

Review Article

# Technological Advances in Bamboo Health Monitoring: A Review of IoT-Based Sensing and AI-Driven Prediction Models

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**Abstract** - Bamboo is a renewable and fast-growing resource that provides a crucial ecosystem service, which supports livelihoods and also contributes to climate change mitigation by means of carbon sequestration. Regardless of its economic and ecological importance, the function of bamboo health and the ecosystem is still understudied comparatively, particularly under increasing pressures from pests, environmental stress, expansion, and overexploitation. The aim of this review is to identify the important health indicators and ecosystem services of Bamboo by exploring IoT and vision-based technologies for monitoring the health of Bamboo and analyzing the application of Machine Learning and Artificial Intelligence for assessment and prediction of bamboo health. The review highlights the recent advances in technologies like remote sensing, camera-based monitoring, and analytics, which are drawn using AI to help in real-time, non-invasive, and scalable assessment of bamboo health. Deep learning and Machine Learning Models notably boost the detection of pests, growth dynamics, and stress. These data-driven and integrated approaches offer an effective decision support for sustainable bamboo management, which strengthens ecosystem resilience and promotes climate-resilient bamboo-based development.

**Keywords** - Bamboo Health Monitoring, Ecosystem Services, Computer Vision, Machine Learning, Sustainable Bamboo Management.

## 1. Introduction

Ecosystem services are the services that can be described as the benefits derived by humans from the ecosystem. Bamboo, a renewable and fast-growing woody grass, provides various ecosystem services, which also include carbon sequestration. However, the services of the bamboo ecosystem remain under-researched, especially in tropical regions, which highlights a necessary need to assess the role of the bamboo ecosystem in sustainable management of forests [1]. Bamboo is increasingly valued as a rapid-growing renewable source with properties similar to wood and potential for erosion control, riparian stabilization, and reforestation. However, the management of Bamboo at a large scale is recent and may lead to invasive risks. Ecological impact assessment is necessary, as the sustainable ecosystems depend highly on native vegetation [2]. Bamboo is a rapid-growing and evergreen grass pivotal to subtropical as well as tropical ecosystems and human economies. Broadly used for industry, food, and construction, it is expanding globally on a rapid scale. This expansion alerts ecological progress, community structure, and soil properties, which raises concerns about intrusive

environmental impacts [3]. Bamboo is a renewable and fast-growing material with growing regulatory acceptance and high mechanical performance in construction. Engineered products like Glulam improves the structural reliability and durability. Regardless of challenges in degradation and joints, the advances in treatments, machine learning, and digital technologies support Bamboo's safe and sustainable use in modern construction [4]. Billions of livelihoods are supported by Bamboo, and it holds a strong potential for sustainable development, but its diverse species have different water needs. It is critical to do efficient management of water. Using IoT, real-time data, and adaptive analytics can help in optimizing water usage and also enhance the productivity of Bamboo and promote climate-resilient and sustainable cultivation of Bamboo [5]. Bamboo is an important economic and ecological resource, and its health directly influences ecosystem functions, long-term sustainability, and productivity. Healthy bamboo forests provide soil stability, livelihoods, and carbon sequestration. Therefore, it is necessary to assess the health of Bamboo Using scientific indicators for improving forest resilience and guiding Sustainable management [6]. Bamboo is a highly



valuable taxon in China, which provides important ecological functions like carbon-oxygen balance, water conservation, and soil protection. Pests like *Pantana Phullostachysae* are increasingly a threat to its health, which can severely kill or damage the bamboo tree. Advanced

technological systems, which are based on remote sensing, help in offering an effective approach for monitoring bamboo health and pest damage accurately and also support sustainable management of the forest [7].

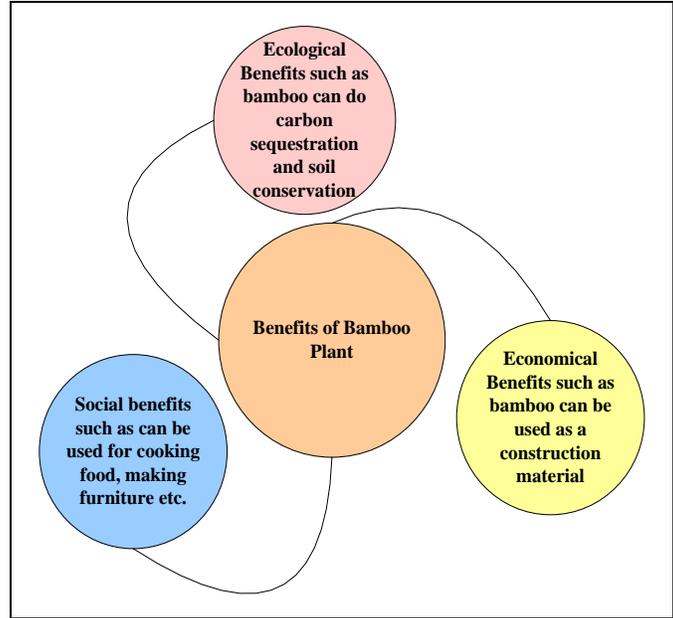


Fig. 1 Showing benefits of bamboo

Bamboo is an adaptable and fast-growing grass that is grown in subtropical as well as tropical regions worldwide. It provides ecological, social, and economic benefits, which include food, carbon sequestration, soil conservation, and construction materials, as shown in Figure 1. Regardless of its potential, there is a requirement for sustainable management that accurately monitors and maps the growth patterns and environmental factors [8]. Bamboo, which is an adaptable grass of the Poaceae family, spans 1,642 taxa across various climates globally. It supports medicine, renewable energy, construction, and food, aids rainforest conservation, and sequesters carbon. With early harvest and rapid growth potential, Bamboo contributes significantly to sustainable development and generates over 2.5 billion USD annually in trade globally [9]. Objectives of the study are as follows:

- To identify bamboo ecosystem services and key indicators of bamboo health.
- To explore IoT- and sensor-based technologies for bamboo health monitoring.
- To analyse AI and machine learning models for bamboo health assessment and prediction.

