Jurnal Kejuruteraan 36(2) 2024: 625–640
https://doi.org/10.17576/jkukm-2024-36(2)-22

Incorporating the Internet of Things (IoT) Learning Module into the Smart Building Course

Shafrida Sahrani[a*], Mohamad Hanif Md Saad[b], Azrul A. Mutalib[b] & Dyg Norkhairunnisa Abang Zaidel[c]

[a]*Institute of Visual Informatics, Universiti Kebangsaan Malaysia, Malaysia*

[b]*Faculty of Engineering & Built Environment, Universiti Kebangsaan Malaysia, Malaysia*

[c]*Faculty of Engineering, Universiti Malaysia Sarawak, Malaysia*

[*]*Corresponding author: shafrida@ukm.edu.my*

Received 21 August 2023, Received in revised form 3 November 2023
Accepted 10 January 2024, Available online 30 March 2024

ABSTRACT

The utilization of Internet of Things (IoT) devices is increasing very rapidly, creating a demand for skilled professionals who can navigate the complexities of this technology. It is a crucial educational challenge to prepare undergraduates to become contributors in this emerging field. The curriculum needs to be updated to offer students both theoretical learning and practical application so they can benefit from it. This paper introduces a comprehensive IoT learning module to the final-year students of civil engineering in an elective course, Smart Building. The proposed learning module includes an introduction to IoT concepts and applications, IoT devices, communication protocols, cloud platforms, user interfaces, and IoT risk management and security, all of which can be easily integrated into existing courses. Results from the module are presented using direct and indirect assessments, including assignments, hands-on practical, examinations, and surveys. These assessments are designed to evaluate the students' understanding and the challenges they encountered in their IoT learning process. The findings indicate that a significant majority, surpassing 90% of the students, have demonstrated understanding of a minimum of three essential components of the fundamental IoT architecture, despite their limited background knowledge at the beginning of the course. Additionally, this learning module can serve as a valuable resource for other educators who intend to deliver IoT-related courses.

Keywords: Civil engineering; Curriculum; Internet of Things; Learning module; Smart building

INTRODUCTION

The Internet of Things (IoT) can transform almost everything to make our lives easier, more distinct, and more pleasant. IoT provides innovative solutions to various business, government, and industry challenges and issues (Laghari et al. 2022). There are already more than 10 billion IoT devices currently in use, and 127 new ones are connecting to the internet every second. By 2025, new connections are predicted to expand 20 times. The growth of the IoT has created new opportunities for skilled engineers and professionals. Immersat Research found that 47% of businesses had to outsource their IoT-based projects due to a lack of internal expertise (Inmarsat Research 2022). Career opportunities in the IoT industry include the development of an IoT product (hardware design, testing, and integration), embedded systems, and cybersecurity.

It is a crucial educational challenge to prepare undergraduates to become contributors in this emerging field. The curriculum needs to be updated to offer students both theoretical learning and practical application so they can benefit from the era of IoT (Abichandani et al. 2022). Some questions that arise when educating students about IoT technologies are: (a) which IoT topics should be covered in a course curriculum? (b) what are the most important IoT skills and knowledge students need to learn? (c) what is the most effective method for encouraging students to learn IoT? Many institutions are developing or delivering IoT courses, but their capacity is limited. This includes a lack of financial resources, complexity, expertise, ethics, risk, and data security. According to a report, there were not enough IoT trainers or experts in Malaysia to deliver and conduct specialized IoT courses (Leong &Letchumanan 2019).

IoT is a relatively new subject that continues to grow at a rapid rate. Students must be prepared with the necessary tools and skills to keep up with the incredibly rapid pace of this sector. The market is currently booming with new products, technologies, and standards; the knowledge they acquire during their studies will be obsolete by the time they graduate. Therefore, a successful IoT curriculum must consider sustainable technical content and teaching paradigms. Few studies on the IoT curriculum for technical and non-technical backgrounds have been proposed in the published literature.

According to (Silvis-Cividjian 2019), future IoT experts must achieve a balance between technical knowledge and user-related issues, including ethics, security, and privacy. The electrical and computer engineering students are introduced to the industry-relevant IoT course by (Seng, Wei, & Narciso 2020). The author concluded that by incorporating more hands-on laboratories in close collaboration with industry, students will have the opportunity to further refine their skills in creating IoT-centric solutions. (Bajracharya, Gondi, & Hua 2021) recommend that IoT courses should be designed and taught differently for non-technical students than for engineering, engineering technology, and computer science majors. (Ronoh et al. 2021) review the suitable learning methodologies for teaching IoT, including problem-based learning (PBL), flipped laboratories, cooperative learning, and other mixed methods. (Ahmed et al. 2022) suggest adding IoT learning modules, which involve device programming, system design, and cloud development, to existing computer science courses so that students can learn about smart-IoT technologies. (Yuan et al. 2023) propose teaching materials for senior undergraduate students and master's students on the IoT operating system. It is important to note that the landscape of IoT education is dynamic, and research in this field is ongoing. Hence, there arose a necessity to standardized curriculum and learning resources for IoT at different educational levels.

This paper describes initiatives to address these IoT educational issues and challenges by introducing IoT topics in the Smart Building course. This is an elective course that is being offered for the first time to final-year students pursuing a Bachelor of Engineering degree at Universiti Kebangsaan Malaysia's (UKM) Department of Civil Engineering in the Faculty of Engineering and Built Environment. The introduction of IoT in this course can leverage every aspect of building management. As an example, IoT technologies help automate traditional building management systems (Kim et al. 2022). Smart buildings also use IoT technologies to connect sensors, lights, and meters to collect and analyze data. The buildings then utilize this data to improve a variety of aspects, including the infrastructure, public utilities, and services. In this course, in four weeks, students will get to engage in a series of hands-on activities that introduce them to all the fundamental aspects of IoT. Indirect and direct assessments such as teaching surveys, assignments, and examinations were executed to determine the performance of the students and the difficulties they encountered.

