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Integration of advanced digital technologies in the hospitality industry: A technological approach towards sustainability

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Abstract

The potential assimilation of Industry 4.0 technologies across diverse sectors unlocks the pathways to achieve sustainability through innovative infrastructure with sustainable approaches. The World Travel & Tourism Council's (WTTC) 2023 report emphasizes the impact of the hospitality industry contributes $9.5 trillion to the gross domestic product (GDP) and provides a workforce of 320 million globally and also strives towards meeting sustainability. Driven by the facts above, this study conducted a review to explore the potentiality of Industry 4.0 technologies specifically focused on meeting sustainability. Along with the review, the study has proposed a scalable-based architecture with the assimilation of many Industry 4.0 technologies. Further, this study has analyzed the real-world examples of Industry 4.0 technologies adoption in the hospitality industry with an objective of innovation and sustainable practices. Finally, the articles discussed the recommendations that can empower the establishment of resilient infrastructure through Industry 4.0 technologies.

Keywords: Hospitality, Industry 4.0, Edge computing, Internet of things (IoT), Sustainability

1. Introduction

The hospitality sector is a considerable industry that offers lodging, food, and other associated services for the comfort and leisure of tourists and visitors [1]. This industry is a significant component of the service industry and is categorized into four primary groupings: tourism and travel, beverage and food, lodging, and accommodation. Even after the COVID-19 outbreak, Hilton is the most beneficial hospitality brand in the world, with a 35% rise in valuation [2]. Following a World Travel and Tourism Council report, the hospitality industry is a significant creator of worldwide value by contributing 8.6 trillion USD in 2022, only 6.4 percent below pre-pandemic levels [3]. Currently, sustainability is the future as it aims to enhance the quality of life, preserve natural resources, and safeguard the ecosystem [4]. Sustainability is fostered to be included in the business model of the hospitality industry, where it drives the new paradigm with the amalgamation of advanced technology [5]. The integration of technology in the hospitality industry establishes an ecosystem that enables us to customize the services concerning customer requirements.

The sustainable development goals (SDGs) that apply to the hospitality industry are zero hunger (goal '2'), good health and well-being (goal '3'), quality education (goal '4'), clean water & sanitation (goal '6'), affordable & clean energy (goal '7'), decent work & economic growth (goal '8'), and industry, innovation, and infrastructure (goal '9'). [6]. These goals force the hospitality industry to effectively manage resources like food, energy, manpower, and infrastructure sustainably. From the previous studies, it has been concluded that the quality evaluation of these resources with manual inspection has limitations as it is difficult to identify a fault in infrastructure, hygiene, and cleanliness in the food, infrastructure, and humans [7], [8]. As discussed earlier, food, lodging, and accommodation are the main categories of the hospitality industry. Visitors are interested and prefer those hospitality hotels that offer exceptional service to them right now, due to changes in environmental conditions and the evolution of pandemics. The hospitality industry can leverage digital-enabled solutions to deliver rapid service to achieve better levels of hygiene in food, lodging, accommodation, and staff [9].

The digital-enabled solutions are realized with the assistance of technologies like AI, IoT, edge/fog computing, big data, robotics, AR, VR blockchain, and digital twins [10], [11]. These digital technologies empower process functions such as data collection, data analysis, and automation. The advancement in the sensors, vision-based, and wireless communication technology boosts every area to implement these digital technologies for establishing an intelligent infrastructure through digital networks [12], [13]. From the previous literature, it has been concluded that there are limited studies that discussed the significance of Industry 4.0 technology with sustainability in all realms of the hospitality industry. To overcome the aforementioned challenges, this study aims to address the significance of Industry 4.0 technology integration in the hospitality industry with real-time examples. The main contribution of the study is as follows:

- The study explored the multiple areas where technological interventions can revolutionize digitalization in the hospitality industry.
- The amalgamation of Industry 4.0 technologies-based architecture for different applications such as monitoring room air quality and room hygiene, safety monitoring of hotel kitchens, real-time monitoring, and management of waste through cloud servers are discussed.
- The real-world examples and practical implications of Industry 4.0 in the hospitality industry are detailed and discussed in the study.
- The study suggested a few vital recommendations such as high computing power-based wearable devices, piezoelectric energy generation, wide adoption of mobile robots for room service, room hygienic and room air quality, the establishment of intelligent IIoT network for feeding the needy people, and blockchain for a circular economy for establishing robust infrastructure.

2. Significance of Industry 4.0 in hospitality

In this section, the significance of the different Industry 4.0 enabling technologies like IIoT, AI, edge and fog computing, robotics, big data, blockchain, AR/VR, and digital twins are detailed presented. The IIoT allows anything to connect to the web and generate data. Data must be managed by its needs to give more valuable services [14]. As a result, IIoT and cloud computing integration are becoming increasingly significant. This new model is known as the "Cloud of Things" (CoTs) [15]. IIoT and WSNs can use CoTs to manage their expanding data and other resources. It also helps to establish a greater range of amenities that may be supplied as a result of the merger [16]. It's used in a variety of industries, including locomotive, health care, engineering, and agriculture [17]. AI is the simulation of the human mind in computer systems designed to perceive and behave like humans, such as learning and solving problems [18] [19]. Natural language processing, computer vision, speech processing, medical applications, consumer and employee engagement, automation, industries, and agriculture are just a few of the sectors where AI has been implemented [20] [21].

Infrastructure, platform, and software as a service (IaaS) are all available through the cloud (IaaS, PaaS, SaaS) [22] [23]. Cloud data centers are vast pools of virtualized resources that may be changed for a scalable workload [24], [25]. According to the National Institute of Standards and Technology (NIST), cloud computing is an approach that encourages pervasive, on-demand networks to gain entrance to shared computing resources [26]. Autonomous mobile robots are employed to enhance services and daily functions in a diversity of fields, including agriculture, hospitals, industries, organizations, and residences [27]. It has emerged as progressively encouraging and potent due to its capacity to explore an environment without the assistance of electro-mechanical and physical guidance devices [28].

Big data is a concept utilized to characterize massive amounts of data that traditional data management techniques and approaches are not able to process and manage [29]. Big data is vital across many industries, including health care, education, agriculture, chemistry, finance, and marketing [30], [31]. Big data analytics is a method of evaluating huge quantities of data to uncover hidden patterns, illogical relationships, and other useful facts that could indeed be utilized to create effective decision-making [32], [33]. Blockchain technology is quickly being adopted in healthcare, business, banking, and the automotive industry [34]–[38]. It's critical to comprehend how blockchain applications affect a company's organizational structure, method of operation, and management model. Decentralization, tamper-proof construction, and information transparency are the unique features of the blockchain [39].

VR can be extensively characterized as a virtual object in a virtual environment, particularly a simulated recreation, computer-generated, real-life environment that fascinates the user with the illusion of experiencing the simulated reality firsthand, mainly by boosting his vision and hearing [40]–[42]. AR is a technology that enhances computer-generated transformations to existing reality to render it much more realistic and substantial because of the potential to engage with it, and it is utilized to enhance the customer experience in a wide range of tasks [43]. The vision of the Digital Twin includes a detailed functional and physical explanation of a product, component, and all accessible transactional data [44]–[46]. A Digital Twin is a set of well-aligned executable models that describe a component, product, or system. It is an interconnected accumulation of critical digital artifacts such as operation data, engineering data, and behavior characterizations that can be obtained via numerous simulation models [47], [48]. The Digital Twin evolves alongside the real system during its life cycle, including all of the current knowledge about it [26].

