Chapter 2
Internet of Things for Building a Smart and Sustainable Environment: A Survey

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ABSTRACT

In the previous decade, internet of things (IoT) has emerged as a transformative force in the quest to create smarter and more sustainable environments. By interconnecting a large array of sensors, devices, and infrastructure, IoT technology enables the real-time collection, analysis, and utilization of data to optimize resource management, improve decision-making, and reduce environmental impact. In smart cities, homes, industries, and agricultural settings, IoT plays a pivotal role in achieving resource efficiency, environmental preservation, and economic growth. However, its widespread adoption also poses several challenges related to privacy, security, and interoperability. As IoT continues to evolve, it promises to shape a future where sustainability and technological innovation go hand in hand, making a path toward more resilient, efficient, and livable environments.

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1. INTRODUCTION

1.1 IoT Fundamentals: Definition, Key Components, IoT Communication Protocols for IoT Systems

The "Internet of Things" (IoT) is a system of networked computing devices, software applications, and physical objects that may collect and share data across various communication networks, such as the internet (Atzori, L., Iera, A., & Morabito, G. 2010) (Al-Fuqaha, A., Guizani, M., et al., 2015). Connecting everyday objects online so they may exchange data, make autonomous decisions, and share their experiences with humans and other systems is what the Internet of Things (IoT) is all about. Internet of Things systems rely on the following key components:

- Physical devices that either collect data from the environment (sensors) or perform actions in the environment (actuators) are known as actuators and sensors, respectively. Sensors can also be motors, temperature sensors, or motion detectors.
- Connection: IoT devices use a wide range of communication protocols to share data with one another, with other mobile devices, and with the cloud. Some popular networking methods include Bluetooth, cellphone networks, Internet Protocol (Wi-Fi), LoRaWAN, and Zigbee.
- Data processing: Many IoT devices can process data in some way, allowing them to analyze data and perform preprocessing before sending it to a cloud service or another device. Examples of this include basic analytics, filtering, and aggregation.
- Data Storage, Processing, and Analysis on the Cloud: Most Internet of Things (IoT) systems rely on cloud computing platforms to handle massive data sets. The scalability and flexibility provided by cloud services are ideal for applications that operate on the Internet of Things.
- The Internet of Things (IoT) generates vast amounts of data, which need efficient data storage. Databases, data warehouses, or storage systems like Amazon S3 are the most common ways to achieve this purpose.
- Machine learning and advanced analytics may glean useful insights from data collected by the Internet of Things (IoT), paving the way for optimization, anomaly detection, and predictive maintenance.
- User Interface: Apps or dashboards let end-users interact with IoT systems; these provide them access to data in real-time, let them operate devices, and display insights visually.

Communication Protocols for IoT Systems

There are a number of different communication protocols that IoT devices use to share data with one another (Zanella, A., Bui, N., et al., 2014) (Gubbi, J., Buyya, R., et al., 2013). Several factors, including as the data payload, the device's power limitations, and range requirements, dictate the protocol choice. Here are a few examples of common protocols used for communication in the Internet of Things:

- Low-power devices and unreliable networks are ideal for the lightweight publish-subscribe protocol known as Message Queuing Telemetry Transport (MQTT). The Internet of Things frequently makes use of it due to its efficacy and little overhead.

- Internet of Things devices with more computing power and reliable network connections typically use HTTP/HTTPS. We use RESTful APIs that are HTTP-based to exchange data with web services.
- The "Constrained Application Protocol," or CoAP for short, is a protocol that is comparable to HTTP but optimized for UDP and made to operate on limited networks like LPWANs. Its original intent was to serve low-power Internet of Things gadgets.
- The Advanced Message Queuing Protocol (AMQP) is a good option when reliable device-to-device connectivity and message delivery are critical. It is common practice to use AMQP in industrial Internet of Things applications.
- Internet of Things (IoT) applications that are mission-critical, scalable, and run in real-time utilize Data Distribution Service (DDS), a middleware standard. Industrial and healthcare settings are two examples of where this standard shines.
- Low-power wide-area network (LoRaWAN) communication is possible. Among other things, it's most often used for IoT devices in smart cities and farms.
- Designed for use in industrial control systems and home automation, Zigbee is a protocol for short-range communication. Built specifically for this purpose, it is low-power and has a low data rate.
- Internet of Things (IoT) applications that often utilize Bluetooth Low Energy (BLE) include smart home devices, beacons, and wearables.
- The Internet of Things (IoT) relies on cellular communication technologies such as LTE-M and NB-IoT (Narrowband Internet of Things). Applications like asset monitoring and smart metering benefit from these standards' broad reach and stability.
- Which communication protocol is best for your Internet of Things application will depend on its specific requirements and constraints, including battery consumption, range, and network infrastructure.

1.2 IoT Security and Privacy Issues in Smart Environment

When it comes to the design and implementation of Internet of Things (IoT) systems, security and privacy are essential considerations (Vermesan, O., & Friess, P. (2014). This is especially true in smart environments, where a large number of networked devices gather and communicate sensitive data by themselves. Important concerns about privacy and security that are unique to smart environments include as follows:

Security Issues:

- Control access to data and other devices on the network and ensure that only permitted devices may join.
- Establish strong authentication procedures, using digital certificates or authentication based on tokens, among others.
- Both the transmission and storage of data should be encrypted to avoid unauthorized access and eavesdropping.
- Data at rest should be encrypted, and data in transit should employ secure communication protocols like TLS and SSL.
- You may isolate mission-critical devices from non-critical ones by segmenting the network.