The remaining section of this paper is arranged as follows: Section 2 discusses an overview of IoT technology and its role in smart buildings, including the evolution of IoT in education. Section 3 focuses on incorporating the IoT into the curriculum and providing guidance for other educators who intend to deliver IoT-related courses. The next section describes the teaching and learning IoT approaches for the Smart Building course. The results are reported using direct and indirect assessments. The paper concludes with some suggestions for improving future offerings.

RELATED WORKS

INTERNET OF THINGS (IOT)

The Internet of Things (IoT) is a network of devices, things, and/or software that are all connected to each other. This network collects, analyzes, and sends information over the internet and cloud technology without the need for human interaction (Lombardi, Pascale, & Santaniello 2021). The deployment of IoT has already benefited a variety of sectors. Smart buildings and home automation allow devices and systems to be controlled automatically. This has improved security and energy efficiency while offering comfort to building occupants (Karimi et al. 2021). IoT technology can also assist in the early detection of structural cracks, leading to timely repairs and potentially preventing catastrophic failures (Abdul Razak et al. 2022). During the COVID-19 pandemic, IoT technology has been widely used in the healthcare sector (Dey & Chatterjee 2022; Velliyangiri et al. 2022). The IoT can reduce unneeded physical contact through remote monitoring and early diagnosis, creating an additional support system for doctors and patients. The IoT also has various advantages in the transportation industry, such as reducing the frequency of accidents, optimizing road traffic, and lowering fossil fuel usage and pollution (Kumar, Tiwari & Zymbler 2019; Malik et al. 2021). The IoT has changed people's lives, making them more adaptive and intelligent.

Adding value to IoT with rapidly evolving technologies such as artificial intelligence (AI), digital twins, virtual reality (VR), blockchain, machine learning (ML), and others will provide a competitive advantage (Hansen & Bøgh 2021; Atlam et al. 2020; Fuller et al. 2020). The blended IoT has the potential to transform the way organizations, industries, and economies operate. For example, pairing IoT with ML and AI technologies enables the automatic identification of patterns and anomalies in the data generated by sensors, such as humidity and temperature, air quality, pressure, and sound. In the insurance sector, the IoT-blockchain technology allows the implementation of smart contracts, fraud, and claims management. The convergence of IoT with VR and digital twins can train personnel through interactive operational process demonstrations in preventative maintenance operation. These advancements also enable technical personnel to conduct maintenance duties with remote supervision immediately.

The IoT ecosystem is based on four key elements which are, devices (for data collection), connectivity (for data transmission), analytic and storage (for information process), and user interface (Lombardi, Pascale, and Santaniello 2021). Devices are the first layer of the IoT ecosystem, and they act as the backbone of the network. Sensors in IoT devices will measure and collect the required data from their surroundings, capturing real-time environmental changes. The sensors will transmit raw data to the cloud using IoT gateways; major elements of IoT communications. It performs as a network router, where it sends data between IoT devices and the cloud. It is also used to manage communication between IoT protocols and networks, providing additional security to the devices. IoT networks communicate signals and data with other devices, gateways, and services running in the cloud. The primary networks that can facilitate various sectors for IoT applications are short-range networks and low-power wide-area networks (LPWAN). Bluetooth Low Energy (BLE), Wi-Fi/802.11, Near Field Communication (NFC), and Zigbee are examples of short-range IoT networks (Bayılmış et al. 2022). LPWAN enables IoT communication between devices over 3 to 20km distances. Long Term Evolution for Machines (LTE-M), 5G, Narrowband IoT (NB-IoT), and LoRa are examples of LPWAN.

The cloud which is known as the IoT network's central processing unit, manages, stores, and makes decisions on data. After the data is transferred to the cloud, it must be processed. Massive data is processed in milliseconds. It is then used for real-time analytics, enabling fast decision-making regarding the collected data and signals. Edge or fog computing is an extension of cloud networks, representing an alternative cloud option. When there is a need for substantial on-premises data processing and storage, edge computing is the preferred option. On the other hand, the cloud could be the favored choice as a high-performance facility with massive scalability and reduced operational expenses. The processed data information is easily accessible and managed through the IoT user interface (UI). The IoT system can be accessed by the user either through the devices themselves or remotely via smartphones, tablets, and laptops. For instance, Amazon Alexa and Google Home smart home systems allow users to interact with their smart devices.

THE ROLE OF IOT IN SMART BUILDINGS

Smart buildings are designed to provide an optimal environment for occupants while minimizing resource consumption and operational costs (Kim et al. 2022). Smart buildings come in various types, tailored to serve specific purposes and industries. These include commercial and residential buildings, factories and warehouses, as well as healthcare facilities, educational institutions, transportation hubs, and many others. The IoT technologies have significantly impacted smart buildings and home automation. It allows devices and systems to be controlled automatically, which improves security and energy efficiency, optimizes building operations, enhances the user experience, and offers comfort to building occupants. Implementation of IoT for smart buildings requires a good understanding of technical needs to ensure that the system is stable, effective, and secure (Jia et al. 2019). Engineers, architects, planners, and others are currently challenged to keep abreast of research on IoT and smart building technology.

In recent years, IoT has begun to penetrate the building industry. Figure 1 depicts the research trends observed in the field of IoT-smart buildings between the years 2018 and mid-2023.