The manuscript organization of this article contains research methodology in Section 2, Overview of Technological Advances in Bamboo Health Monitoring in Section 3, IoT-Based Sensing Technologies for Bamboo Health Monitoring in Section 4, Artificial Intelligence and Machine Learning Models in Bamboo Health Prediction in Section 5, Recommendations in Section 6, Conclusion in Section 7, as shown in Figure 2.

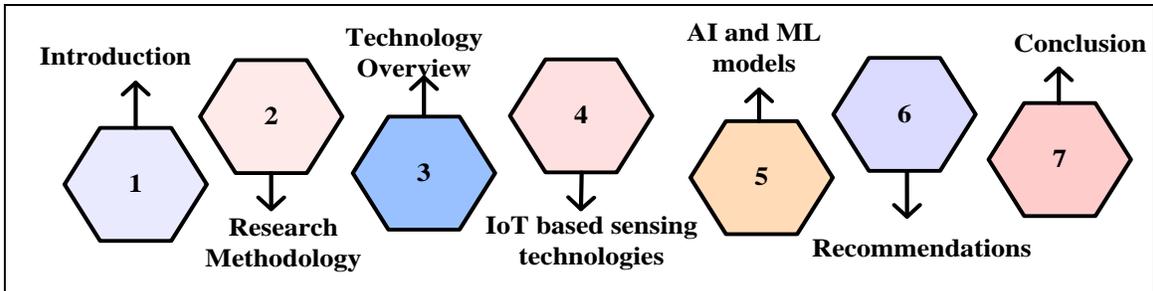


Fig. 2 Manuscript organization

## 2. Research Methodology

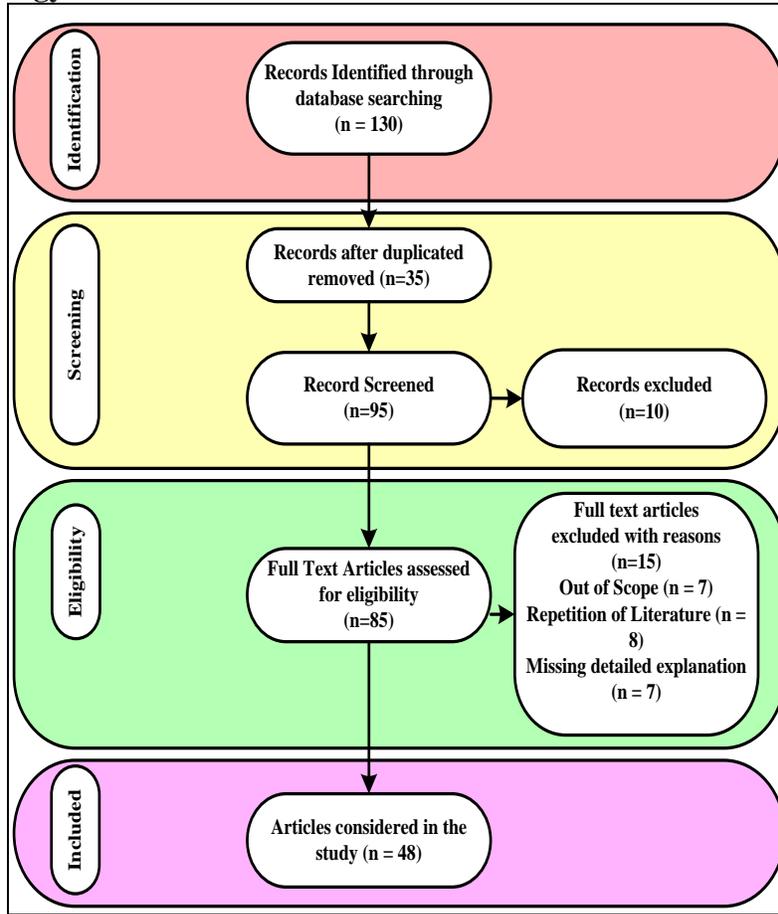


Fig. 3 PRISMA model

At the initial stage, a search across the major scientific databases resulted in 130 downloaded articles, as shown in Figure 3, by using keywords like bamboo health monitoring, sensing technologies, artificial intelligence, and ecosystem services. After removing duplicates, abstracts and titles were screened to assess relevance. Data was taken from renowned publishers like Wiley Online, Springer, IEEE, Elsevier, Sage, Oxford, etc. The articles that are not directly focused on Bamboo and lack analytical or technological components or are outside the review scope were excluded.

Screening of full-text was then conducted for evaluating methodological rigor, relevance to health assessment of Bamboo, and application of image-based techniques, IoT, or AI and machine learning. Based on predefined exclusion and inclusion criteria, only 48 peer-reviewed articles were finally selected for qualitative synthesis. These studies were systematically categorized and analyzed to identify technological approaches, key themes, algorithms used, research gaps, and benefits. This structured process helps in ensuring that only relevant and high-quality studies informed the review while maintaining methodological reliability and consistency.