- Firewalls, intrusion detection systems, and intrusion prevention systems are suggested with the aim of keeping an eye on and warding off potential dangers to a network.
- In order to fix any known vulnerabilities, it is recommended that software and firmware on IoT devices be updated regularly.
- It is advised to use a secure updating technique to prevent unauthorized changes.
- In situations involving critical infrastructure and industrial settings, be sure that equipment have sufficient physical protection.
- Make sure that devices can't be accessed or manipulated by unauthorized individuals.
- Establish a role-based access control mechanism to restrict users' ability to access and modify the device's settings and data.
- The idea of least privilege should be put into place to decrease the attack surface.
- It is necessary to set up monitoring systems in order to detect any questionable activities or security breaches.
- An incident response strategy can help you deal with security incidents quickly.

Privacy Issues

- Only gather data that is absolutely necessary for the intended purpose to reduce the possibility of privacy infringement.
- Data anonymization or pseudonymization protocols should be put in place to safeguard user identity.
- Users' unambiguous and informed permission is essential prior to data collection and processing.
- Make transparent and easily understood privacy policies available, detailing how data is collected, used, and shared.
- Incorporate user-defined permissions so they may manage who can access their data and when.
- It is critical to provide channels by which consumers may revoke consent and have their data erased.
- Protect user information from unwanted access by encrypting it both during transmission and storage.
- Make it possible for users to choose the quantity of data that may be shared and prevent data collecting on Internet of Things devices.
- Establishing guidelines for data deletion and retention will ensure that records are not stored for longer than necessary.
- It is important to be wary of sharing personal information with unaffiliated third parties without first verifying that they have adequate privacy protections in place.
- Build privacy issues into Internet of Things technology design and development from the start.
- The General Data Protection Regulation (GDPR) in Europe and the California Consumer Privacy Act (CCPA) in California are two examples of relevant privacy regulations that must be followed.
- It is important to educate users about the risks to their privacy and how to make the most of Internet of Things devices in a smart home.

To win over users' trust and guarantee the sustainable success of IoT installations in smart environments, it is crucial to address their privacy and security concerns (Dohr, Modre-Osprian, et al., 2010) (Jara, A. J., Zamora, M. A., & Skarmeta, A. F. 2014) (Atzori, L., & Santis, A. D., 2017) (Rekha G.,

Tyagi A.K., Anuradha N., 2020) (Nair M.M., Kumari S., Tyagi A.K., 2021). To keep up with the ever-changing security threats and privacy regulations and adapt your approach accordingly, it is necessary to be informed.

1.3 Definition, Evolution, Benefits, and Challenges of Smart Environment

(11, 12) Modern technology, sensors, data analytics, and networking are the building blocks of a "smart environment," which aims to enhance environmental sustainability, efficiency, and quality of life. Houses, businesses, communities, and even factories can be considered smart settings. The goal of creating intelligent settings is to improve resource utilization while simultaneously improving human well-being and experiences through the use of data collected, processed, and acted upon by various forms of information and communication technology (ICT).

- Making Intelligent Environments a Reality: There has been a lot of progress in the concept of intelligent settings throughout the years:
- Home automation systems that managed temperature, lighting, and security were the first kind of smart environments. A different name for smart environments was "home automation." The sole parts of these systems were a remote control and some basic sensors.
- The proliferation of IoT-related technologies has resulted in the widespread installation of sensors and other devices in both suburban and city dwellers' homes. This made it possible to automate operations and gather data in real-time, leading to smarter and more responsive environments.
- Analytics and Big Data: Smart environments are starting to employ data-driven insights to make better decisions and run more efficiently thanks to the growth of data analytics and big data technology.
- AI and machine learning have played a pivotal role in creating smart environments that are more intelligent and flexible. They provide capabilities like predictive analytics, personalization, and autonomous decision-making.
- Energy Efficiency and Sustainability: Utilizing technologies like smart grids, energy management systems, and renewable energy sources, smart environments have been increasingly focused on energy efficiency and sustainability.

Using intelligent technology to enhance public services, transportation, infrastructure, and healthcare is what "smart cities" are all about. Improving residents' quality of life and encouraging economic growth are two main objectives of smart city initiatives.

Benefits of Smart Environments

- Smart environments enhance the quality of life of their users and occupants by including aspects that make life more convenient, comfortable, and safe. These components include healthcare monitoring, intelligent transportation, and home automation.
- Resource Efficiency: By optimizing the use of energy, water, and transportation, these settings minimize waste and their environmental impact.
- Security and reaction times in an emergency are both enhanced by smart environments' real-time monitoring and alerting. An atmosphere of increased safety and security is the result of this.

- Relying on Data for Decisions: Better outcomes in domains like healthcare and urban planning are achievable as a consequence of data analytics and AI-powered more efficient decision-making.
- Through reduced energy consumption, reduced pollution, and promotion of environmentally friendly behaviors, smart environments foster sustainability.
- Financial Benefits: They can create new industries and jobs related to technology development, installation, and maintenance, which can boost the economy.

Challenges of Smart Environments

Security and Privacy: Hackers and data breaches are real problems due to the massive volumes of data collected in smart environments (Nair, Tyagi, Amit Kumar, 2021) (Amit Kumar Tyagi, 2022) (M. M. Nair, A. K. Tyagi and N. Sreenath, 2021).

- The capacity of various smart devices and systems to connect with one another without issues is a major concern when it comes to interoperability. This is due to the fact that these devices and systems employ various protocols and standards.
- Data Management: Reliable data management and storage solutions are essential for efficiently handling and analyzing the massive volumes of data generated by smart environments.
- Costs: Intelligent technology deployment and upkeep can be expensive, and the returns on investment aren't always good enough to cover them.
- Not every area has access to the necessary infrastructure to support smart settings, which means that reliable and fast connections are not always available.
- Ethical dilemmas may arise from the use of data and monitoring, and it can be challenging to comply with regulations like data protection laws. Problems like this are known as ethical and regulatory difficulties.
- A "digital divide" exists when some groups of people do not have the same opportunities to benefit from smart environments, which might lead to unintended consequences.
- Although there may be environmental impacts associated with the production and disposal of electronic devices, smart settings are made to promote sustainability.