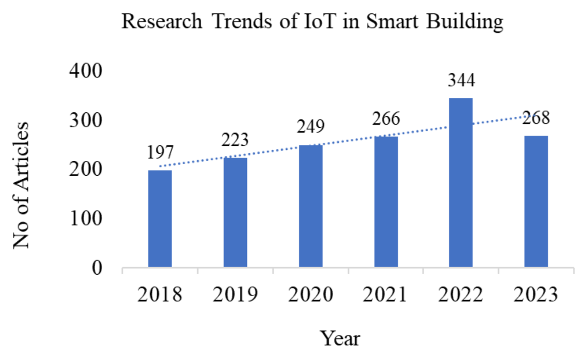


FIGURE 1. Trends in IoT and Smart Building Research from the Year 2018 to Mid-2023

The Scopus database was used to identify publications on the adoption of IoT and smart buildings. These publications covered a wide range of topics, including but not limited to energy efficiency, automation, security, privacy, and human-centric design. The trend shows an increase in yearly publications and will likely continue to evolve and expand in the future. Statista also predicts that the smart home market alone will continue to expand at a 11.43% annual growth rate and reach around USD 231 billion by 2028 (Statista 2023). Hence, there is a clear need for IoT technologies to be deployed in a smart building environment.

The researchers have implemented sensors and IoT technologies to track and monitor various parameters, including temperature, humidity, water level, air quality, and energy consumption, within residential or general building settings. This data is analyzed in order to facilitate real-time adjustments and support long-term improvements. The lighting, room temperature, and other environmental factors can be adjusted to create a comfortable and productive atmosphere. It can be monitored and controlled remotely through computer or mobile applications. In the event of an emergency, the IoT system has the capability to trigger an alarm or promptly issue an alert, such as by activating warning lights, sounding sirens, sending mobile and email notifications, or displaying an alert on a web dashboard. Table 1 summarizes the selected examples of a published article related to IoT-based technologies, considering various scenarios for a smart building such as energy management, occupant comfort, ergonomics and user-friendly design, indoor air quality, indoor positioning, building analytics and data visualization, predictive maintenance, safety and security, and integration with other technologies.

TABLE 1. Selected research on IoT for the development of smart buildings

Category	Type	Application Area	Description	IoT-related Technologies	References
Energy management	Residential	Monitoring of loads and recognition of activities.	IoT architecture-based system for activity recognition	Low-end meter device, short-range wireless communication (Bluetooth, Wi-Fi, Zigbee)	(Franco et al. 2021)
	Residential	Room temperature monitoring and controlling household electronic devices	GUI interface for LoRa-based smart homes	LoRa, NodeMCU (ESP8266 Module), smartphone apps (Android or iOS), web-based	(Mu'Amar Wildan, Hamidi, and Juhana 2020)
Ergonomics/ User-friendly	Residential	Barrier-free stair system	Smart home system for individuals who have access problems when entering and exiting homes	NodeMCU (ESP8266 Wi-Fi module), RFID tags, temperature-humidity, motion detection, gas and moisture sensors	(Unaldi, Yalcin, and Elci 2023)
	Restroom	Monitoring restroom condition and availability	IoT-based system to check restroom status	Infrared proximity sensor, motion sensor, ESP32, ESP8266 Wi-Fi module, Blynnk	(Thaenthong, Kwanjun, and Charoensuk 2022)
Indoor air quality	General	Indoor air quality monitoring	IoT-based system and web portal for air quality monitoring	Raspberry Pi, gas sensor, Google Firebase	(Vaheed et al. 2022)
	General	Indoor and outdoor air pollution monitoring	An innovative, low-cost device for monitoring air pollution (APMD)	NB-IoT, Wi-Fi, Particulate Matter (PM) sensor, gas sensor	(Das et al. 2022)
	General	Indoor air pollutant assessment	Indoor air quality and humidity management system	IoT-connected sensor (Waspmote sensor), Wi-Fi, Meshlium gateway router, cloud service	(Ha, Metia, and Phung 2020)

continue ...

... cont.

Occupant Comfort	Office	Detection personal exposures to office air pollutants and building occupancy	Real-time estimation of personal exposure and occupancy using smart sensing technologies	IAQ (PM, CO_2) sensors, Raspberry Pi	(Yun and Licina 2023)
Indoor Positioning	Museum	Enhance the user experience in a museum	IoT-based smart museum by receiving notification about the exhibit	BLE, iBeacons, Android apps	(Spachos and Plataniotis 2020)
Building analytics and data visualization	Residential	Tracking activity data in a smart home setting	IoT-centric multiactivity recognition system	Wearable IMU sensors, interactive web-based dashboard	(Perumal et al. 2022)
	Residential	Monitoring the level of tanks and detecting leaks.	IoT-based system that utilises live water usage data	ThinkSpeak IoT platform, Raspberry Pi, water flow meter	(Harika, Chowdary, and Kiranmai 2020)
Predictive maintenance	Public toilet	Proactive management of maintenance for public hygiene and sanitation facilities	A monitoring framework for public toilet management based on IoT and cloud technology	Ambience sensor, smart energy meter, cloud platform, web-based user interface	(See-To et al. 2022)
	General	Building facility monitoring and visualizations	IoT alert systems with BIM models	DHT22 sensor, light-dependent resistor (LDR) sensor, ESP8266, Raspberry Pi, MQTT, NodeRED	(Villa et al. 2021)
Safety and security	General	Door lock system	IoT-based home security system	Raspberry Pi 3, Wi-Fi camera, Bluetooth, Android and OS apps	(Hashim et al. 2023)
	General	Locate the fire and occupants of the building and guide them to a secure exit	IoT system to enhance building fire evacuation process	BLE beacons, Wi-FI, MQTT, smoke sensors, Raspberry Pi, ESP32	(Zualkernan et al. 2019)
	Kitchen	Real-time gas leakage detection	Low-power IoT devices for natural gas detection with smart notification system	LoRa, Arduino, Wi-Fi, GPS, MQ4 natural gas sensor	(Islam et al. 2020)
	Industry	Oil leak remote monitoring and detection	IoT-based oil leak detection system	LoRa, flow meters, temperature sensors, The Things Network, NodeRED, ThingSpeak	(Baiji and Sundaravadivel 2019)
Integration with others	Hotel	A digital smart system that uses touch-based technology to manage the entire meal ordering and serving process	Integration of IoT-based sensor and VR projector	Zigbee, Arduino, Wi-Fi	(Reddy SP et al. 2023)
	Campus	Automated collection of garbage from the autonomous bins	Autonomous waste management system using IoT and AI	Arduino, Pi camera, ultrasonic sensor, ESP8266, Wi-Fi, environment sensor	(Nguyen, Le, and Dao 2021)