## 3. Overview of Technological Advances in Bamboo Health Monitoring

The Internet of Things means to connect the physical objects with the internet, which are equipped with connectivity technology, software, and sensors, enabling them to process, collect, and exchange data without direct human intervention or control. The key components of an Internet of Things system include sensors for gathering environmental data from the Bamboo plantation and the connectivity protocol, Such as Wi-Fi, used for transmitting the data, the hardware units are used for processing the data, and the cloud platforms are used for analysis of data. The Internet of things helps in providing real-time monitoring, data aggregation, and decision-making support by providing transformative potential for revolutionising the management of bamboo plantations. It helps in enabling the early detection of stress factors that can affect Bamboo, such as humidity levels, pest infestations, and temperature fluctuation, which helps in providing timely intervention for protecting the health of the bamboo plant [10]. By integrating communication technologies with WSNs i.e. wireless sensor networks, which are connected to the cloud servers, allows fast transmission of data for analysis. Sensors

detect vital parameters like ambient temperature, CO2 emissions, pest presence, and soil moisture. Collective data are then processed by using the microcontrollers for triggering alerts regarding pest or stress outbreaks. Communication modules, such as Wi-Fi, send the notification to managers of the plantation [11]. The systems of the Internet of Things help in ensuring continuous and uninterrupted monitoring of bamboo plants even under hard conditions by integrating the GPS, image processing techniques, and drones, which can improve the accuracy of the systems. Additionally, they are cost-effective, and the real-time alerts are sent via SMS and mobile apps, hence providing a better approach for safeguarding the productivity and plantation of Bamboo [12] as there are threats from invasive pests, environmental changes and water stress to the

bamboo plants, which shows that there is a requirement for early detection crucially. Internet of things networks are equipped with humidity, CO2, and temperature sensors for examining the irregularities across the plantation of Bamboo. Data is transmitted using WSNs to the cloud servers, which are processed by means of microcontrollers and enable the proactive majors. In this way, the technologies of IoT show a future-oriented approach in maintaining the bamboo health and ensures the economic as well as ecological benefits [13]. Bamboo is a major timber forest product that holds economic as well as ecological importance and provides soil stabilisation, income generation, and carbon sequestration for the rural communities. Modern IoT-enabled management practices optimise sustainable harvesting and simplify health monitoring [14].

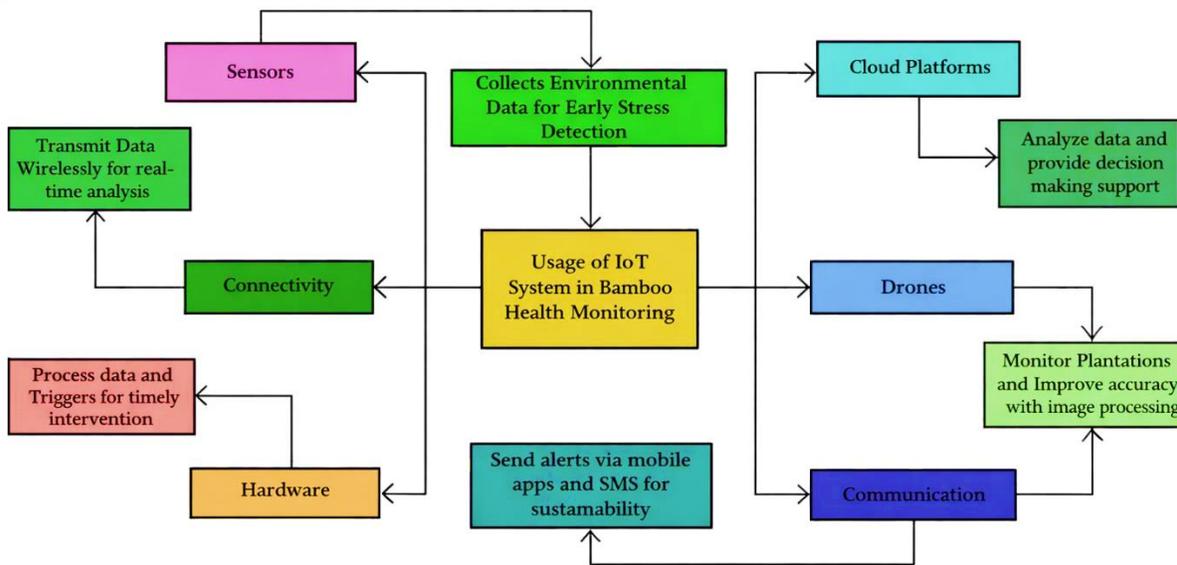


Fig. 4 Use of IoT technologies in bamboo health management

Environmental stress and overexploitation of Bamboo pose a serious risk to the productivity of Bamboo, which plays a critical role in ecosystem functioning. For ensuring the long-term sustainability of Bamboo, there is a requirement for scientific IOT approaches for monitoring environmental interaction, health, and growth while safeguarding the ecological, economic, and social benefits [15]. There is a requirement for a monitoring system that is based on IoT for addressing threats like climate variability, drought, and pests in bamboo plantations [16]. Advancements in smart sensors and IoT technologies in forest and agricultural sciences show their transformative ability for bamboo management, as shown in Figure 4. Integration of wireless sensor networks, cloud computing, data analysis, and radio frequency identification provides monitoring of soil moisture, quality, pest activity, environmental conditions, and bamboo growth. These innovations help in enhancing the operational efficiency, plantation productivity, and resilience against climate unpredictability [17].

#### 4. IoT-Based Sensing Technologies for Bamboo Health Monitoring

For optimising bamboo habitats, a local environmental monitoring system is made by using a Zigbee-based wireless sensor network for enabling long-term monitoring in real time. The system uses gateways, routers, a monitoring centre, and sensor nodes, which allows flexible placement of nodes regardless of geographical constraints. Key environmental parameters like humidity, atmospheric temperature, CO2 concentration, light intensity, and soil moisture content are monitored by using the Zigbee WSN. The data collected by means of these sensors is transmitted using GPRS to a surveillance station for real-time visualisation, analysis, and display [18]. For monitoring the critical parameters such as temperature, pest attack, and soil moisture in bamboo plantations, the systems that are based on IoT improve efficiency notably. The temperature sensor monitors conditions of essential growth, while the soil moisture sensor precisely measures the water content in the

soil and improves the irrigation and growth of the Bamboo. A pest detection sensor, which is installed in bamboo plantations, provides the early identification of the activity of

pests by enabling the timely intervention for improving productivity and minimising damage in bamboo plantations, as shown in Figure 5 [19].