Careful planning, innovation, and ongoing efforts to address privacy and security concerns while simultaneously ensuring equal access and its long-term viability are necessary to strike a balance between the advantages and disadvantages of smart settings.

1.5 Smart and Sustainable Environment

The term "smart and sustainable environment" is used to describe the combination of eco-friendly practices, data-driven insights, and advanced technology in the context of building environmentally responsible, pleasant, and efficient living spaces. These environments aim to lessen people's harmful effects on the planet while simultaneously raising their standard of living. The following are the essential components of an intelligent and long-term ecosystem:

- Saving Energy: Modern, eco-conscious places prioritize energy-saving measures and products like smart thermostats, energy-efficient appliances, and LED lights. Renewable energy sources,

including solar panels and wind turbines, are often considered while trying to reduce reliance on fossil fuels.

- Resource Conservation: In these types of landscapes, the focus is on lowering water usage with the help of smart irrigation systems and low-flow plumbing fixtures. On top of that, they push for less trash, more recycling, and eco-friendly items in construction and daily life.

Building smart and sustainable environments requires intelligent infrastructure. Modern infrastructure and careful city planning are equally crucial. Reduced energy usage and better congestion are two side effects of smart grids, efficient public transportation systems, and optimum traffic management (Tyagi A.K., Fernandez T.F., et al., 2021) (Goyal, Deepti & Tyagi, Amit. 2020).

- Intelligent and environmentally friendly structures are constructed with a focus on green construction practices. Among these ideas are well-insulated walls, enough windows to let in natural light, and energy-efficient HVAC systems. With the help of smart sensors and automation, we can manage our energy usage and the indoor air quality.
- Managing trash: Smart systems for managing trash employ sensors to track how full each bin is, which in turn optimizes collection routes and reduces fuel use. Programs for recycling are also encouraged.
- Electric vehicles (EVs), bike-sharing programs, and well-functioning public transportation systems are all examples of sustainable mobility options that may help reduce pollution and gridlock. Transportation may be made more efficient with the help of smart transportation.
- Using Data to Draw Conclusions: In order to improve urban planning, foresee maintenance needs, and make the most efficient use of resources, data collected and analyzed via sensors, IoT devices, and other sources is crucial.
- Green roofs, parks, and urban forests are just a few examples of urban green spaces that may enhance an area's aesthetic value while simultaneously benefiting the air quality and residents' health.
- Smart services, remote work, and digital communication are made possible by the infrastructure for high-speed internet and connection, which in turn decreases the need for physical travel and the quantity of resources utilized.
- Community Involvement: Getting the residents and communities involved in sustainability initiatives fosters a sense of shared duty and empowerment. Awareness campaigns and educational activities promote the use of sustainable practices.
- Resilience: In light of the fact that climate change will inevitably bring about more frequent and severe weather events as well as higher sea levels, smart and sustainable environments prioritize resilience. Important parts include making plans to deal with floods and other disasters and putting those plans into action.
- Regulatory Backing: Government policies and regulations often play a big role in sustainability efforts. Renewable energy subsidies, pollution reduction targets, and building codes are all part of these policies and laws.
- The Circular Economy: This economic model seeks to minimize waste by promoting the repurposing of goods and components via processes such as refurbishing, recycling, and reusing.

- Possibility from an economic perspective Many people believe that sustainable and forward-thinking business methods will pay off in the end. This is because they may improve resource management and reduce energy usage, two factors that can lead to financial savings.

To create an intelligent and sustainable environment, it is essential that individuals, communities, companies, and governmental authorities work together. Responsible resource management and technological innovation are key components, as is a shared commitment to preserving and improving the world for the sake of future generations.

1.5 Scope, Background, and Motivation for a IoT Device-Based Smart and Sustainable Environment

An ambitious and very relevant modern attempt is the use of Internet of Things devices to build an intelligent and sustainable environment. The following will go over the scope, background, and reasons for using solutions based on the Internet of Things in smart and sustainable environments. An Internet of Things (IoT) smart and sustainable environment includes many aspects of modern life and city planning and has numerous potential uses. The following are included:

- "Smart Homes" refer to dwellings that make use of sensors and Internet of Things (IoT) gadgets to enhance comfort, security, and efficiency. In this group you'll find home automation systems, smart appliances, lighting controls, and thermostats.
- "Smart Cities" refer to metropolitan regions that have integrated intelligent technology to improve resource utilization, reduce environmental impact, and raise the standard of living for all residents. Everything from smart mobility to smart waste management to smart energy grids to smart public service delivery technologies falls under this category.
- Industrial Internet of Things (IIoT) refers to the use of IoT devices in manufacturing and industrial settings to increase efficiency, decrease waste, and track and fix machinery and equipment.
- Optimization of crop yields, smart irrigation, soil monitoring, and animal management are all aspects of precision agriculture that make use of Internet of Things (IoT) sensors. This is known as AgriTech, or agricultural technology.
- Medical equipment management, remote patient monitoring, and telemedicine are all made possible with the integration of Internet of Things devices into healthcare systems.
- Through the use of sensors, environmental monitoring tracks variables such as air and water quality, weather patterns, and natural resource availability. This data may then be utilized to advocate for better environmental protection measures.
- Academic and Scientific: The integration of IoT-based technologies into academic and scientific institutions for the aim of automating labs, developing "smart classrooms," and collecting data.
- The following is the context: Several significant advancements, such as the Internet of Things (IoT), are the foundation of smart and sustainable environments.
- Advances in the Internet of Things: Many industries are now able to deploy large-scale Internet of Things solutions thanks to the rapid evolution of Internet of Things technology, which includes cheaper sensors, many connection possibilities, and edge computing.
- Rising awareness of environmental issues such as pollution, resource depletion, and the effects of urbanization has led to calls for greener lifestyle choices and approaches to city planning.