EVOLUTION OF IOT IN TEACHING AND LEARNING

The emergence of IoT in teaching and learning has undergone a significant transformative process, reshaping education in various ways. Two important categories of IoT in education activities include utilizing IoT devices to teach any subjects effectively and incorporating IoT courses into the curriculum. IoT technology was in its initial stages in the early 2000s. The educators began experimenting with basic technological applications, such as radio frequency identification (RFID), for tracking assets and monitoring student attendance. Smart classrooms also emerged with the introduction of interactive online whiteboards, stylus pens, and early e-learning platforms (Mircea, Stoica, & Ghilic-Micu 2021).

The proliferation of mobile phones, portable devices and the availability of cost-effective sensors have facilitated the development of smart campuses. Academic institutions are increasingly adopting IoT solutions to address energy management, security, and building maintenance needs. Learning management systems (LMS) are also becoming more prevalent, enabling online assignments, quizzes, tests, and educational content sharing. Such an approach offers students improved accessibility to learning resources and communication channels while also allowing educators to evaluate students' progress in real-time. The collected data can also be analyzed through IoT analytic platforms, which will be a valuable resource for educators to monitor academic performance and identify those who need further assessment or intervention, as well as to improve teaching strategies.

The COVID-19 pandemic expedited the adoption of IoT in education (Khan, Tarimer, & Taekeun 2022). Academic institutions, including schools and universities, are increasingly utilizing IoT technology to facilitate remote and blended learning approaches. Consequently, the utilization of virtual classrooms, online proctoring, and AI-driven chatbots for student support experienced a significant increase. The scope of smart campuses has also grown to include contactless access control, temperature monitoring, and social distancing enforcement. The integration of IoT with other technologies, such as AI and machine learning algorithms, helps to predict student outcomes, recommend personalized resources, and automate administrative tasks. This also includes gamification, driven by IoT sensors and mobile devices, which has transformed the way students engage with educational content. The utilization of augmented and virtual reality (AR/VR) technology, integrated with the IoT, is being employed for immersive and interactive learning experiences. Students could engage in virtual field trips, collaborate on projects remotely, and access resources from anywhere. Remote labs equipped with IoT devices enable science and engineering students to conduct experiments from home.

The evolution of IoT in teaching and learning continues to adapt to the shifting educational landscape, with a strong focus on personalized and data-driven approaches to enhance the quality of education and the student experience. In the coming years, the integration of IoT technology promises to further transform education.

INCORPORATING IOT INTO CURRICULUM

As more IoT devices become connected, we must ensure that students nowadays are equipped with the necessary abilities to drive this technology forward. Developing the IoT learning module for smart building based on current trends can provide several motivations. This includes giving students useful information about the latest changes, making the learning materials more relevant, and helping students stay on the cutting edge of the field. Many academic institutions offer IoT courses ranging from introductory to advanced levels. Some institutions also offer specialized courses on IoT as a certificate program. Most IoT courses emphasize hands-on, hardware-centric projects. Several core technical concepts must be covered for a thorough understanding of IoT (Nelke & Winokur 2020). This includes the following topics:

INTRODUCTION TO THE CONCEPTS AND APPLICATIONS

This module covers the IoT fundamentals, elements of the IoT ecosystem and architecture, IoT applications and trends in various sectors, and the benefits and challenges of the IoT. Students should be able to understand the definition and significance of the IoT and identify how it differs from traditional data collection systems.

IOT DEVICES

Connected IoT devices; sensors and actuators play an important role in creating solutions using the IoT. In this module, different types of sensors, actuators, and embedded development boards that are commonly used for IoT technology should be introduced. This includes an explanation of how it is designed as well as the connection between the devices, networks, and sensors. Students should be able to determine appropriate devices (sensors, microcontrollers, and others) to be used in a particular IoT system.

IOT COMMUNICATION PROTOCOLS

Connectivity is one of the main pillars of the IoT. Different communication and network protocols are required due to the variety of IoT data types and applications. This module should introduce the basic IoT networks and communication protocols such as cellular, Wi-Fi, Bluetooth, Zig-Bee, LoRaWAN, Message Queuing Telemetry Transport (MQTT), and many others. Students should be able to determine the appropriate protocol for communication between IoT devices.

CLOUD COMPUTING

In this module, the role of cloud computing in IoT, the cloud platform and its architecture, cloud types and services, and integration with the IoT platform should be covered. Students will then be able to construct IoT systems and utilize cloud services for the processing and storage of data generated by IoT devices.

IOT PLATFORM AND USER INTERFACE

The IoT platform is utilized for managing, collecting, storing, visualizing, and analyzing data from IoT devices. The functionality and demonstration of available IoT platforms on the market (AWS IoT, ThingSpeak, NodeRED, Kaa, to name a few) can be introduced in this module. Students should be able to create online dashboards for data analytics and telemetry.

SECURITY AND RISK MANAGEMENT

This module should cover the factors impacting IoT security, how to build trust in IoT, security management for IoT systems, and IoT device security itself. This includes privacy problems, cyberattack threats, big data problems, and compliance that needs to be followed with the laws and regulations. Students should be able to understand the evolving risks and challenges in IoT.