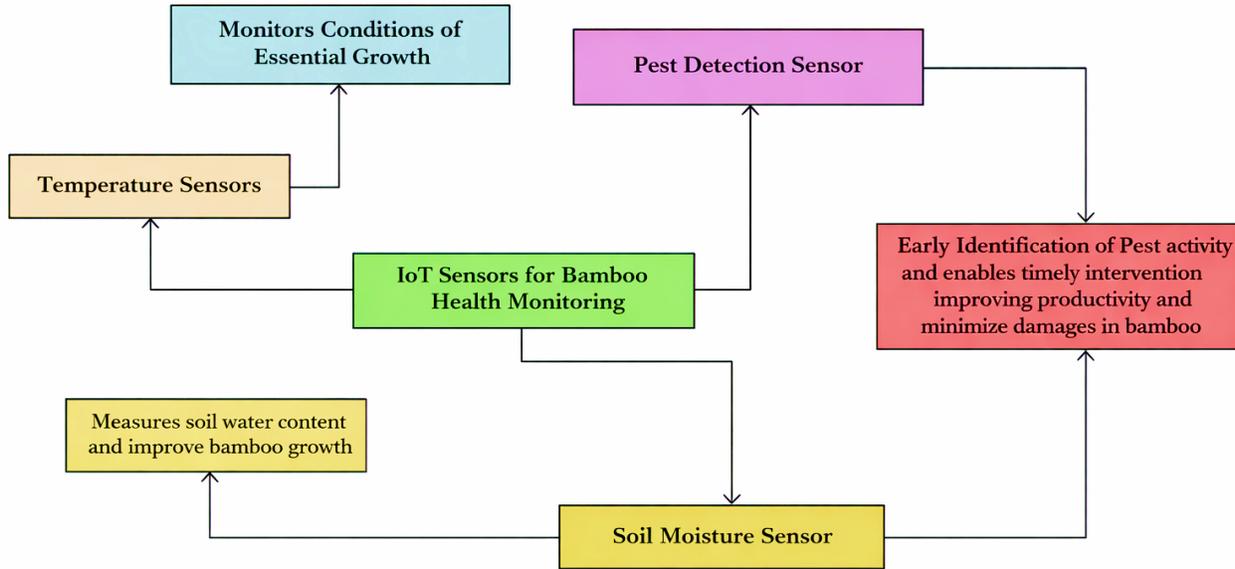


Fig. 5 IoT sensors for bamboo health monitoring

Wireless sensor networks are important for climate-smart bamboo management by enabling the real-time monitoring of the growth of Bamboo, ecosystem health, and environmental conditions. Wireless sensor networks are comprised of interconnected sensors that collect data on air temperature, bamboo physiological responses, and soil moisture. This collected data is then transferred by means of GSM or LoRaWAN to the remote servers for analysis and visualisation. The generalised sensors, such as rain gauges and thermistors, monitor the environmental conditions, while the specialised sensors, such as Sap-flow probes and dendrometers, provide high-frequency data on stress response and bamboo growth [20]. Wireless Sensor Network (WSN) helps in supporting the early warning systems by identifying signs of stress, which include drought or pest outbreaks, which can make a significant impact on the bamboo plantation. The Internet of Things further enhances WSN by using remote sensing technologies for broader coverage of spatial areas while maintaining accuracy. AI techniques and computer vision algorithms like machine learning models, deep learning, and Support Vector Machines (SVM) are transforming the assessment of bamboo health. Bamboo species are classified based on texture and morphological attributes by using the Convolutional Neural Networks (CNN) and ensemble method, such as majority multiclass voting, which helps in getting an accuracy of 96.1% [21]. When the UAV-mounted sensors are integrated with the machine learning models, they provide a promising solution for monitoring Bamboo in real-time. UAVs help in enhancing the precision through hyperspectral and

multispectral imaging, which improves efficiency and accuracy in detecting the health issues of Bamboo [22]. Automatic Diagnosis of bamboo health helps in addressing the issues of stress and pest outbreaks by using aerial imaging, YOLOv5, and modified generative adversarial networks. YOLOv5 provides detection of unhealthy bamboo plants in real time, while MGANs provides additional data for addressing scarcity. Tabu search algorithms are used for identifying the specific areas where the bamboo plants are showing stress signs [23]. Cameras mounted on the drones are used for capturing the images across the plantations of Bamboo, which undergo segmentation and feature extraction. Using the improved algorithm of YOLOv3, images are processed with 95% accuracy and within 0.5 seconds, which enables Fast detection of bamboo health issues [24]. IoT-enabled frameworks play a critical role in monitoring the bamboo ecosystem, as the sensors send the data for predictive analysis. Integration of MQ-series sensors, such as MQ2, MQ4, MQ9, and MQ135, with the IoT-enabled microcontrollers, such as Arduino and NodeMCU, TCP/IP protocols provides efficient analysis and visualisation [25]. Aerial Hyperspectral LiDAR (AHSL) is used for monitoring pests, diseases, and disturbances in bamboo plantations. AHSL captures both spectral and structural data and provides superior accuracy over hyperspectral imaging in identifying the levels of stress in middle and lower bamboo canopy layers. 3D modelling helps in reconstructing virtual scenarios of Bamboo by supporting the advanced bamboo management strategies and simulating disturbances [26].