3. Technology intervention in hospitality with proposed architecture

In this section, previous literature is reviewed for the Industry 4.0 technologies implementation within the hospitality industry. Subsequently, the proposed architecture is presented in detail, where it outlines its potential to enhance the various operational domains in the existing hospitality industry.

3.1. Smart reception and valet parking

To evaluate hospitality products and services, hotel managers are fast adopting integrated management solutions and using predictive analytics. Demographic information, ordering habits, and hobbies, among other things, can be gathered via automated and data-driven corporate solutions [49]. By automating future hotel structures, customers will be able to enjoy ambient hospitality that adapts to their surroundings automatically, giving them a green and comfortable experience. Mining big data from sensors and other IoT devices and employing an approachable building, frontend systems, and autonomous equipment, will change the function area layout according to the needs of guests and the hotel staff [50]. Customer service request desk automation helps to maintain stronger client relationships. Workflow automation is a revolutionary technology as it reduces human errors and increases overall efficiency by using digital tools to build, automate, and execute business processes [51]. In the hospitality industry, new developments including augmented reality, predictive analytics, beacons, robotics, blockchain technology, IoT and AI play a significant role in facilitating and improving the customer service experience. The hotel front desk is becoming more automated, with fewer human interactions [52].

The automated Valet Parking (AVP) system provides a cost-effective and efficient parking solution for the hospitality industry, allowing cars to park easily and quickly. Wireless sensors-based parking systems based on the IoT are interesting alternatives for hospitality industry adoption [53]. For the hospitality business, a smart parking system should include a wireless sensor network (WSN), radio frequency identification (RFID), near-field communication (NFC), and a cloud server. An alarm system can be utilized to notify a driver that his service is needed to pick up or drop off a customer using a custom software application stored on a cloud platform [44]. Vehicle location, a map of previously visited places, and a passable area around the vehicle are all provided by the Autonomous Valet Parking (AVP) technology. The data is utilized as input to keep the integrity of the automotive control system during navigation [54]. There are two forms of AVP: long-range AVP (LAVP), and short-range AVP (SAVP). The HI smart parking solution set includes digitally smart routing, enhanced parking, vacant slot detection technologies, and high-density parking [55].

Hospitality industry might use IoT in combination with other technologies to avoid the unpleasant concerns of waiting. The most creative method is to hide the delay by creating automated queues through AI and IoT that allow customers to accomplish other things while waiting in the hotel's lounge [56]. Despite significant progress in the field of social robotics, there is still a lack of research on robots in tourism and HI [57]. It then goes on to examine AI, robotics, and automation, as well as their current and potential roles in smart hotels, as well as their key workplace implications [58]. Investigating some of the most cutting-edge hotel technologies now in use and how they enhance client experiences and transform the hospitality service sector. As IoT technology evolves, we can predict future hospitality [59]. Using a speaker or a smartphone, guests will be able to control the equipment. The guest is automatically recognized at the room's entrance and the door is unlocked for them. A voice assistant or a separate drone will be used to transform the check-in counter. Administrative support robots and drones might clean, deliver, transport, and serve breakfast, lunch, and dinner. The hospitality industry can deploy robotic guards to assure guest safety [53]. Integrating guest-facing (GF) systems into the hospitality industry enhances the guest experience through an array of practices such as keyless entry, automatic check-in and checkout, and management of room services. Another key service associated with customer desire is location-based services, which are provided through GF systems. Furthermore, by gathering data on unique guest preferences, activities, and locations, GF systems allow service providers to keep a close eye on the guest cycle. It ensures guest's happiness by giving them control over their surroundings [54].

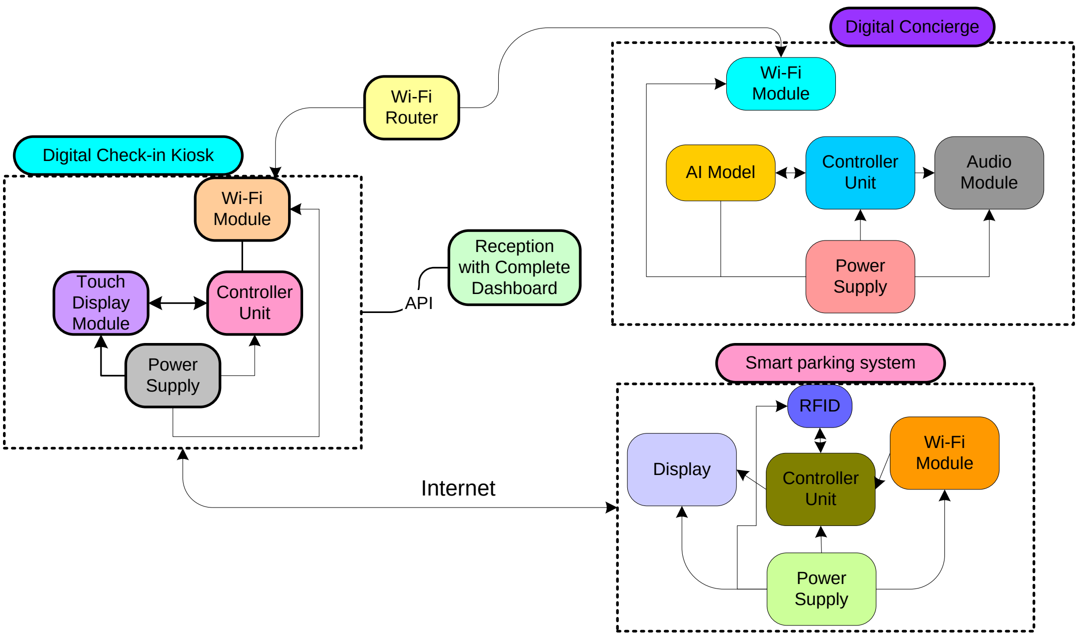

Figure 1. Smart reception with digital check-in

Figure 1 illustrates the proposed architecture to enhance the application of smart receptionists with digital check-in. In the architecture, the multiple components are interconnected to each other through internet connectivity. The digital check-in kiosk device will be positioned near the receptionist, where it consists of the touch display module, Wi-Fi module, and a power supply are interfaced with the controller unit. This device is connected to the receptionist through an application programming interface (API), where it can visualize the available and occupied rooms on the display. The information related to the selection and check-in of rooms by visitors will be displayed on the receptionist dashboard and the receptionist provides the room key to the visitors. Along with this feature, digital check-in is also connected to the smart parking system of the hotel, where the visitors can connect their vehicle in digital check-in for real-time monitoring and visualization. The smart parking system obtains the vehicle data through RFID and based on the request from the digital check-in device it allows sending the car details for connecting to digital check-in through internet connectivity obtained through the Wi-Fi module. In the receptionist premises, there is a digital concierge, who acts as a personal assistant for the visitors to get information related to the facilities and infrastructure of the hotel digitally. Moreover, the visitor can have a real-time experience of the tourist's place around the hotel. The artificial intelligence (AI) model empowers the digital concierge to update real-time weather information, tourist places, and video conversations with their family members or representatives. The internet to this digital concierge is provided through a Wi-Fi modem attached to it, where a Wi-Fi modem obtains internet from a Wi-Fi router. The detailed workflow of Figure 1 can be better understood through Figure 2.