- Technological Convergence: New innovations in areas such as cloud computing, data analytics, AI, and communication have enabled the development of intelligent systems capable of observing, analyzing, and improving intricate environments.
- Motivating factors: Smart and sustainable environments are driven by the installation of Internet of Things devices for several compelling reasons:
- Resource Conservation: Solutions based on the Internet of Things have the ability to significantly reduce resource use, which encompasses the utilization of materials, water, and power. There could be financial and ecological benefits to this.
- Environmental Protection: By tracking and lessening the effects of certain actions on the environment, technologies based on the Internet of Things help to preserve ecosystems and reduce pollution.
- Life Quality: Smart environments enhance the overall health, safety, and convenience of its residents, which boosts their life quality. One example is the reduction in travel time and air pollution that intelligent transport systems provide.
- Individuals, companies, and governments often get financial rewards as a result of energy efficiency and sustainability practices. Reduced energy bills and operational expenditures are the outward manifestations of these advantages.
- Among the many ways in which IoT technologies can make communities more resilient is by providing real-time data that may be used for catastrophe prediction, response, and recovery.
- Health and Healthcare: Healthcare solutions built on the Internet of Things allow for remote monitoring and better access to healthcare, which might lead to better health outcomes and cheaper healthcare costs.
- Innovation, economic growth, and worldwide competitiveness are all boosted by implementing sustainability solutions built on the Internet of Things.
- A lot of countries and regions are implementing regulations and incentives to promote sustainability and energy efficiency, therefore it's important to comply with these. Organizations may satisfy these criteria and ensure compliance with the help of technologies based on the Internet of Things.

Thus, the pressing desire to resolve environmental issues, enhance quality of life, and capitalize on technological advances is driving the introduction of solutions based on the Internet of Things in smart and sustainable settings. These initiatives may promote sustainability and resilience in the face of global challenges while also having the possibility to change our daily lives, at work, and in our interactions with the environment.

1.6 Organization of the Work

This work has been summarized in 9 sections.

2. IOT APPLICATIONS IN SMART AND SUSTAINABLE ENVIRONMENTS

In order to build and keep intelligent and sustainable ecosystems, Internet of Things applications are crucial (Tyagi, Dananjayan, et al., 2023) (Tyagi, Swetta, et al., 2022) (Tyagi, A.K., Bansal, R., Anshu, Dananjayan, S. 2023). In order to improve resource efficiency, enhance quality of life, and lessen envi-

ronmental impact, these applications utilize internet-connected electrical devices, sensors, data analytics, and automation. Important uses of the Internet of Things in environmentally conscious and intelligent environments include:

- Smart thermostats and other energy-efficient appliances are examples of Internet of Things devices that can optimize energy consumption by adjusting settings based on occupancy and preferences. This can lead to improved energy management. Overall, this contributes to less energy being used.
- Lighting Control: Smart lighting systems reduce power consumption by modifying the light's intensity and color temperature in response to environmental conditions, human occupancy levels, and other user-defined parameters.
- With the help of the Internet of Things (IoT), devices like security cameras, doorbell cameras, and motion detectors can provide real-time monitoring and alerts, which is great for keeping everyone secure.
- Water Management: Smart irrigation systems improve watering schedules by reducing water waste by using weather data and soil moisture sensors.
- Traffic Management: Connected cameras and sensors track traffic patterns, adjust the timing of signals, and provide real-time traffic reports to alleviate gridlock and pollution.
- Transportation Networks: With the help of Internet of Things technologies, people can track their favourite public transportation routes in real-time, purchase tickets online, and view schedules, all of which promotes using the bus or train instead of driving alone.
- Automotive telematics: Vehicles equipped with telematics systems that are Internet of Things (IoT) enabled collect data for study of driver behavior, maintenance needs, and fuel efficiency.
- Garbage Management: Garbage cans equipped with Internet of Things sensors track their level of fullness, allowing for the optimization of collection routes and the reduction of operating expenditures.
- Smart Grids: Energy may be distributed more efficiently through the Internet of Things, which allows for smart grids to integrate renewable power sources and reduce energy waste.
- Using Internet of Things (IoT) sensors, cities can monitor air quality in real time, allowing for improved regulation of air quality and reduction of pollution.
- Internet of Things devices play an important role in urban planning by collecting data that impacts decisions about infrastructure, public services, and transportation.
- Precision Agriculture: By monitoring soil, weather, and crop health with Internet of Things sensors, farmers can maximize the use of irrigation, fertilizer, and pesticides.
- Animal welfare and agricultural productivity are both enhanced by the use of Internet of Things (IoT)-enabled wearables for animal monitoring, which allows for better animal management.
- Industrial machinery equipped with Internet of Things (IoT) sensors may gather data to predict when maintenance is needed, reducing unscheduled downtime and increasing the machinery's lifespan.
- Improving Supply Chain Visibility and Efficiency: Internet of Things devices track commodities' whereabouts and state in real-time, leading to optimisation of the supply chain.
- Wearable health trackers and medical sensors are examples of Internet of Things technology that enable continuous patient monitoring. This improves healthcare outcomes.

- Asset Tracking: Hospitals utilize the Internet of Things (IoT) to keep tabs on where their medical supplies and equipment are at all times, which helps them save money and makes sure they are always available.
- Water Quality Monitoring Water quality in lakes, rivers, and reservoirs is monitored by Internet of Things sensors to guarantee the safety of drinking water and to protect the environment.
- Improved weather forecasting, made possible with the use of Internet of Things (IoT) data gathered from satellites and weather stations, aids in disaster preparedness.
- Internet of Things (IoT) devices in the classroom enhance the learning experience by facilitating the use of interactive whiteboards, individualized learning platforms, and attendance tracking capabilities.
- Research labs that are Internet of Things enabled automate a number of processes, including experiment control, data collection, and teamwork.