**Table 1. Advanced monitoring technologies for bamboo ecosystem assessment**

Technology	Purpose / Key Features	Main Parameters	Citation
ZigBee-based WSN	Real-time Bamboo habitat monitoring via WSN and GPRS	Temperature, humidity, pressure, CO <sub>2</sub> , light, soil moisture	[18]
IoT-based monitoring	Efficient irrigation, growth, and pest control	Soil moisture, temperature, pest activity	[19]
Climate-smart WSN	Continuous growth, stress, and ecosystem monitoring	Soil moisture, air temperature, growth indicators	[20]
AI-based species classification	Automated bamboo species identification using CNNs	Morphological and texture features	[21]
UAV + ML monitoring	Precision bamboo health assessment	Multispectral and hyperspectral data	[22]
Automated health diagnosis	Real-time stress and pest detection using YOLO and MGAN	Aerial imagery	[23]
Drone-based detection	Rapid bamboo health analysis using YOLOv3	Plantation imagery	[24]
IoT gas sensing	Environmental monitoring using MQ sensors	Gas concentrations	[25]
AHSL remote sensing	Disease and stress detection using LiDAR	Structural and spectral traits	[26]

### 5. Artificial Intelligence and Machine Learning Models in Bamboo Health Prediction

Artificial intelligence helps in enhancing the environmental monitoring and conservation by analysing the huge data for climate forecasting, ecosystem management and population detection. AI tools, which include sensors, satellite imagery and drones help in enabling the sustainable land use, precise wildlife tracking, predictive modelling and habitat protection by providing data-driven and efficient strategies for a healthier and sustainable planet [27]. Conventional management of forests highly depends on reactive and manual methods which usually struggle with complex challenges such as climate impacts, disease and pests. Machine learning helps in enabling data-driven and proactive management of forests by analysing sensor inventory and satellite data for enhancing long-term forest health and resilience, predicting risk, optimising resource allocation and improving decision-making [28]. Deep Learning, Machine Learning, and Artificial Intelligence help in enhancing the sustainable forest management by enabling forest mapping, predictive analysis, forest monitoring,

biodiversity conservation, carbon stock optimization, and wildfire detection. These technologies use LiDAR, Remote sensing, and satellite data for supporting decision-making, detecting threats, promoting long-term ecological balance, optimizing resources, and climate mitigation [29]. Combining hyperspectral, LiDAR, radar and optical data with machine learning helps in improving above ground biomass estimation and forest monitoring. The algorithms, such as SVM and random forests, use topographic, textural, and spectral variables for enhancing accuracy. Fusion methods increase precision but the challenge remains, which includes computational demands, the need for standardised evaluation, and data costs [30]. A non-destructive method was developed using Machine Learning to evaluate the mechanical performance of Bamboo. Bamboo section images were used for analysis, by using UNet segmentation as per shown in Figure 6 for classifying special feature, texture and frequency extraction. Artificial Neural Networks were used for predicting the elastic modulus and bending strength of Bamboo with high accuracy (R: 0.85–0.89; MAPE: 7.4–11.6%), which shows a stable and precise assessment [31].