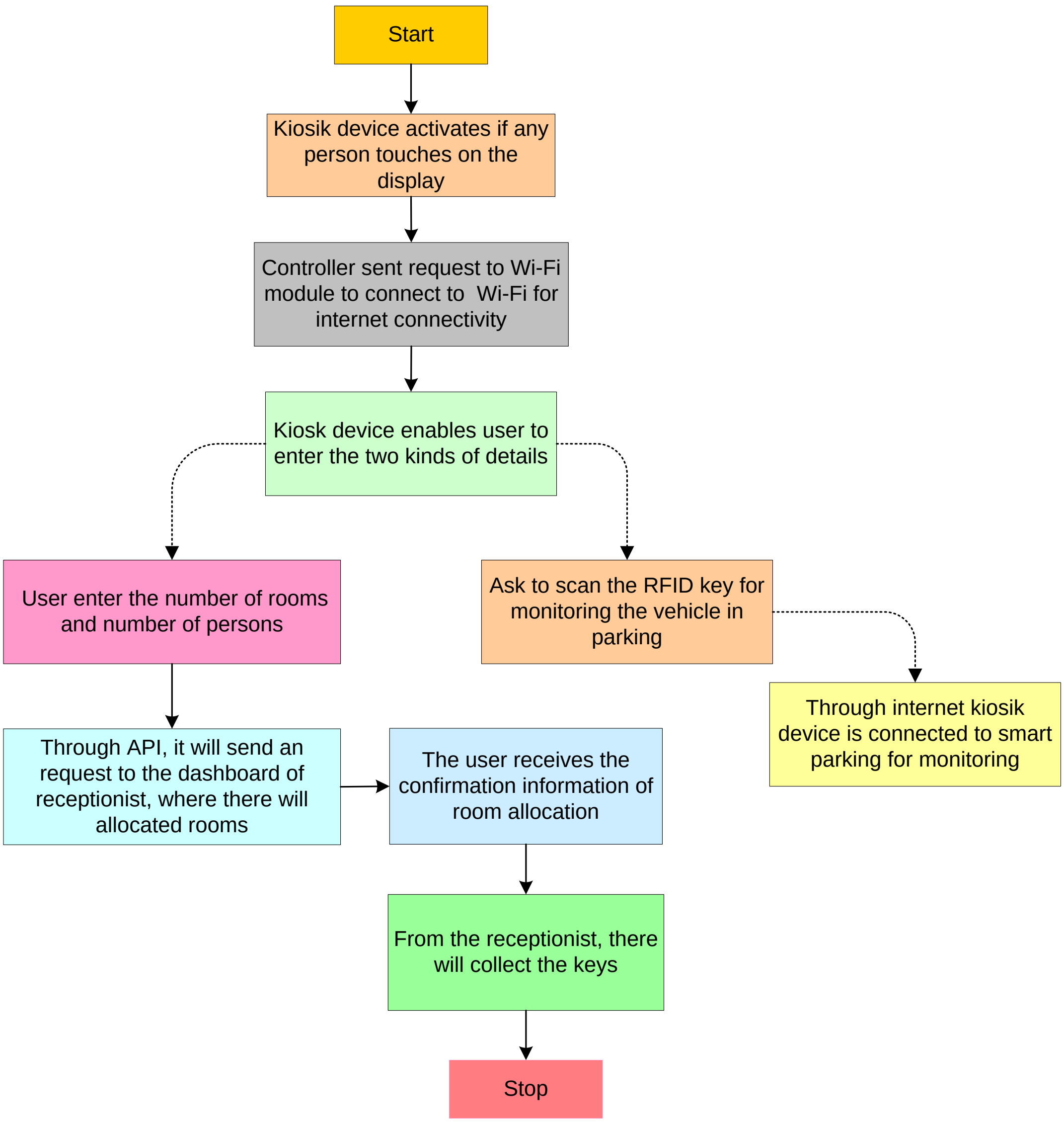

Figure 2. Flowchart of smart reception with digital check-in

3.2. Room hygiene, room service, and room air quality

IoT and AI, robotics, and sensor technologies are currently having a limited impact on the hospitality industry's guest room service sector. Utilizing AI, IoT, sensors, as well as other technologies to generate an ambient ecosystem that evaluates its environment non-invasively and adjusts its behavior to provide intelligent and personalized facilities to guest room tenants [55]. HI might be able to provide much-desired client room service by combining AI technologies, virtualization, cloud architecture, IoT, and big data. AI-assisted hotels are gaining popularity among the general public. To attain successful and adaptive development platforms such as SaaS and PaaS hotels must construct a holistic hotel management platform [60]. The most effective way to save energy in hotel rooms is to implement smart hotel solutions. The hotel information system, Internet access, minibar management, fixed and mobile telephony, TV/video amenities, lighting control, and smart card usage are all integrated. Better management is achieved, thus providing a higher quality of care to tourists, increasing the overall system's safety, and allowing hotel personnel to act on new evidence [61]. Sending instructions to the IoT devices through the hotel servers to open the curtains, increase or reduce the cooling of the room's temperature, switch the television ON/OFF, play music at a low frequency, and open the low-intensity light before the guest's wakeup time, depending on the guest's preference. The hotel's server will transfer this data to a Raspberry Pi, which will validate and store the instructions on a MySql server running on the Raspberry [62].

A smart key, multiple beds and pillow varieties, a large rain shower to relax in, selectable lighting options, a spacious working area, and a specifically created bed desk are all part of the high-tech environment included in the smart rooms. A microprocessor-controlled station monitors the customer’s movement in and out of the room, temperature, sensors, alerts, and other factors in smart hotel rooms. These room stations are linked to a central computer, allowing for control of many rooms, floors, or the entire hotel [63]. It has been discovered that indoor areas have much higher amounts of air pollution than outdoor environments. The hotels have a particular architectural character, with high ceilings and large windows. AI and IoT, along with sensors, can be used, making it easier to recognize poor air quality in corridors, kitchens, restaurants, lounges, front-desk areas, bedrooms, fitness centers, etc., and to fix the problem right away [64].