In this way, these IoT apps aid in the development of sustainable ecosystems by facilitating more efficient use of resources, lessening waste, and providing crucial insights for decision-making. They play a key role in finding solutions to global issues including climate change, resource shortages, urbanization, and the quest for a more sustainable and livable future. The Internet of Things has many potentials uses beyond these ones, including smart building management, healthcare, assisted living, industrial applications, environmental conservation, and smart home automation.

3. AVAILABLE TYPES OF IOT DEVICES, SENSORS, AND ACTUATORS IN BUILDING A SMART AND SUSTAINABLE ENVIRONMENTS

A wide range of sensors, actuators, and Internet of Things (IoT) devices can collect data, run systems, and enable automation; they are crucial building blocks for an intelligent and eco-friendly environment. “19,” “20,” and “21” These devices help lessen negative impacts on the environment, improve comfort, and maximize the use of available resources. To help with the development of these kinds of settings, the following are some of the IoT devices, sensors, and actuators that are available:

- One example is smart thermostats, which control a building’s temperature. They optimize energy efficiency by adjusting temperature settings according to occupancy and user preferences.
- Intelligent Lighting Controls: Lights that are networked through the Internet of Things may change their color temperature, on/off schedules, and brightness depending on factors like the percentage of people in the room, the amount of natural light, and personal preferences.
- Smart Plugs and Outlets: With these handy gadgets, you can manage and keep tabs on your energy usage from anywhere in the house. Additionally, they allow users to power down devices while they’re not being used.
- The Internet of Things (IoT)-enabled smart lock provides a safe and convenient way to regulate who may enter and exit a building remotely from a user’s smartphone or other electronic device.
- Internet of Things cameras, such as smart cameras and doorbell cameras, provide security and surveillance with real-time video monitoring and alerts.

- A range of environmental factors, including temperature, humidity, and motion, may be detected by smart sensors, which are Internet of Things (IoT) sensors. Applications like analytics and automation may make use of the data collected by these sensors.
- To facilitate the speech-activated control of IoT devices, voice assistants and smart speakers serve as command centers. The Google Home and the Amazon Echo are two examples of such gadgets.
- Appliances like refrigerators, stoves, and washing machines that have Internet of Things capabilities allow customers to control them from a distance and make them more energy efficient.
- Environmental Temperature Sensors: These sensors measure the ambient temperature and help control HVAC systems to reduce energy consumption.
- Humidity sensors: Keeping an eye on relative humidity is key to keeping things comfortable and preventing mold growth.
- When occupancy sensors identify people in a space, they turn on the lights, HVAC, and security systems that are most suited to the situation.
- Light Sensors: Light sensors adjust the levels of artificial lighting in response to the quantity of available natural light, resulting in reduced energy use.
- Security and automation may both benefit from motion detectors. When they sense motion in certain areas, they may instantly trigger actions like turning on lights.
- Ensuring high-quality air within the building and energy-efficient ventilation requires constant monitoring of carbon dioxide levels.
- Smoke and carbon monoxide detectors: with the Internet of Things, these devices can alert homeowners and authorities in the case of an emergency.
- These devices can find water leaking from pipes in places like bathrooms and basements, allowing you to save water and prevent damage.
- To analyze noise pollution, heating, ventilation, and air conditioning (HVAC) systems or lighting systems can be adjusted based on the readings from noise sensors.
- Automated Window Treatments: Motors allow for the opening and closing of blinds and curtains in response to the quantity of light entering the room and the user's personal preferences.
- By controlling the flow of air to certain areas, actuators in HVAC systems help to maximize efficiency in controlling temperature and reducing energy usage. An actuator that finds use in HVAC systems are smart HVAC dampers.
- To improve water efficiency and avoid leaks, plumbing systems can benefit from intelligent valves, which regulate the flow of water.
- The opening and closing of vents may be adjusted by actuators to achieve the best possible ventilation and air circulation. Motorized ventilation describes this kind of airflow.
- Irrigation systems with smart valves: actuators monitor the weather and soil moisture levels to determine when and how much water should be applied.
- The mechanism that controls the locking and unlocking of gates and doors is the smart lock actuator. The term "smart lock" can describe these locks.
- The use of actuators allows for the control of natural ventilation and temperature adjustment through the opening and closing of windows. This is accomplished by use of motorized windows.

With the help of real-time decision-making, data collecting, and resource optimization, these sensors, actuators, and Internet of Things devices work together to create smart and eco-friendly environments.

They lessen the building's effect on the environment while also improving the health, safety, and comfort of the occupants and the building as a whole.

4. IOT PLATFORMS FOR SMART ENVIRONMENTS

The primary components of smart environments are IoT platforms, which offer the necessary infrastructure and tools for connecting, managing, and analyzing data from IoT devices (Mishra S., Tyagi A.K. 2022) (Amit Kumar Tyagi and Meghna Manoj Nair, 2022) (Shruti Kute; Amit Kumar Tyagi; et al., 2021) (Tyagi, Amit Kumar, 2019) (Reddy K.S., Agarwal K., Tyagi A.K. 2021) (Tyagi A.K., Rekha G., Sreenath N., 2020) (Li, S., Da Xu, L., & Zhao, S. 2015) (Perera, C., Liu, et al., 2014). These platforms enable the development of apps and services that improve smart environment user experiences, efficiency, and sustainability. Some popular Internet of Things platforms for building intelligent settings are:

