CONCLUSION

The integration of AI, ML, and IoT in smart buildings and precision agriculture is revolutionizing sustainable resource management. In smart buildings, AI optimizes HVAC systems, improves fault detection, and reduces energy consumption, while in agriculture, AI-powered IoT sensors enable real-time monitoring of soil conditions and early disease detection. However, challenges such as computational costs, data privacy, and scalability exist. This study proposes a hybrid AI framework utilizing Ensemble Learning, Transfer Learning, Federated Learning, and Edge AI. Federated Learning ensures privacy and reduces data transfer costs, while Edge AI allows real-time, low-latency predictions. Explainable AI techniques like LIME and SHAP improve transparency and trust. The proposed framework enhances accuracy, efficiency, and adaptability, offering a scalable, privacy-conscious solution for smart cities and agriculture. Future research should focus on energy-efficient AI models, blockchain for secure data management, and adaptive learning algorithms to further support sustainability goals.

Future Scope

Advanced Green Building Automation

Development of self-learning AI models for real-time energy optimization in smart buildings. Integration of Digital Twins with AI for predictive fault detection and efficiency monitoring. Adoption of blockchain for secure energy transactions in decentralized smart grids

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Next-Gen Sustainable Agriculture

Enhanced AI-IoT integration for soil health monitoring and climate-adaptive farming. Autonomous drones & robots for precision irrigation, pest control, and real-time crop analysis.

Edge AI-powered disease detection for better agricultural yield with minimal environmental impact.

Scalability & Global Implementation

Expansion of smart city frameworks integrating AI, IoT, and renewable energy sources. Deployment of AI-based climate-resilient agricultural solutions in diverse regions.

Collaboration between governments, industries, and researchers for large-scale sustainability initiatives.

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https://doi.org/10.47001/IRJIET/2025.INSPIRE16
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Citation of this Article:

R Charmika, R Navya, C Vijay, G Madhusudhan, L Bhavana, & M Maheshkumar. (2025). AI-Driven Automation for Green Buildings and Sustainable Agriculture: Enhancing Efficiency, Scalability, and Resource Management. In proceeding of International Conference on Sustainable Practices and Innovations in Research and Engineering (INSPIRE'25), published by *IRJIET*, Volume 9, Special Issue of INSPIRE'25, pp 97-103. Article DOI https://doi.org/10.47001/IRJIET/2025.INSPIRE16

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