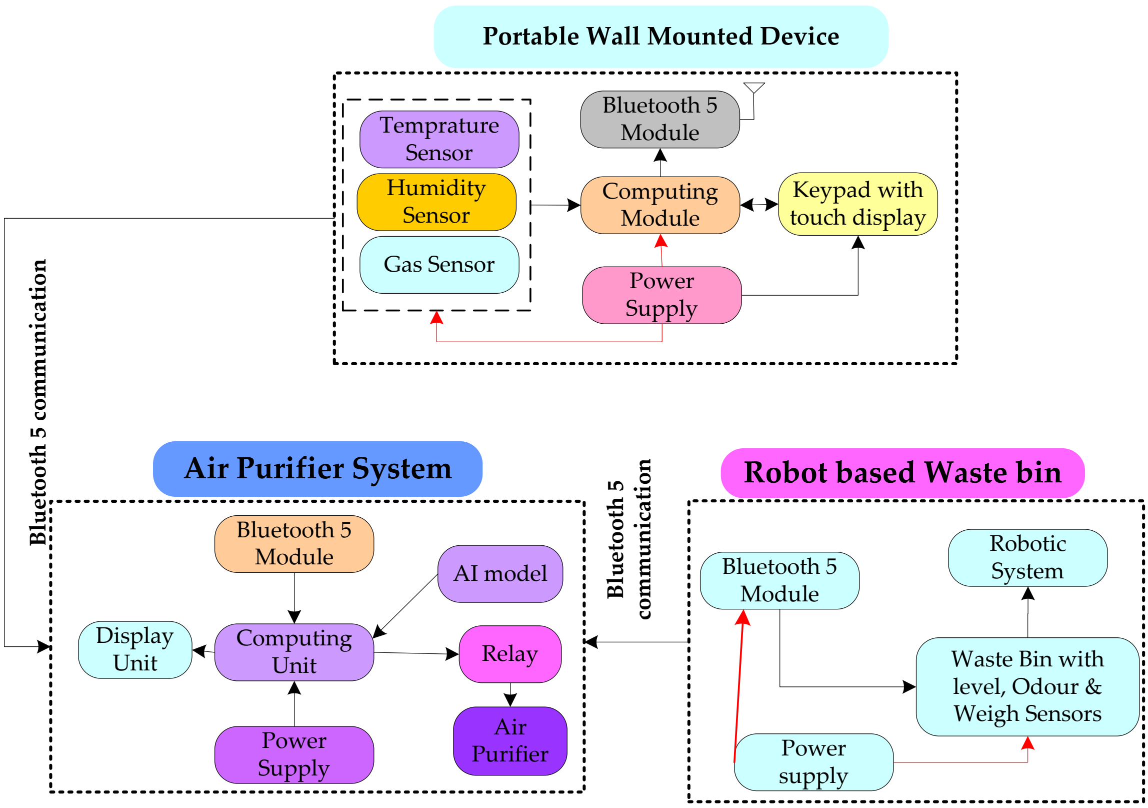

Figure 3. Monitoring room air quality and room hygiene using IoT, AI, and robotics

The automation in the room service, room air quality, and room hygiene have an important role in facilitating a quality environment for the customers/visitors. The proposed architecture (Figure 3) comprises three different components a portable wall-mounted device, an air purifier system, and a robot-based waste bin. Each component is specifically dedicated to the parameters like room air quality and hygiene.

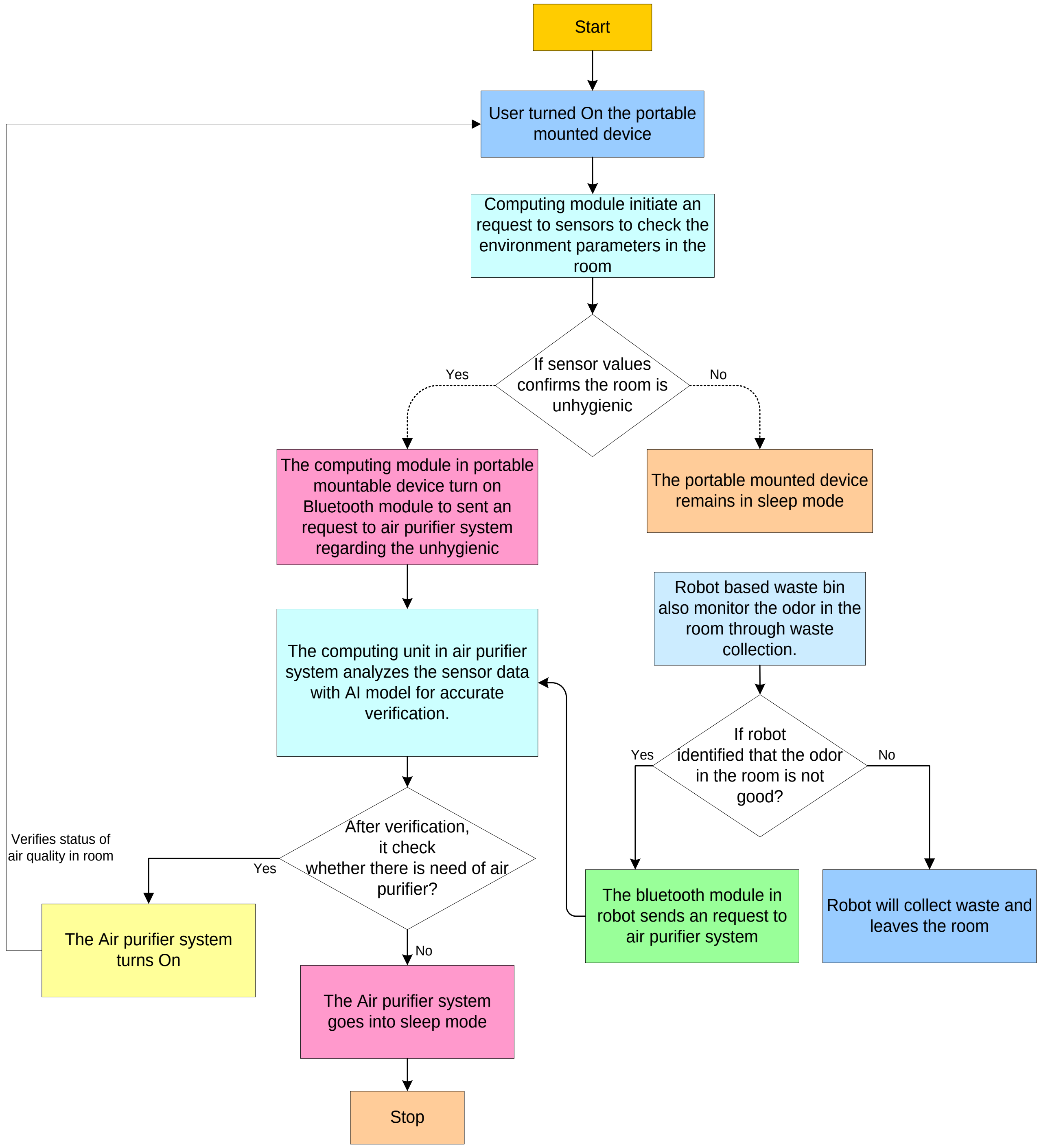

Figure 4. Flowchart of room air quality and room hygiene using IoT, AI, and robotics

This device senses the environmental parameters such as temperature, humidity, and gas in the room and also visualizes the display. Based on threshold values set for the gas sensor value, the computing module in the device sends a request to the air purifier system to refresh the room's air quality. The air purifier system comprises multiple components, which it is capable of detecting the requirement for freshening the room air based on sensor value received from the portable wall-mounted device. AI model in air purifier system boosts the computing unit to detect the anomalies in the sensor values and also to enable automatic functioning

(ON/OFF) of air purifier system in real-time. A robot-based waste bin is embedded in the architecture to monitor the odor and also to maintain hygiene in the room by collecting and disposing of the waste generated in the room. The multiple sensors like weight, odor, and level sensors in the robot system enable to monitoring of weight, the level of waste in the bin, and also the odor generated in the room. In case a bad odor is generated, then this system intimates/sends instructions to the air purifier system to maintain a good odor in the room through Bluetooth 5 communication. The detailed workflow of Figure 1 can be better understood through Figure 4.