- This service is provided by Amazon Web Services (AWS). Among its most notable characteristics is an Internet of Things platform that is both safe and extensible, capable of handling data processing, managing devices, and integrating with other services offered by Amazon Web Services.
- Azure is a Microsoft service. Interaction with Azure services for analytics and machine learning, centralized device management, and bidirectional connectivity are the most significant characteristics.
- GCP, or Google Cloud Platform, is the service provider. Features such as a Device Registry, support for MQTT and HTTP, and the ability to interface with services on Google Cloud Platform are essential to this scalable and completely managed Internet of Things platform.
- IBM Cloud (total) This product's main features are device management, real-time data analytics, and integration with IBM's AI and ML services.
- The supplier is PTC. Among the most important components of an advanced Internet of Things platform are features like application development tools, data storage, analytics, and the ability to connect devices. One of the suppliers is Bosch Software Innovations.
- The provider is Cisco, and the most essential characteristics are an IoT platform with capabilities for device management, data analytics, and edge computing.
- This smart city application takes advantage of Oracle Cloud's device registration, data storage, analytics, and connectivity with other cloud services to connect devices, manage data, and implement edge computing capabilities tailored to urban environments. Key features include these.
- The supplier ends up with no profit. Key features include an easy-to-use Internet of Things platform for developers, which includes capabilities like real-time monitoring, data visualization, and process automation.
- The service provider is Ubidots. Notable Features: Offers intuitive tools for developing Internet of Things applications, as well as integrated device administration, data visualization, and integration possibilities.
- The supplier is the particle. With an emphasis on IoT hardware and connectivity, this platform facilitates rapid prototyping and development.
- KaaIoT Technologies, Inc. A key component is an open-source IoT platform that provides tools for managing devices, analyzing data, and developing personalized IoT solutions.

- There is a provider named Tuya. Some of the most important aspects of this Internet of Things (IoT) platform for commercial and consumer use include the ability to connect devices, manage data, and create apps.
- The service is offered by C3.ai. Main Features: An enterprise-level platform for internet of things and artificial intelligence that caters to a range of industries, such as energy, healthcare, and manufacturing.

There are several factors to think about when selecting an IoT platform for a smart environment project. These include the platform's capacity to scale, its security features, how easy it is to integrate with current systems, the devices and protocols it supports, and the tools available for development and analytics. The specific requirements and goals of your smart environment initiative should guide your platform decision.

5. BIG DATA ANALYTICS AND DATA MANAGEMENT IN SMART ENVIRONMENTS

Data management and Big Data analytics play an important part in smart environments by handling the massive amounts of data generated by sensors and Internet of Things (IoT) devices. These technologies are particularly important for maximizing resource utilization, improving decision-making, and increasing the overall sustainability and utility of smart settings. The following is a case study of a real-world use of Big Data analytics and data management:

- Sensors and devices connected to the Internet of Things (IoT) gather information on a wide range of environmental factors, including but not limited to: air quality, temperature, humidity, energy use, and occupancy.
- Cameras capture images with the aim of keeping an eye on things, keeping tabs on people, and studying things like traffic patterns and crowd behavior.
- To effectively monitor and manage urban resources, smart infrastructure collects data from smart grids, transportation systems, and water management systems.
- Some examples of healthcare devices that gather data related to a patient's health for the purpose of monitoring and care include medical sensors and wearable health gadgets.
- It is common practice to incorporate real-time or near-real-time data acquired from sensors and Internet of Things devices into data storage systems. Simply said, this is called "data ingestion."
- Distributed storage systems or data lakes are commonly used in smart settings to store large volumes of diverse data kinds.
- Due of its scalability and accessibility, cloud-based storage systems are utilized by many smart environment efforts.
- Raw data is usually preprocessed before it can be organized, filtered, and transformed into a usable format.
- Applications like predictive maintenance and security can benefit from real-time insights made possible by streaming analytics technologies, which process data as it is produced. Streaming analytics includes real-time analytics as one of its subsets.

- The batch analytics method makes use of batch processing for looking back at data, finding patterns, and making plans for the future.
- Data correlations, trends, and outliers may be found with the use of sophisticated analytics and machine learning tools. A combination of machine learning and AI allows us to do this. Consequently, tasks like optimizing resources, detecting anomalies, and predicting maintenance become feasible.
- Users, operators, and decision-makers can get insights via the use of dashboards and other data visualization tools.
- In order to respond quickly to important events, real-time alerts and notifications are generated based on pre-established patterns or criteria. Notifications and alerts like this are created instantly.
- Important information is protected from prying eyes by encrypting it before it is stored or sent.
- To keep sensitive information safe, role-based access control ensures that no one other than approved employees may see or change it.
- When it comes to data management in smart settings, it's common for them to adhere to privacy regulations like GDPR, HIPAA, or standards set by certain industries.
- In accordance with the regulations regulating data retention, ascertain the time for which data should be kept and then either archived or deleted.
- To make sure data is robust and can be recovered in case of a system failure, it is recommended to do data backups regularly.
- Big Data solutions may be easily expanded horizontally to handle the ever-increasing data volumes generated by smart settings.
- By utilizing analytics, the inefficiencies in resource utilization may be identified, leading to better allocation and optimization of resources.
- By analyzing data, we can anticipate when infrastructure or pieces of equipment will break. This allows us to do preventative maintenance, which cuts down on expenses and downtime.
- Transportation systems and buildings may both benefit from analytics that reveal ways to reduce their energy use and carbon impact.
- Optimization of traffic flow, reduction of congestion, and augmentation of transportation services are all aided by data analysis in traffic management.

As a result, smart environments and Big Data analytics allow enterprises and municipalities to make data-driven choices, which boosts sustainability and improves residents' quality of life. It is possible to do all of this while reducing operational expenses and environmental impact at the same time.

6. CRITICAL CHALLENGES TOWARDS FOR BUILDING SMART AND SUSTAINABLE ENVIRONMENT

To ensure the successful completion of major initiatives, it is necessary to overcome a number of substantial challenges. Building sustainable and intelligent ecosystems is one of these challenges. A few of the most major obstacles are these:

- One challenge with the Internet of Things is the need for a wide variety of communication protocols and standards, which can lead to issues with interoperability. Making sure all these gadgets

can talk to one other and work together seamlessly is a significant challenge. Establishing and adhering to industry standards, as well as the procedures that control them, can help with this problem. There are now a number of groups and consortiums working on developing solutions that can communicate with one another. Data security and privacy is of the utmost importance in smart environments because of the massive amounts of data that are gathered. This is rather difficult. Data breaches and unauthorized access might potentially have serious consequences. To address this, it is critical to adhere to data protection laws and to establish rigorous security mechanisms like authentication, encryption, and access control. It is crucial to conduct security audits and updates on a regular basis.