It takes a different approach to teach IoT concepts to students with diverse backgrounds (both technical and non-technical). These include technical lectures, open discussions, continuous assessments such as assignments, project and test, laboratory exercises, blended learning, and many others.

IOT LEARNING MODULE IN SMART BUILDING COURSE

In this paper, an introduction to IoT technology topics was integrated in the Smart Building elective course for final-year Bachelor of Engineering students in the Department of Civil Engineering, Faculty of Engineering and Built Environment at Universiti Kebangsaan Malaysia. The course aims to expose students to the technology and tools for operational control of smart buildings. Smart buildings use internet-connected devices to provide occupants with safety and comfort while monitoring and controlling many aspects of the building environment, such as energy efficiency and security. These devices are part of the IoT, which consists of electronic sensors and actuators connected to the internet through gateways, allowing for real-time data collection. Thus, students need to understand the ecosystem of IoT and how it can be implemented to create a smarter building. The framework for the IoT teaching and learning approach in the Smart Building course is shown in Figure 2.

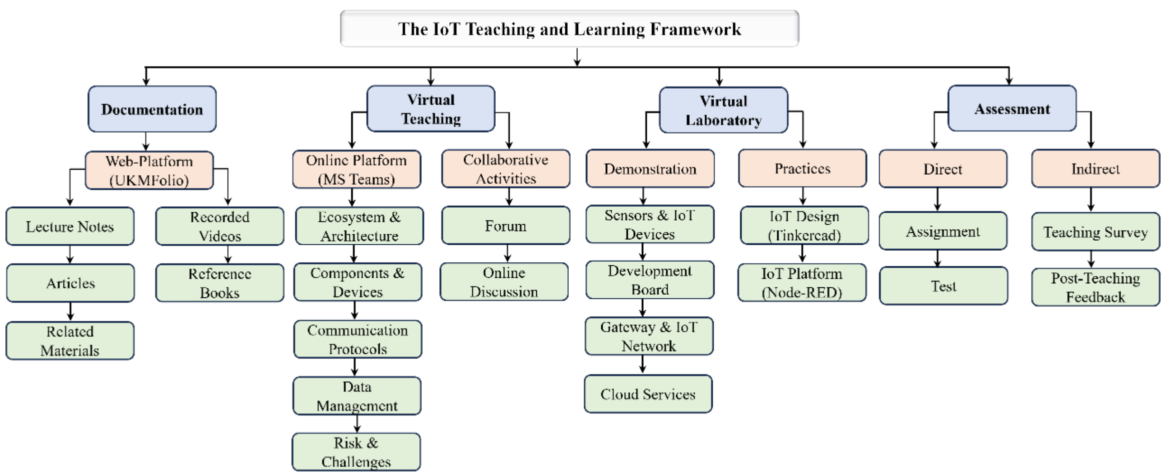


FIGURE 2. Smart Building Course IoT Teaching and Learning Framework

Given a duration of four weeks (two hours for two sessions per week), the integrated IoT topics into the existing Smart Building syllabus include the following:INTRODUCTION TO IoT (ECOSYSTEM AND ARCHITECTURE)

In the first week, students will learn the fundamentals of IoT and the importance of IoT in society. Students will also explore the ecosystem and architecture of IoT. Examples of IoT applications for smart built environments, including smart buildings, smart homes, and smart cities, to address current technologies that have been incorporated were also introduced in the lectures. These smart systems (refer Figure 3) include security and access control, energy management, climate control including temperature, humidity, and ventilation, building management systems such as structural health and predictive maintenance, and automation systems (lighting control, fire detection, water monitoring and many others). The drivers and emerging trends related to IoT-based smart buildings, as summarized in Table 2, were also discussed.

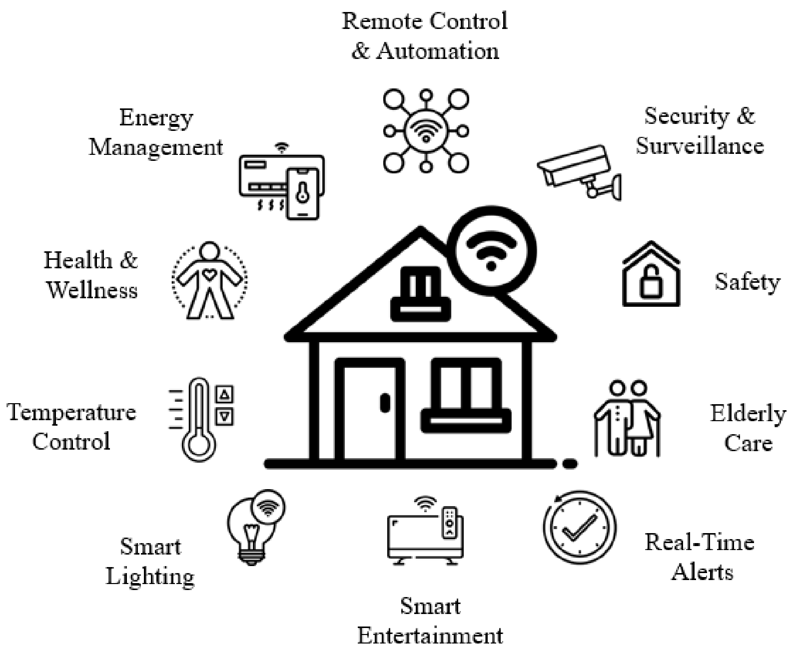


FIGURE 3. IoT application in buildings and home

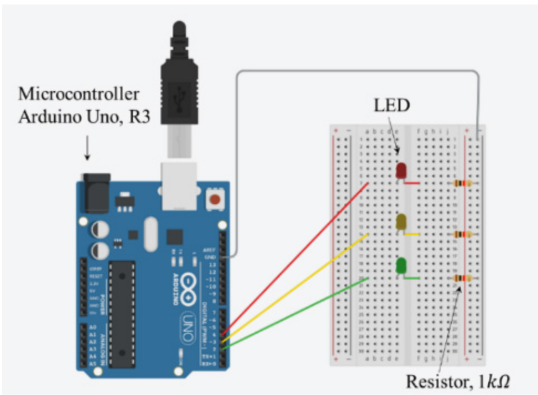
TABLE 2. Future trends for IoT-based smart building.