From the aforementioned discussion, it is concluded that the Industry 4.0 enabling technologies, especially IoT and cloud server has the capability of enhancing the sustainability in room hygiene and air quality, as the integration of IoT enables obtaining real-time air quality data continuously and these data is analyzed in cloud server to find potential concerns in air quality and it also automates the smart system to improve air quality with respect to recommendations received from the cloud server. In the aspect of room hygiene, robots integrated with IoT and connected to cloud server offers automatic disinfection. These robots not only clean the room but are also connected with smart bins. As it receives the overflow alert, through the cloud platform, it empties it within in stipulated time to avoid an unhygienic room and also improves room ambiance. As per the sustainability aspect, these technologies deliver good air quality, and room hygiene sustainably with automation and intelligent features and also drive the realization of SDG 3 (Good Health and Wellbeing), and SDG 9 (Industry, Innovation, and Infrastructure).

Figure 5 illustrates a proposed architecture that comprises three modules that enable to realization of the smart room service related to food: smart room service module, smart kitchen service module, and portable device with staff. The smart room service module and smart kitchen module are connected through the LoRa communication and these modules are connected to the gateway for logging the real-time information of room service. The smart kitchen module is connected to the portable device staff through Bluetooth 5 communication.

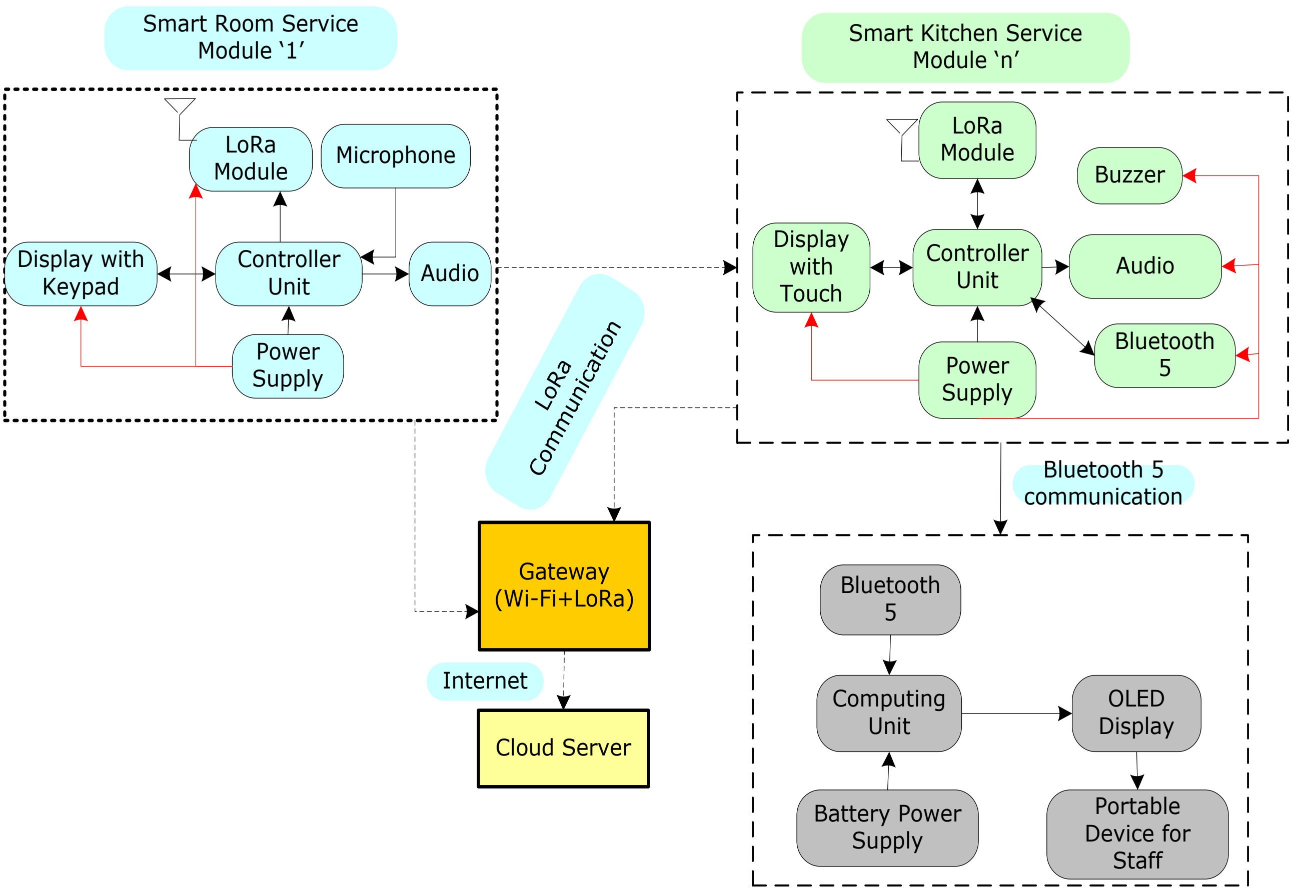

Figure 5. Implementation of smart room service with IoT and cloud server

The microphone available in the smart room service module enables the customer to request food through voice. The controller unit of this module communicates the audio message to the kitchen through the LoRa communication. Now the buzzer in the smart kitchen module, confirms that a request is received for the food, and by clicking on the accept button through the keypad, an audio message of the food request is listened to by the respective kitchen authority. The acceptance of the food request is sent to the smart room service module and also generates an alert on the portable device of a particular staff to carry food to the particular room through Bluetooth 5 communication. The same information is updated in the cloud server through the gateway. The portable device comprises an OLED display, computing unit, Bluetooth 5 module, and power supply.

3.3. Monitoring of the kitchen

IoT in the hospitality industry kitchen and restaurant to make much-needed improvements. The BOT kitchen software will assist the hotel kitchen staff in keeping daily inventory records. The interactive BOT kitchen cabinet is a cutting-edge technological system that employs load sensors, an RFID reader, an Arduino UNO, and tags to deliver detailed information on ingredients and availability for better hotel kitchen inventory management [65]. Customer Relationship Management (CRM), Kitchen Order Ticket (KOT), and Billing System are all part of the digital hospitality industry management system. It improves service quality and speed, as well as the place's appeal to a wide spectrum of clients. Furthermore, giving clients a tailored service experience saves money because they have control over what they want and when they want it, as well as taking feedback via chatbots [66]. For a smart hotel kitchen service, the current paper-based menu card could be changed by a touchscreen-centered menu card. A PIC microprocessor is used to connect the input and output modules. To build a graphic image display that receives user input and communicates it to the microcontroller, the touchscreen sensor is mounted atop a Graphical Liquid Crystal Display (GLCD) [67]. A Raspberry Pi, a touch screen, a barcode scanner, and a stepper motor are used to present customers with an Internet-connected MySQL database of available food products in the hotel kitchen. In a touchscreen interface, the back-end system delivers tracking information and related food item details. The customer can use the interface to select and order food according to his or her preferences. Furthermore, if the item is not accessible, the kitchen staff will be notified via IoT [68].

Monitoring the hotel kitchen room has attracted considerable emphasis as a way of guaranteeing the safety of people and the environment. In the previous studies, the researchers have implemented different techniques in kitchen monitoring in the aspects of placing orders and bill collection, however, there are limited studies that focused on the safety of the kitchen. Figure 6 illustrates the proposed architecture in this study, to ensure the safety and early detection of the cause of fire incidents in the kitchen through a sensor and vision-assisted system. The edge computing and AI models are powered by the vision-assisted system for accurate detection of fire through visuals and sensor data.