- One difficulty with IoT devices is the massive amounts of data they generate, which may be difficult to manage and interpret. Data storage, administration, and analytics must be top-notch if you want to get useful insights.
- Utilizing analytics tools and Big Data technologies might be the answer; they could facilitate data management and value extraction. Cloud computing also offers the possibility of scalable storage and processing.
- Smart environments aim to improve energy efficiency, but the power consumption of IoT devices and infrastructure can be considerable, potentially mitigating any advantages. Possible answers to this issue include using renewable energy sources, installing Internet of Things devices with lower power consumption, and optimizing algorithms. It is essential to consistently monitor and optimize.
- Not everyone can enjoy the advantages of smart settings because of disparities in connectivity, infrastructure, and technology availability. This is rather difficult. Some potential remedies to the digital divide include increasing the availability of bandwidth, making devices more affordable, and enacting inclusive regulations to ensure equal access. One challenge is that smart and sustainable solutions can be costly to install, and the ROI isn't always obvious right away. The advantages would accumulate over several years, which would make it harder to convince stakeholders. One possible answer is to do thorough cost-benefit analyses, with an emphasis on long-term sustainability, and to identify clear financial and environmental benefits to help justify investments.
- Delays in smart environment initiative implementation might be caused, in part, by the difficulty of complying with various regulations. Privacy regulations, data protection standards, and land use constraints are all part of these settings.
- Critical components of the solution include proactive compliance, collaboration with regulatory bodies, and lobbying for regulatory frameworks that support innovation.
- The success of smart environments depends on the acceptance and engagement of communities and people, which is a problem in and of itself. It could be difficult to progress if you are ignorant or skeptical.
- Building trust and support for the solution may be achieved by community engagement, teaching people about the advantages, and incorporating them in the decision-making process.
- One environmental concern is the potential influence of electronic device and infrastructure production and disposal on the natural world. Smart settings must find a middle ground if they are to accomplish their sustainability goals.
- Possible strategies to lessen the impact on the environment include recycling schemes, ecologically friendly design principles, and ethical disposal practices. The problem is that smart environments are becoming more attractive targets for cyberattacks as they become more networked.

Cybercriminals can take advantage of security holes in systems and devices connected to the Internet of Things.

- To secure smart environments, it is essential to implement robust cybersecurity measures, perform regular security audits, and set up threat detection systems.
- It will need a concerted effort including governments, enterprises, communities, and technology providers to successfully tackle these enormous challenges. Prioritizing inclusiveness, security, and sustainability while also adapting strategies, technology, and laws to ever-changing conditions is vital for the establishment of smart and sustainable environments.

7. FUTURE TRENDS AND INNOVATIONS TOWARDS FOR BUILDING SMART AND SUSTAINABLE ENVIRONMENT

There are a lot of exciting new trends and innovations that will shape how smart and sustainable homes are built in the future. These inventions aim to enhance living quality, minimize harmful impact on the environment, and make the most efficient use of existing resources. Important developments and trends in this field are outlined below:

- 5G networks will provide faster and more reliable connectivity for Internet of Things devices, making low-latency applications and real-time data transmission more feasible. Technologies that follow 5G, such as 6G and beyond, are the subject of ongoing research with the ambition of delivering even greater speeds, better coverage, and novel capabilities for smart environments.
- Processing and decision-making may now take place closer to the physical location of the data source, thanks to edge computing. This trend is only going to grow in importance. This improves the responsiveness of IoT applications and reduces latency. It is expected that edge artificial intelligence, defined as the deployment of machine learning models directly on edge devices, would become more common for real-time analytics.
- When it comes to smart environments, machine learning (ML) and artificial intelligence (AI) will be more important for tasks like autonomous decision-making, anomaly detection, and predictive analytics. Reason being, ML and AI are at a level of sophistication never previously seen. Many industries may benefit from enhanced automation as a result of advancements in robots driven by artificial intelligence. These include healthcare, maintenance, and waste management for example.
- The use of digital twins, which are exact replicas of real-world systems, is going to become more prevalent in smart environmental management as they continue to evolve and become more sophisticated. Digital twins will be in charge of intelligent ecosystems. Thanks to them, we can now do simulations, real-time monitoring, and predictive modelling. With the advent of digital twins for both buildings and cities, comprehensive optimization and planning of urban regions will be a reality.
- Efforts to lessen our impact on the environment will place a greater emphasis on recycling, refurbishing, and reusing items and resources as part of the circular economy. The use of IoT devices will facilitate the tracking of product lifecycles and the assurance of correct disposal and recycling processes.
- In the future, smart grids will be enhanced with the support of distributed energy resources, intelligence at the grid edge, and better sensors. This will lead to better energy distribution, more

resilience, and the use of renewable energy sources. Microgrids and peer-to-peer energy trading will become more common, allowing communities to generate and distribute renewable energy.