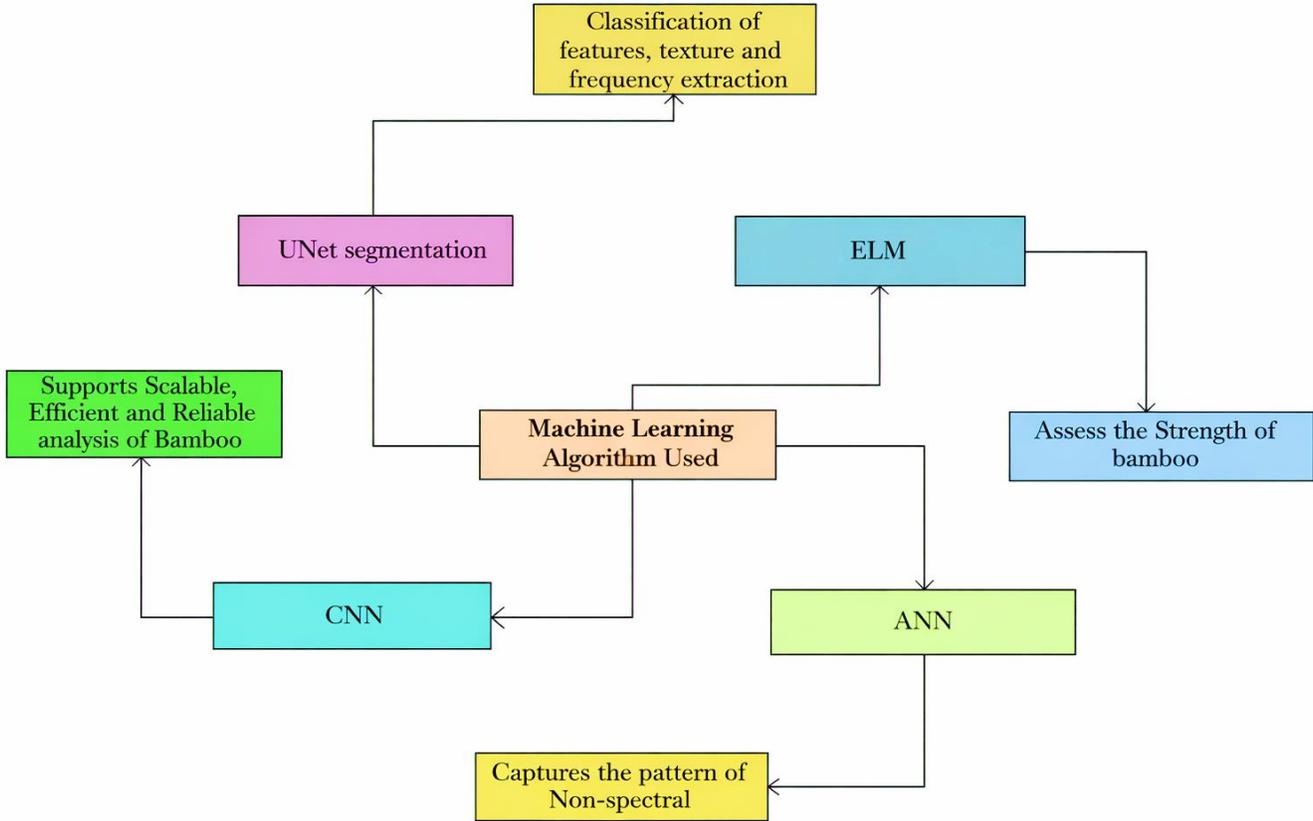


Fig. 6 Different machine learning algorithms used for bamboo health monitoring

A Machine Learning approach was used for predicting the comprehensive strength of Bamboo by using approximately 150 samples, considering the characteristics like cross-sectional area, density, and culm thickness. Among SVR, ELM, and ANN algorithms, the highest accuracy was shown by the ELM algorithm ( $R^2$ , MSE, RMSE, MAE, MAPE), hence providing a reliable and precise method for assessing the strength of Bamboo as shown in Table 2 [32]. Machine learning is used in Bamboo cultivation for enhancing irrigation by analysing real-time temperature, humidity, and soil moisture data. Machine learning models help in predicting how much water is needed for Bamboo by analyzing the data related to weather and growth stages, and these models also help in doing precise agriculture of Bamboo by optimizing the health and yield of Bamboo. These models support sustainability via data-driven and species-specific water management [33]. Machine learning helps in studying how the bamboo Composite walls react to the heat by analysing the monitoring data related to temperature, moisture, and humidity content. Artificial Neural Networks help in predicting the damage to the wall and the ambiguities in design. They also help in predicting the complex non-linear transfer patterns, optimise the wall design, and assess the potential damage. Reservoir and clustering computing techniques pattern optimizes the time-series analysis by enabling evaluation, which is data-driven,

for energy-efficient and sustainable bamboo-based building envelopes [34]. He et. al. 2025 in their study used machine learning models such as random forest, ID-CNN, XGboost and SVM for analysing the bamboo canopy spectral data. The results demonstrated that considering the differences in growth stages of Bamboo helps in improving how accurately the models of machine learning detect the damages caused by pests and prove that Machine Learning is effective for assessing the health of Bamboo [35]. At the same time, the Machine Learning Models combined with recursive feature removal were applied for classifying Bamboo using the features related to hyperspectral. The comparisons among the random forest, XGboost, and SVM showed that XGboost is highly accurate and generalized. This shows the effectiveness of ensemble learning and feature selection for precise identification of bamboo resources [33]. Machine learning enables data-driven analysis of bamboo behaviour, performance, and properties. Models such as ensemble learners, Support Vector Machine, and Neural Networks help in extracting patterns from the provided data sets and help improve decision-making, predictions, and classification for the bamboo material applications and processing with reliability consistently [36]. Linderman et al. (2004) in their study showed the use of Artificial Neural Networks for mapping understory bamboo from the data of Landsat remote sensing. In spite of the complex interaction of canopy, the

Neural Network has achieved about 80% accuracy in classifications, which suggests that Machine Learning is capable to capture the patterns of non-linear spectral and reliably mapping the distribution of Bamboo Spatial [37]. Deep learning and Machine Learning help in enabling the automated identification of bamboo species by using the

texture, morphological features, and image data. Models such as transfer learning, SVM, and CNNs effectively collect complex visual patterns, while assembly strategies like majority multiclass voting helps in improving the classification accuracy effectively and also support scalable, efficient, and reliable analysis of Bamboo [38].

**Table 2. Machine learning applications in bamboo assessment and management**

Application Area	ML Methods Used	Key Inputs / Features	Main Outcomes	Citation
Mechanical performance prediction	ANN, UNet segmentation	Image-based texture, frequency, and spatial features	Accurate prediction of elastic modulus and bending strength	[31]
Compressive strength assessment	ANN, SVR, ELM	Culm thickness, density, cross-sectional area	ELM showed the highest accuracy for BCS prediction	[32]
Precision irrigation management	ML predictive models	Soil moisture, temperature, humidity, and weather data	Optimized irrigation, improved yield, and sustainability	[33]
Hygrothermal performance analysis	ANN, clustering, reservoir computing	Temperature, humidity, and moisture content	Damage assessment and optimized bamboo wall design	[34]
Pest-induced health detection	SVM, RF, XGBoost, 1D-CNN	Canopy spectral and phenological data	Improved pest stress detection accuracy	[35]
Bamboo species classification	SVM, RF, XGBoost + RFE	Hyperspectral features	XGBoost achieved the highest classification accuracy	[33]
Material behavior analysis	ANN, SVM, ensemble models	Physical and mechanical datasets	Reliable prediction and decision support	[36]
Spatial mapping of Bamboo	ANN	Landsat remote sensing data	~80% accuracy in understory bamboo mapping	[37]
Automated species identification	SVM, CNNs, transfer learning, ensembles	Image, texture, morphological features	High-accuracy, scalable bamboo identification	[38]

Machine learning helps in enabling the fast characterization of the bamboo plant by using the data from spectrometry. Machine learning models, which include the random forest, support vector machines, and discriminant analysis, learn the complicated patterns related to spectral data after feature selection and preprocessing. SVM shows the highest accuracy and provides robust, scalable, and non-destructive identification of bamboo species for industrial applications and quality assessment, as shown in Table 3 [39]. Automated monitoring of Bamboo is enabled by machine learning through the deep neural networks for the detection of objects. An optimised model, which is YOLO-based, was used for accurately counting the bamboo shoots and also tracks the pixel level height growth from fixed images by achieving robust performance and low errors.