Along with this, the architecture comprises three different modules that visualize the real-time kitchen environment data on the cloud server. A smart sensor node, vision-based edge node with AI model, and gateway with LoRa & Wi-Fi. ‘n’ number of the smart sensor nodes and vision-based edge node with AI model will be deployed according to the requirement and area of the kitchen room. The smart sensor node is interconnected bi-directional with a vision-based edge node with an AI model through LoRa communication. The smart sensor node consists of multiple sensors for monitoring the temperature, humidity, fire, gases, and smoke in the kitchen. Here, the vision-based edge node with an AI model will be trained with different datasets with the highest accuracy for the accurate detection of fire and smoke in the kitchen that enables the fire accident. Edge computing with an AI model ensures the decision based on the sensor and vision data in real-time. In case the fire and smoke are detected by the vision-based edge node with an AI model then it immediately sends the alerts to the smart sensor node via LoRa connectivity. The controller unit immediately activates the buzzer in response to alerts received from the edge node. In normal events, the necessary sensor data and visual data of the kitchen are communicated to the cloud server via a gateway with LoRa and Wi-Fi communication.

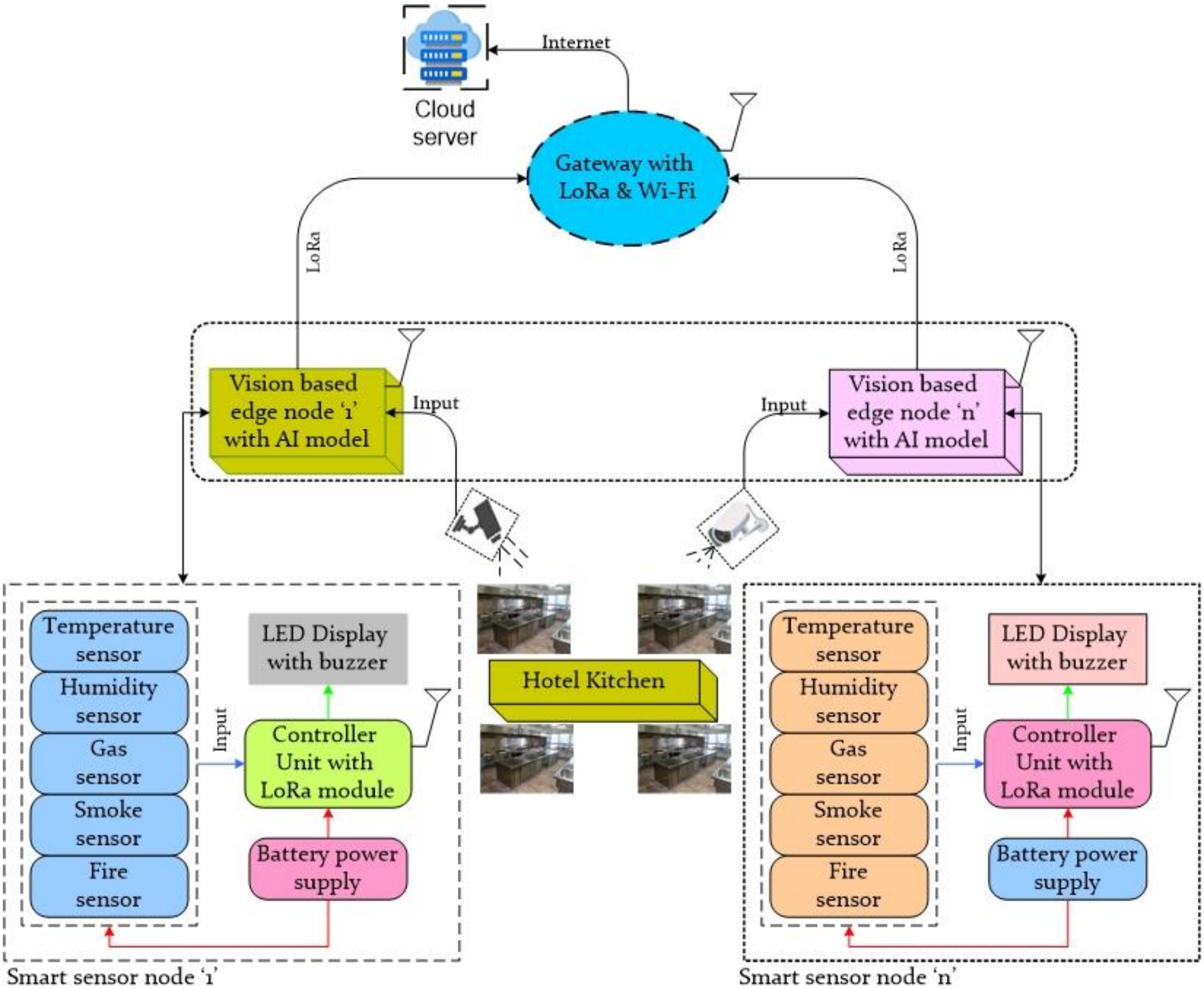

Figure 6. Vision-assisted edge node and sensor node-based safety monitoring of hotel kitchen

The proposed vision-assisted edge node and sensor node obtain the real-time sensory data and also live streaming video from the kitchen. From previous studies, it has been proved that edge-based vision and sensor nodes powered by advanced AI models are able to detect open flames, spills, and leakage of poisonous gases in real time [69], [70]. As these nodes are powered with edge computing, they process the data at the edge, which enables real-time decision-making that drastically reduces the risk of accidents. Furthermore, the vision-assisted edge node and sensor node drive sustainability, as it creates innovative infrastructure with an intelligent and smart ecosystem, where it only minimizes the loss of human lives and also damage to the kitchen infrastructure. This also directly contributes to supporting SDG 3 by ensuring the safety of workers and SDG 9 by promoting innovative infrastructure with advanced industrial technologies for smart operations.

3.4. Waste management and utilization

Food waste occurs at all levels of the hospitality business and makes up a significant amount of total waste. Blockchain technology can help with food supply chain coordination by breaking the supply chain down into minor segments and allowing kitchen workers to effectively manage food [19]. A recent study has highlighted the potential of blockchain technology which revolutionized waste management through Peer-to-Peer (P2P) architecture, which empowers different stakeholders to track and monitor in real-time with transparency and immutability about the status of waste management at every stage [71]. Another study explored that the capability of smart contracts within the blockchain enables to generation of a digital agreement between the participants of waste management processes with enhanced security, faster response, and decentralization [72].

A study has highlighted the significance of blockchain for the implementation of a circular economy in waste management, as blockchain provides an opportunity to incentivize recycled materials and also monitors the track waste waste-related emissions [73]. A novel approach leveraged blockchain technology to optimize the waste management process, where it incentivizes the citizens for proper sorting and management of waste while optimizing the cost through a mathematical model [74]. An AI meal management system that is cost-effective, flexible, customer-friendly, easy-to-use, and staff-oriented for hotels with an 'all-you-can-eat' buffet. Guests can select from a wide range of ready-to-eat items, which makes the kitchen work more smooth [75]. IoT provides a foundation for the development of e-tourism services by uniquely identifying and linking physical objects to virtual representations. This allows customers to do actions on their virtual reflections instead of actual objects, which are faster, less expensive, and more convenient [76].