Drivers	Description
Urbanization	Increasing urbanization will create rural areas and require the relocation of cities.
Technology	Enhances the application of existing methods and knowledge to make building systems work better or easier to use.
Health and Wellbeing	Support a healthy lifestyle through healthy noise management, optimal temperature, and clean air.
Lifestyle	Making it possible to work and live by combining work and living spaces and giving people access to the internet 24 hours a day.
Climate Change	Climate-resilient structures to withstand natural disasters.
Space Utilization	Flexible buildings that are scaled to facilitate multiple functions
Security	Enhances the procedures for the safety of the building and its occupants to minimize risks and reduce their consequences.
Efficiency	Reduces the consumption of natural resources and energy by enhancing the performance of the building's systems.

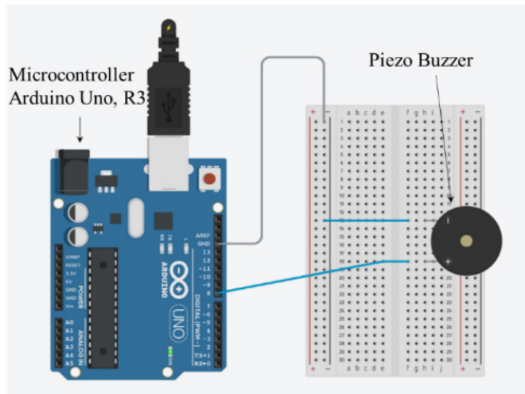
A blended learning (BL) approach was implemented in this session to encourage student engagement and active learning. The lecture is conducted online, and the recorded videos will be provided on an e-learning platform (UKMFolio), with a total duration of 1.5 to 2 hours for each session. Students may also download the lecture notes that go along with the videos. A post-quiz was conducted after the session to measure students' understanding of the topic taught and will allow educators to evaluate their teaching and learning methods.

IOT DEVICES (SENSORS, ACTUATORS, AND MICROCONTROLLERS)

A variety of IoT-applicable sensors, actuators, and microcontrollers used in smart buildings will be introduced in the second week session. These devices should be capable of collecting environmental and operational data about the buildings. These include the types of sensors and actuators, the criteria for choosing the sensors and actuators, the classification of sensors, and the main benefits of each. Some of the important smart building sensors are temperature and humidity sensors, motions sensors, smoke sensors, and light sensors. Different types of microcontroller development boards, which include single boards, Arduino, and Raspberry Pi, their applications, and an integrated development environment (IDE) are also introduced.



(a) Smart lighting system



(b) Buzzer sound for alarm system

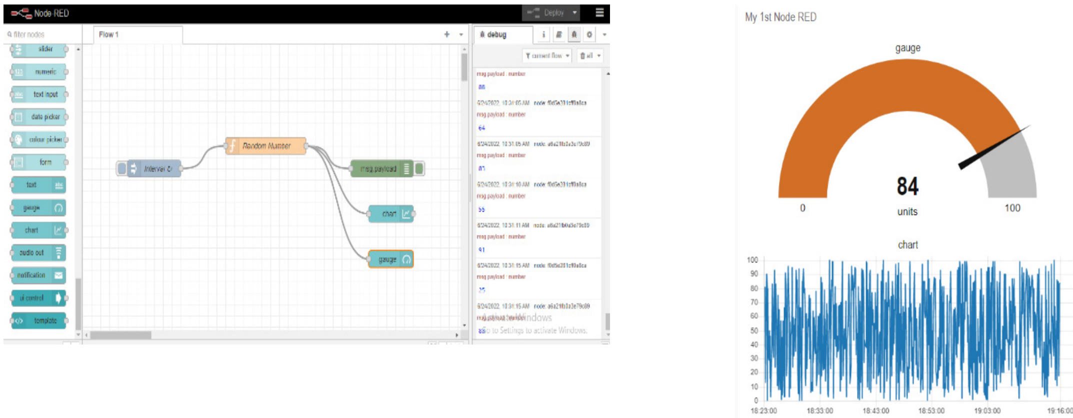
FIGURE 4. Sample of IoT based projects in Tinkercad

A demonstration and hands-on session are conducted to allow the students to learn how to use Arduino communication modules that can be applied to different IoT systems. Students can replicate the IoT prototype without the need for physical hardware by using the online simulator Tinkercad, which is suitable for beginners and those without technical backgrounds. In this session, two exercises with Arduino IoT-based projects were given to the students to get familiar with the IoT devices and their functions. Arduino is a simple and versatile microcontroller that requires a basic programming language such as C or C++. A sample source code is also provided for students' reference. Figure 4 shows the students' work in Tinkercad for the smart lighting system and buzzer sound for the alarm system.

COMMUNICATION PROTOCOLS AND CLOUD-IOT PLATFORM

IoT devices communicate using IoT protocols to ensure that data retrieved from sensors is received and understood by another device, a gateway, or an application. In the third week, students will be introduced to the types of IoT communication protocols, their pros and cons, and their compatibilities. There are many IoT protocols, and each one of them has its own set of different features. Each IoT protocol supports device-to-device, device-to-gateway, device-to-cloud, or a combination of these communications. The ideal IoT deployment methodology is determined by cost, power consumption requirements, geography, battery-operated options, and the presence of physical barriers. Some protocols work well for the IoT systems in buildings, while others work well for IoT deployments in multiple or outside buildings.