This shows real-time and scalable Machine Learning solutions for the analysis of bamboo growth [40]. When Machine Learning is combined with the hyperspectral data, it enables the practical analysis of the health of Bamboo. Algorithm like LightGBM helps in analyzing the physiological as well as spectral features of Bamboo for classifying the severity by past damage. The results showed that declining nitrogen and chlorophyll with stress boosts,

getting valid classification accuracy, and also showed the potential of data-driven monitoring of bamboo health [41].

Artificial Intelligence supports advanced bamboo research through Neural Networks, Data Analytics, and Machine Learning. Artificial Intelligence helps in enabling the efficient analysis of characteristics of bamboo species classification and prediction of machine performance evaluation of growth and applications. These data driven approaches help in enhancing the decision-making, scalability, and accuracy in sustainable utilisation of Bamboo [42]. Advanced bamboo monitoring is enabled by using Artificial Intelligence, which integrates the sensor data with algorithms of Machine Learning.

Artificial Intelligence-driven analytics can assess stress, health conditions, physiological responses, and the growth of Bamboo in real time. Such intelligent systems help in improving automation, decision-making and accuracy for sustainable bamboo utilisation and management [43]. Machine Learning Models help in analysing the bamboo patterns of spectral for identifying health and damage differences across the cycles of growth. Algorithm such as Gradient Boosting, Neural Networks, and Support Vector Machines helps in improving the condition detection of

Bamboo by accounting for phenological variation and selecting important features by enabling monitoring of bamboo forest sustainability [35].

Zhang et al., in their study, used a mega-scale vision data set with 60M images and 28M bounding boxes of Bamboo. By using active learning with OOD rectification they filtered uninformative data and ensured high-quality, in-distribution samples. The labels were validated by human-machine synergy. Pre-trained models got superior detection

performance and classification, which made Bamboo scalable, efficient, and information-dense [44]. Kim et al. in their study demonstrated that bamboo-based conductive fibres can be analysed effectively by using machine learning algorithms. ANN and CNN models can help in predicting accurately the electrical resistance, which helps in improving the strength, sustainability and conductivity of Bamboo. This supports the development of eco-friendly materials using Bamboo for environmentally responsible and smart manufacturing [45].

**Table 3. Artificial intelligence and machine learning applications in bamboo classification, monitoring, and materials research**

Domain of Application	AI/ML Techniques	Data Modality	Key Scientific Outcomes	Citation
Bamboo shoot classification	SVM, RF, discriminant analysis	Spectrometric signatures	Robust, non-destructive species and quality discrimination with high classification accuracy	[39]
Automated shoot detection and growth dynamics	Optimized YOLO-based DNNs	Time-series RGB imagery	Accurate shoot enumeration and pixel-level height growth estimation under field conditions	[40]
Health status and pest severity assessment	LightGBM	Hyperspectral and physiological traits	Reliable classification of pest-induced stress and health degradation	[41]
AI-enabled bamboo research and utilization	ML, ANN, data-driven analytics	Multisource bamboo datasets	Enhanced prediction, classification, and decision support across bamboo applications	[42]
Intelligent real-time bamboo monitoring	Sensor-integrated ML systems	Growth, physiological, and stress indicators	Automated, high-accuracy assessment supporting sustainable management	[43]
Spectral phenology-aware health monitoring	SVM, gradient boosting, neural networks	Spectral and phenological features	Improved detection of damage across growth cycles	[35]
Large-scale vision dataset development	Active learning, pre-trained DL models	69M images, 28M bounding boxes	High-quality, scalable dataset enabling superior classification and detection performance.	[44]
Smart bamboo-based materials	CNN, ANN	Electrical and mechanical property data	Accurate prediction of sheet resistance and optimized sustainable material performance	[45]

**6. Recommendations**

We recommend a vision-based system for monitoring the health of Bamboo. The system consists of Raspberry Pi at its centre as a processor. A camera is attached to the Raspberry Pi to collect vision-based data, as shown in Figure 7. There is a camera on/off sensor that will automatically switch on and off the camera, which helps in saving energy. There is SD card attached with raspberry Pi which will store data locally. A Neural stick is attached to the system. They have attached a TFT screen, keyboard, and mouse for operating the system at the local level. The system has Wi-Fi connectivity. The system is powered by a battery which is

connected to a battery management system and a solar panel which makes the system work in low resource areas and also makes the system sustainable. Our recommended system can be installed on poles for precise monitoring of bamboo health, as shown in Figure 8. Working principle of the vision-based system is as follows: the system, when inclined on the poles, will collect the image data of the bamboos and then, by using the Wi-Fi module, will send the data to the cloud storage, where the preprocessing will take place, which will extract, remove, add the data if required for analysis, and will make the datasets. Then the dataset will be fed to the machine learning module, which is already pretrained by the

existing data of Bamboo. The Machine Learning Module will then analyse the data and predict the health of Bamboo,

which will be shown on the mobile application as well as the web interface.