As previously discussed in the room hygiene section, the same technology is integrated into this architecture to ensure real-time monitoring of waste generated in the hotel on the digital platform. 'n' number of robot-based waste bins in the kitchen and rooms are deployed in the hotel to ensure safe collection and management of the waste. The robotic system in the waste bin decides when to dispose of the waste in the central disposal bin based on the level and weight sensor data, as illustrated in Figure 7. The central disposal bin will be located outside of the hotel to ensure hygiene and also for the safer collection of waste by the collectors. Here the central disposal bin is connected to the blockchain network through the API and cloud server. In the blockchain network, the collector, inspector, and hotel authorities are connected in a peer-to-peer network. As real-time information on the amount and level of waste generated in the central disposal bin is available on the blockchain network, the collector has an idea of when to collect it, and the inspector of the waste management department has an idea about the management of waste. Even the hotel authorities are also able to visualize the real-time management of the waste generated by the hotel. In addition, a smart contract can be created between the collector and hotel authority to realize the waste-to-money model. The hotel authorities can earn money by giving collectors the option to collect significant amounts of waste and vice versa.

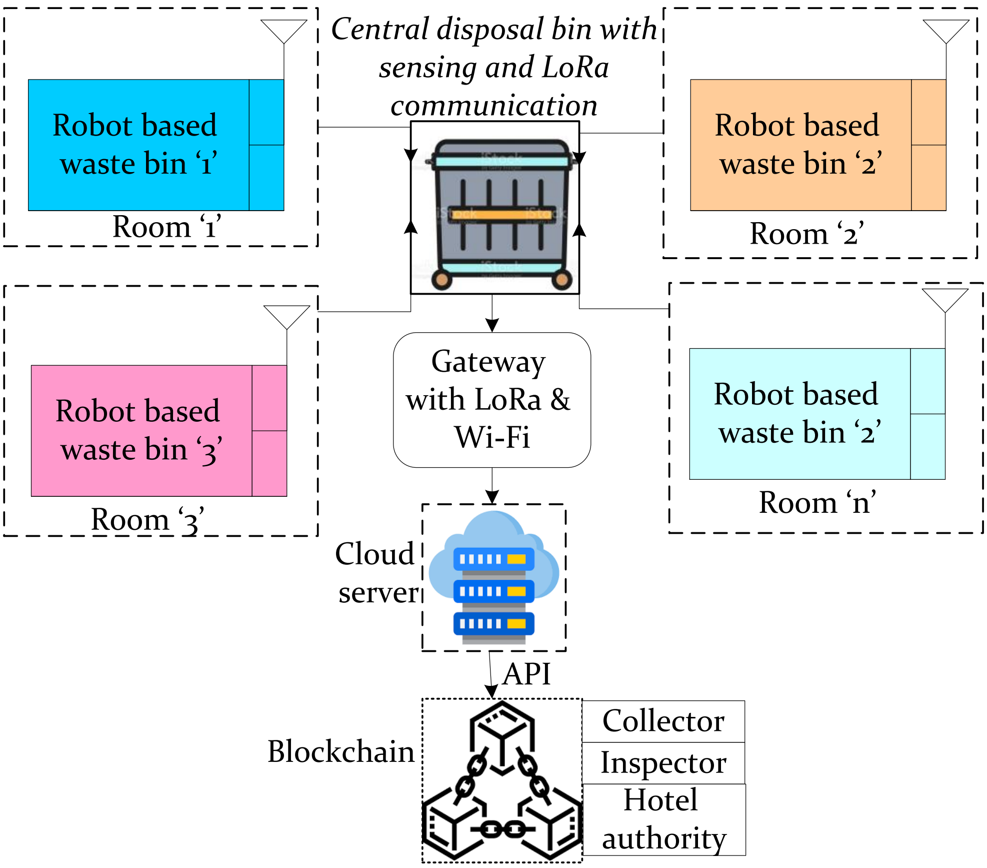

Figure 7. Robot and blockchain-based real-time monitoring and management of waste through cloud server

3.5. Video and audio-enabled chatbot for feedback

The hospitality industry is concentrating on implementing 'No Physical Contact' technologies in response to growing consumer expectations. Smart technologies, sensors, and IoT usage can assist operators in providing a positive and consistent customer and employee experience, creating fresh opportunities for smart hotels [37]. Big data, IoT, and blockchain technologies will be employed for real-time monitoring of visitor behavior, shopping trends, trips to each fascination, time spent, and financial advantages created. All of the data gathered will contribute to the tourist's overall experience, including location, amenities, staff training, approachability, transportation, lodging, food, and other elements [38]. The hospitality industry is increasingly embracing big data approaches to collect, extract, analyze, and visualize customer data. Many data-driven digital technologies in tourism and hospitality can benefit from BD analytics like AI and IoT [39].

Voice assistants (VAs) increase human-computer interactions by recognizing human speech and implementing commands spoken by customers and employees. VAs are used in smart hospitality to facilitate interactions between hotels and tourists as well as employees [40]. IoT in the hospitality industry has evolved in recent years in such a way that hospitality is developed by applying this current technology for improved customer happiness and occupancy. The majority of cutting-edge advancements in the hospitality industry, such as Wi-Fi, electrical devices, thermal and body sensors, and near-field communication (NFC), are utilized for customer satisfaction [41]. In addition, Radio-Frequency Identification (RFID), NFC, Wi-Fi, mobile connection, sophisticated data warehouses, and data mining techniques are all important components of a smart hospitality infrastructure [42]. By forecasting online grievance assumptions for travelers using big data analytics and data mining (DM) algorithms. Big data extracts data that can be used in areas like service encounter complaints, room space, value for money, cleanliness, and so on. Customer feedback data is then processed and evaluated using DM. As a result, assisting the hospitality industry in addressing the issue and putting remedies in place for the complaints concerning improved customer satisfaction [43].

3.6. Practical implications of the proposed architecture

Data transmission to these nodes is vulnerable to tampering, which may jeopardize the credibility and reliability of the acquired information. Further, the absence of effective authentication processes might enable unauthorized users to view the stored data of these nodes, providing an extensive privacy risk. However, these challenges can be overcome by integrating advanced security encryption and also blockchain technology. The previous study [77] concluded that blockchain technology with its unique features like immutability, traceability, and decentralization with an advanced hash algorithm enhances the security levels in the edge and sensor node in terms of access authentication, attack detection, and trust management.

The feasibility of implementing these nodes in existing infrastructure depends upon the facilities provided by that particular hotel. The setup of these infrastructures is composed of a multitude of systems with unique features. The cost of deploying this multitude of systems may be varied, as the user can customize the system concerning the structure of the hotel and also the investment put up by the users. Further software licensing is required to boost the security levels and also implement the operating systems. The users can assess the feasibility by deploying the system in phase-wise to evaluate the performance and address integration issues before scaling the system.

3.7. Real-time examples of Industry 4.0 technology integration

Industry 4.0 outlined as the adoption of digital technologies into the manufacturing and service sectors, has extensive implications for hospitality, client experiences, transforming operations, and business models. Industry 4.0 helps hospitality companies to implement dynamic marketing strategies by leveraging real-time data and predictive analytics. Hotels can use data-driven insights to target specific client categories, adjust pricing strategies, and increase brand engagement in a competitive market setting.