In addition, students will also explore the concepts, infrastructure, and capabilities of a cloud based IoT platform. IoT platforms are middleware that facilitates data flow throughout the network and connects IoT devices to the cloud. There are numerous IoT platforms in the market, including Cisco IoT Cloud Connect, Microsoft Azure IoT Suite, IBM Watson IoT Platform, Google Cloud IoT Platform and AWS IoT Platform. For a better understanding of IoT architecture, students will learn how to develop a simple IoT application with Node-RED in the second session. Node-RED is a powerful and easy-to-use programming platform for the simulation of IoT scenarios. It is an open-source software that connects the input and output (I/O) of devices, cloud-based systems, databases, and application programming interfaces (API). Figure 5(a) shows a sample of Node-RED programming flows to display the IoT data and Figure 5(b) shows the gauge and chart display in the Node-RED dashboard in real-time.



(a) Node-RED workspace (b) Gauge and chart in Node-RED dashboard

FIGURE 5. Node-RED IoT Platform

In the final week, students will learn about the risks and challenges of IoT, including threats and attacks, risk management, and compliance with laws and regulations. Exploratory and case study activities are conducted during this session. The discussion covers several categories, including data and applications, technology acceptance, security and privacy, infrastructure, network and physical environment, and finance as shown in Table 3. IoT devices without virus or malware security are vulnerable to becoming bots that attack other network devices. The routing and forwarding functions of the IoT devices can potentially be taken over by hackers. Additionally, they can have access to sensitive information that IoT devices collect and transmit. Therefore, understanding risk management enables users to effectively employ IoT technologies while minimizing risks, such as data loss, security breaches, system failures, and other scenarios.

TABLE 3. IoT risk factor in smart built environment

Data and Application	Manual data feed Poor device management
Technology Acceptance	Non-users IoT IoT skill gaps
Security and Privacy	Data interception Radio frequency jamming Firmware exploits Unauthorized access
Infrastructure	Outdated infrastructures Complex environments Inefficient IT support
Network and Physical Environment	Lack of bandwidth Packet loss Intermittent communication Compatibility & standardization
Financial	Financial constraint Third party suppliers and vendors

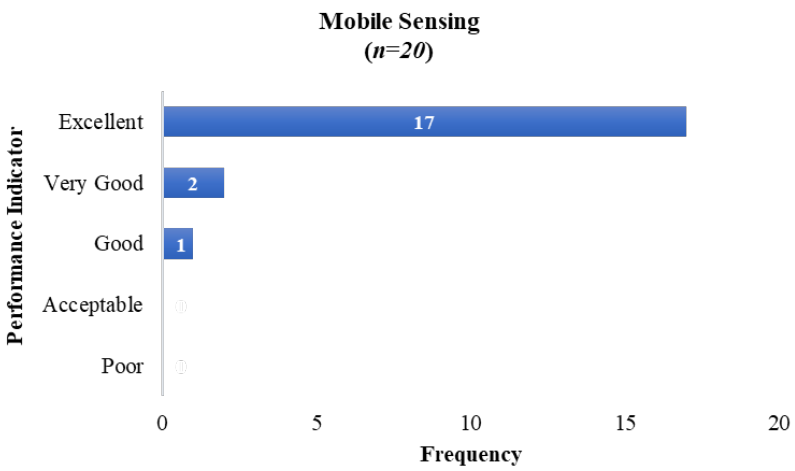
STUDENT FEEDBACK AND PERFORMANCE

This section used primary data from final-year Civil Engineering students () who enrolled in the elective Smart Building course to determine the understanding and challenges of IoT implementation. In this 4-week experience out of a total of a 14-week course, students take part in a series of lectures and practical exercises that introduce them to all the fundamental IoT concepts. Direct and indirect assessment from the assignment, mid-term examination and teaching survey were analyzed to measure students' performances and the challenges and difficulties they were struggling with.

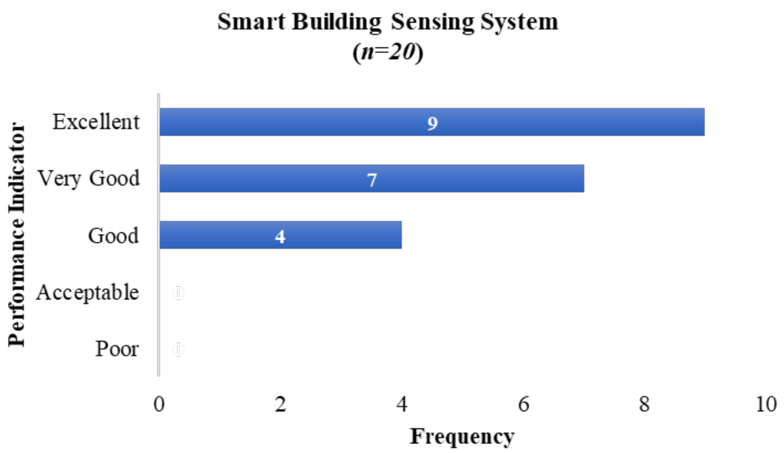
The students were assigned to write a report identifying the sensors available in smartphones and discussing their functions and applications in the context of smart buildings.

During class lectures, sensors on smartphones were not discussed. Students were only exposed to sensor technology in general. This study is motivated by the fact that smartphones are arguably the most versatile IoT devices that we use daily. Investigation of mobile sensing is well-suited for this introductory course as it is equipped with multi-communication interfaces (Bluetooth, Wi-Fi, and cellular communication including 4G and/or 5G) and sensors for user identification, monitoring, tracking, localization, and even personality traits. Table 4 shows the rubric for the assignment, with two performance indicators chosen. By assigning this as an independent study project, the first indicator will evaluate the students' ability to understand a smart sensor in the IoT. The other indicator is used to measure students' understanding of the types of sensors that are commonly used in smart buildings. The outcome scored by the rubric was separated into five different performance indicators ranging from excellent to poor.