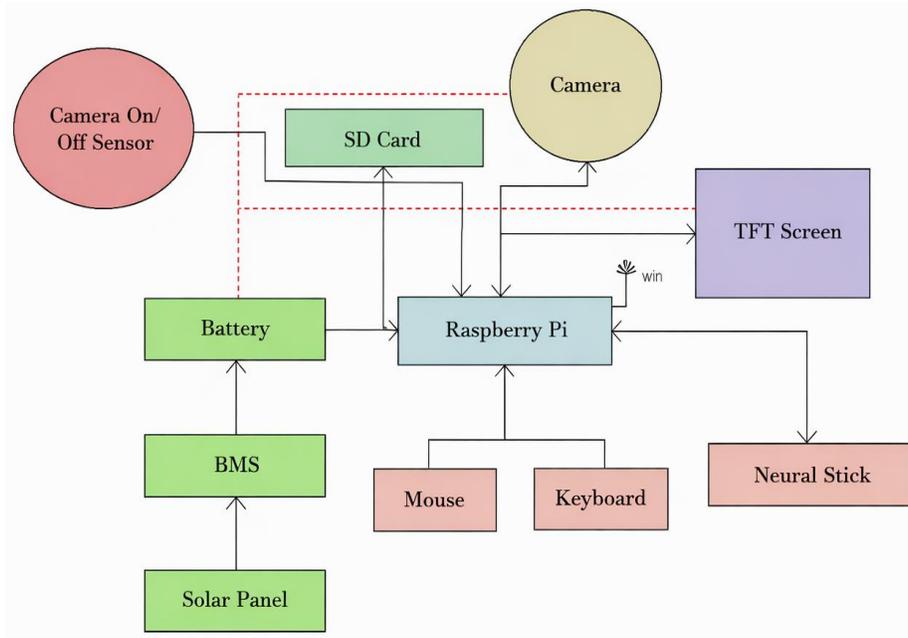


Fig. 7 Bamboo health monitoring system

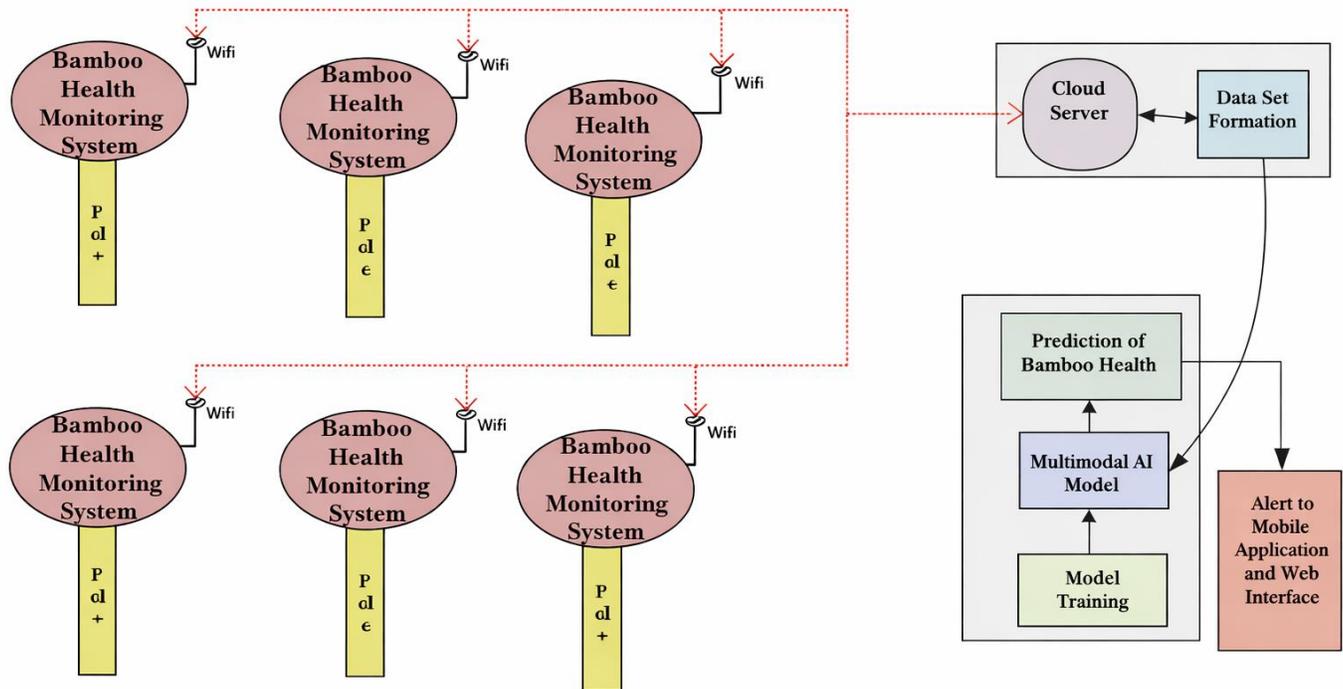


Fig. 8 Overall architecture

## 7. Conclusion

This review highlights the importance of Bamboo as a sustainable and multifunctional resource that plays an important role in supporting rural livelihoods, climate change mitigation, and ecosystem services. Due to its increasing utilization, fast growth and increasing utilization bamboo

ecosystems are exposed to different challenges, which include climate variability, environmental stress, and biotic disturbances such as diseases and pests. Hence, due to these pressures, there is a need for a non-invasive, reliable, and efficient approach to bamboo health monitoring and

assessment. Recent advances in technologies, which include Wireless Sensor Network (WSN), IoT-enabled monitoring systems, computer vision and remote sensing have greatly improved the capacity for observing the conditions of Bamboo at large temporal and spatial scales. Furthermore, integration of Machine Learning and Artificial Intelligence has improved evaluation of bamboo health by providing early stress detection, predictive analysis and automated classification of species using spectral, sensor and vision data. Cloud-supported and Vision-based monitoring systems help in reducing dependency on labour-intensive field surveys and also reduce the human error while providing

real-time decision support. Together these innovations provide a strong foundation for optimized resource use, precision bamboo management, ecosystem resilience, promoting timely intervention and sustainable bamboo utilization and conservation in a changing climate.

### Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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