- The utilization of biophilic design principles to bring elements of nature into built environments has the dual benefit of enhancing air quality and people's overall health. Green roofs, vertical gardens, and other forms of urban greenery will become more common. Smart sensors will be installed in these regions to keep an eye on things and make them better.
- Transportation and Driverless Vehicles: By reducing traffic congestion, pollution, and the need for personal autos, shared mobility services and autonomous cars will revolutionize transportation in smart cities. Autonomous navigation and traffic management will both benefit from IoT-enabled infrastructure.
- Medical professionals will greatly benefit from Internet of Things devices since they will pave the way for telemedicine, tailored health recommendations, and remote patient monitoring. Health and happiness will be positively affected by this. Incorporating sensors and artificial intelligence into smart places that prioritize wellness will promote better living.
- Communities and towns will spend money on resilience planning to prepare for the impacts of climate change, including more frequent and severe weather events, flooding, and higher sea levels. Smart sensors, early warning systems, and flexible infrastructure will increase resilience.
- With an emphasis on accessibility, usability, and inclusivity, the design of smart environments will prioritize the needs and experiences of occupants and users. This approach is known as design with the user in mind. Data analytics focused on users will guide the design selections.
- Utilizing blockchain technology for sustainability purposes entails tracking and verifying the origin and sustainability of products. All links in the supply chain will be open and accountable thanks to this. The implementation of blockchain-based smart contracts and incentives will promote sustainable practices.
- Improvements in energy storage and grid management will allow for intermittent renewables, such as solar and wind, to be more seamlessly integrated into the energy system. Sources like solar and wind power are examples of this.
- Collaborative government: By adopting forms of collaborative and participatory government, citizens will have a direct say in the initiatives that affect their smart city and sustainable environment.

Note that these changes and tendencies reflect a growing commitment to sustainability, advancements in technology, and the goal of creating smart environments that are better for people, the planet, and the economy. As they continue to evolve, they have the potential to improve our daily lives, our jobs, and our interactions with the natural world.

7.1 Role of Artificial Intelligence and Machine Learning in Smart Environments

The development and administration of smart environments rely heavily on two technologies: artificial intelligence (AI) and machine learning (ML). These technologies enhance smart environments in several ways, making them more productive, helpful, and sustainable. Among the many vital functions and uses of AI and ML in smart environments are:

- By examining past data acquired from sensors connected to the Internet of Things, algorithms for artificial intelligence and machine learning are able to generate forecasts on future events. For ex-

ample, preventative maintenance may save money by avoiding expensive downtime by using predictive maintenance algorithms to determine when a piece of equipment is likely to break down.

- Machine learning models can detect unusual patterns or outliers in data, which is crucial for smart environment security. That way, unexpected events will always have quick solutions.
- Artificial intelligence (AI)-driven energy management systems have the potential to optimize the use of water, gas and electricity in buildings. These systems optimize energy efficiency by modifying temperature, lighting, and ventilation based on factors such as user preferences, current weather conditions, and occupancy levels.
- By analyzing real-time data collected from sensors and cameras, machine learning algorithms may enhance smart city transportation efficiency, optimize traffic flow, and decrease congestion all at once.
- Sensors connected to the Internet of Things collect information about patients' health from various medical devices and wearable tech. By analyzing this data, AI and ML can improve patient outcomes, detect early warning signs of health concerns, and provide customized therapy recommendations.
- Security threats, intruders, or unusual activity in surveillance footage can be detected using video analytics driven by artificial intelligence. For monitoring and security purposes, this is helpful. These systems have the capability to alert the proper authorities or security personnel when certain alarms are activated.
- Users may interact with smart environments in a natural and straightforward way using voice-controlled AI assistants and chatbots. Users are able to manage equipment, access information, and receive help through the use of voice commands and text-based queries.
- Tools for data analytics powered by artificial intelligence extract useful information from the massive volumes of data collected in smart environments. Data visualization tools are used to help stakeholders make educated decisions using these insights.
- Automated buildings use AI and ML algorithms to learn occupancy patterns and adjust HVAC, lighting, and security systems accordingly, resulting in more efficient building operations. Both the energy consumption and the comfort level of the passengers are enhanced by this.
- Air quality, pollution levels, and early warnings for natural disasters may all be assessed using data collected from environmental sensors using machine learning algorithms. Actions to protect the environment are taken in light of these facts.
- Artificial intelligence (AI) is used by intelligent waste management systems to optimize garbage collection routes, reducing operational expenditures and fuel consumption. There are sensors in trash cans that can let you know when it's time to empty them.
- AI-powered simulations and models help city planners maximize sustainability and quality of life by reducing inefficiencies in land use, transportation, and infrastructure development.
- Investigation of User Actions in smart environments, machine learning algorithms study user behavior data to provide tailored recommendations, services, and experiences. One feature that may be included in a smart house is the ability to customize the lighting and temperature.
- Through the analysis of soil conditions, meteorological data, and crop health, artificial intelligence and machine learning are utilized in agriculture to improve resource allocation. While improving yields, this helps to decrease water and fertilizer usage.

- In order to predict and react to natural disasters like earthquakes and hurricanes, artificial intelligence systems can assess data from several sources. This helps communities strengthen their defenses and get ready for anything.

Incorporating AI and ML into smart settings has the potential to increase operational efficiency, enhance the quality of life for residents, reduce environmental impact, and contribute to sustainability initiatives. The importance of these technologies in creating smart environments will grow as they advance, leading to smarter and more flexible homes and workplaces.

8. CONCLUSION

With the help of the Internet of Things (IoT), smart and sustainable ecosystems may be built, and the world might become more efficient, livable, and environmentally responsible. The IoT, a system of vastly distributed networks of devices and sensors, is crucial in helping contemporary civilizations deal with the complicated challenges they face. The Internet of Things (IoT) allows for the collection of real-time data from many sources, such as smart sensors, devices, and infrastructure, with the goal of optimizing resource utilization, improving decision-making, and decreasing environmental impact. Furthermore, it paves the way for the implementation of complex analytics and automation. To sum up, the future of cities, buildings, transit systems, and industries will be shaped by the Internet of Things, which is a key component in the development of smart and sustainable environments. With further technological advancement, stakeholder collaboration, and a resolve to tackle challenges, the Internet of Things may guide us towards a future that is more efficient, resilient, and environmentally conscious. Responsible and ethical deployment of Internet of Things technology must be our top priority going ahead if we are to ensure that these technologies contribute to societal well-being and sustainability.

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