In the aspect of smart room management, the implementation of IoT devices in hotel rooms empowers to customize the guest experience with effective management, where the sensors can real-time controlling of temperature and light concerning guest preferences. The Henn-Na Hotel in Japan is a renowned instance, featuring robots handling check-in operations and IoT devices regulating room conditions, highlighting potential Industry 4.0 technology that could revolutionize traditional hotel operations [78]. Currently hospitality business integrates AI and data analytics to identify the preferences of guests. In real-time, Marriott International obtains guest data to deliver customized promotions and recommendations to enhance guest loyalty and satisfaction.

Industry 4.0 promotes sustainable practices in the hotel industry by lowering energy use and eliminating waste. For instance, MGM Resorts International employed IoT systems to monitor energy consumption in its spots, leading to substantial decreases in energy usage and greenhouse gas emissions [79].

Hilton in the United States has been active in adopting sustainability initiatives in hotels, where it introduced a proprietary system named LightStay which measures and analyses the water, energy, and waste management metrics using IoT devices and data analytics [80]. The implementation of industry 4.0 enabling technologies has helped Hilton to identify the significant areas to improve and implement effective strategies to lessen environmental impact.

InterContinental Hotels Groups in England utilized Industry 4.0 technology and established the Green Engage system, a new digital environmental sustainability platform that allows hotels to measure and manage their environmental effect [81]. The green engagement system empowers organizations to achieve resource efficiency and environmental sustainability by establishing sustainability benchmarks in the hospitality industry through waste reduction methods, energy-efficient technologies, and community involvement programs.

Marriott International in the United States employs smart building technologies and IoT-enabled devices to monitor energy consumption in real-time, enhance heating, ventilation, and air conditioning (HVAC), and reduce water consumption [82]. Marriott's innovative waste management strategies use circular economy principles to minimize the environmental impact of waste. AccorHotels is a French multinational hospitality company that integrated Industry 4.0 technologies to achieve zero carbon emissions with energy conservation by implementing renewable energy and smart thermostats. From the aforementioned real-time examples, it is concluded that the hospitality industry is leveraging Industry 4.0 technologies to achieve sustainability through sustainable practices.

4. Recommendations

In this study, we have explored the different issues present in the hospitality industry. Along with this, digitalization and real-time technology implementation in the wide aspects of the hospitality industry are addressed in this study. This study also presented the role of advanced technologies integration in the hospitality industry for delivering a robust and resilient infrastructure and environment experience to the customers visiting the hotel. In addition to this, the study proposed architectures with the integration of multiple technologies such as AI, IoT, edge computing, robots, and blockchain for the realization of real-time monitoring and controlling of the hotel. Based on the exploration, we present the recommendations that can be employed for the wide adoption of technologies and also to enhance the existing infrastructure:

- In general, it is difficult for the current hospitality sector to implement digital technologies because doing so raises the investment in establishing infrastructural upgrades. To integrate all digital technologies into the current infrastructure, researchers must find a solution. Additionally, to widely incorporate digital technologies with hardware in the current infrastructure, hardware development businesses must also customize the devices [83].
- In the current scenario, wearable devices have delivered significant features such as real-time monitoring of health, safety, and other applications [84]. It has been observed from previous studies

and real-time scenarios, that the employees in the hospitality industry require wearable devices for health monitoring and a hygienic environment [85]. The wearable devices should be empowered with edge computing units and machine learning for performing high computational activities with real-time physiological data [86]. Moreover, connecting these wearable devices to a cloud server through wireless connectivity empowers sustainable and digital infrastructure in monitoring the health of employees.

- Blockchain technology integration in the hospitality industry has significant benefits such as real-time monitoring, digital transactions with robust security, peer-to-peer networks, and data protection [87]. In the hospitality industry, food and beverages are one of the main element, where it needs to be integrated with the blockchain network for visualizing the supply chain of the goods and products [88]. Along with this blockchain can also be used for protecting the analytics generated based on customer feedback. Moreover, a circular economy may be implemented in managing food waste and supporting sustainability [89].
- An intelligent network needs to be established with food distribution centers in the local area. Generally, the hotel generates the food that is preferred to be thrown away rather than used for the needy people in the local area. The establishment of an intelligent network with the local food distribution centers enables to proper utilization of food to feed needy people. This indeed assists in achieving the SDGs like zero hunger and also combat climate change [90], [91]. IoT and cloud servers with LoRa technology can be integrated for the establishment of this intelligent network.
- Renewable energy concepts like piezoelectric need to be integrated into hotels to generate electrical power for powering IoT-enabled devices. Piezoelectric converts kinetic energy in the form of vibrations generated by the customers walking on the floor into electrical energy [92], [93]. The generation of this renewable energy lessens the electricity cost and also supports achieving the SDG of clean energy generation [94]. The microgrid of piezoelectric generation can be integrated with the blockchain network for real-time monitoring of power generation.

5. Conclusion

Sustainability is encouraged to be implemented into the hospitality sector, as it drives the new paradigm through the integration of advanced technologies for delivering quality and robust service to customers. This article explored the significance of Industry 4.0 technologies in the hospitality industry. The study of various elements of the hospitality industry where technology involvement is significantly required is identified. Further, the key findings which are observed from the study are that hotel managers employed demographic information, and ordering habits, with predictive analytics to evaluate hospitality products and services. It is identified that the IoT and AI, robotics, and sensor technologies are currently having a limited impact on the hospitality industry's guest room service sector. In the previous studies, the researchers have implemented different techniques in kitchen monitoring in the aspects of placing orders and bill collection, however, there are limited studies that focused on the safety of the kitchen.

Based on the findings, the study has proposed scalable architecture with the assimilation of Industry 4.0 technologies to enhance automation with innovation and sustainability. Following, this study discussed recommendations such as high computing power-based wearable devices, piezoelectric energy generation, wide adoption of mobile robots for room service, room hygienic and room air quality, the establishment of intelligent IoT network for feeding the needy, and blockchain for a circular economy for establishing robust infrastructure. These recommendations can be adopted in the hospitality industry for establishing infrastructure that satisfies customer requirements and also meets the goal of sustainability in the future.

5.1. Future directions

Currently, most of the hospitality industry has adopted IoT and AI in their operational flow. However, the implementation of edge computing with blockchain, virtual reality, and digital twins is yet to be assimilated in the hospitality industry. Integrating these emerging technologies has the potential to strive the industry towards sustainable practices and innovative infrastructure, enhancing the guest experience and operational efficiency.

Declaration of competing interest

The authors declare that they have no known financial or non-financial competing interests in any material discussed in this paper.

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Author contribution

Rajesh Singh: conceptualization, writing-original draft, writing-review and editing, investigation. Anita Gehlot: formal analysis, writing-original draft, writing-review and editing. Shaik Vaseem Akram: formal analysis, writing-original draft, writing-review and editing. Amit Kumar Thakur: formal analysis, writing-original draft, writing-review and editing. Lovi Raj Gupta: formal analysis, writing-original draft, writing-review, and editing. Neeraj Priyadarshi: formal analysis, writing-original draft, writing-review and editing. Bhekisipho Twala: formal analysis, writing-original draft, writing-review and editing. All authors approved the final version of the manuscript.

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