Figure 6 summarizes the results of the assessment for the IoT sensing device assignment. A total of 85% of students (refer to Figure 6(a)) were rated excellent for providing a detailed discussion on the types of sensors integrated in smartphones and their functions. Figure 6(b) demonstrates that 45% of students discussed smart building sensing systems, including their concept, features, and applications, at an excellent level. This result shows that all of the students have a good ability to understand the main components of IoT devices.



(a) Sensors in smartphone



(b) Sensors in smart Building

FIGURE 6. Results of IoT sensing device assignment

TABLE 4. Rubric and performance indicators

No	Description	Poor	Acceptable	Good	Very Good	Excellent
1	Discussion of sensors in smartphones and their function	No discussion of sensors in smartphones and their functions	Discussion of sensors and its functions but did not incorporate with smartphone	Discussion of required sensors in smartphones but no details explanation of its functions	Specified types of sensors incorporated into smartphones and their operational mechanisms	Provide a detailed discussion on the types of sensors integrated into smartphones and their functioning principles
2	Discussion on the sensor's application in the context of smart buildings	No discussion of sensors' application in the context of smart buildings	Discussion of sensors and their functions, but did not incorporate them into smart buildings	Discussion of the required sensors in smart buildings but no detailed explanation	Specified the used of sensors in smart building application	Provide a detailed discussion on smart building sensing systems, including their concept, features, and applications

TABLE 5. Interactive teaching and learning activities

No	Items	Scale					Average	Standard Deviation
		1	2	3	4	5		
1	Optimizing the use of space (physical/digital) to achieve learning outcomes	0	0	0	1	16	4.94	0.24
2	Using a variety of teaching methods to meet the needs of a variety of students	0	0	0	1	16	4.94	0.24
3	Challenge students to present and reinforce their ideas	0	0	0	2	15	4.88	0. 32

Note: Scale Reference: (1-Very Dissatisfied; 2-Dissatisfied; 3-Neutral; 4-Satisfied; 5-Very Satisfied)

TABLE 6. Knowledge content.

No	Items	Scale					Average	Standard Deviation
		1	2	3	4	5		
1	Relating teaching content to learning materials	0	0	0	0	17	5.00	0
2	Give relevant examples	0	0	0	2	15	4.88	0.32
3	Explain concepts that are difficult to understand clearly	0	0	0	1	16	4.94	0.24
4	Utilizing technology efficiently in the classroom	0	0	0	1	16	4.94	0.24

Note: Scale Reference: (1-Very Dissatisfied; 2-Dissatisfied; 3-Neutral; 4-Satisfied; 5-Very Satisfied)

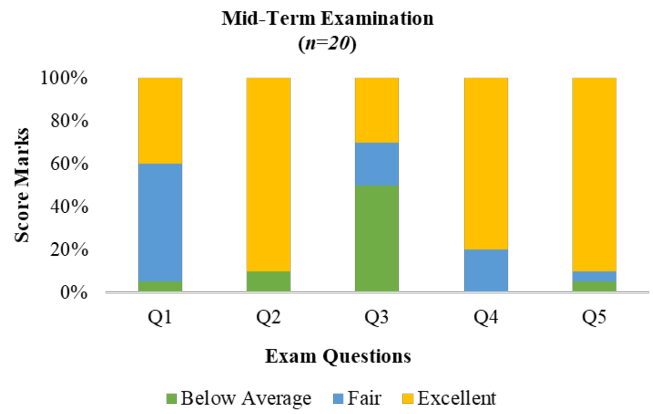


FIGURE 7. Student performance on mid-term exam

After four weeks' session, all of the students were given a mid-term examination. In the context of smart buildings, five open-ended questions were designed, concentrating on the IoT ecosystem, devices, communication protocols, the IoT cloud platform, and security and risk management. In Figure 7, the grading statistics were reviewed to determine how well the newly introduced IoT topics were received by the students. It is observed that more than 90% of the students achieved excellent scores on questions related to IoT devices (Q2), IoT-based cloud platforms (Q4), and IoT security and risk management (Q5). The results show that the students are able to understand at least three basic components of the fundamental IoT architecture, despite their limited background knowledge at the beginning of the course. However, 55% of students scored a fair grade in Q1 and 50% of students scored below average in Q3. The Q1 relates to the IoT ecosystem in smart buildings, while the Q3 focuses on IoT communication protocols. It can be concluded that students have a fair understanding of the transformation of conventional buildings into smart and sustainable buildings. In contrast, the students dealt with difficulties in understanding the IoT communication protocols, for which technical background regarding building automation networks is needed. The findings from this study have significant implications for teaching and learning approaches.

At the end of the four weeks class session, the teaching survey is conducted, and the students respond with both quantitative and qualitative feedback on the IoT module. Questions about teaching and learning approaches and knowledge contents are included in the quantitative surveys. The scores of teaching surveys from respondents () are tabulated in Table 5 and Table 6. The outcome was separated into five scales ranging from (very dissatisfied) to (very satisfied). The course achieved an excellent overall rating in this teaching survey. The highest possible score is , and the weighted average score is .

The teaching survey comment, which included the following "*The lecturer provides activities at the end of each class that really help the students understand the topic*" shows the satisfaction of the students. One of the IoT module's most valued aspects, according to some students, was their experience learning with Node-RED and Tinkercad, with comment, "*Lecturers have provided various platforms to give new exposure, and students can learn about IoT such as Node-RED and Tinkercad*". The hands-on experience added an extra dimension to the course, which was interactive and interesting. In general, the module assists students in acquiring IoT knowledge. The assessment results show that the module was successful in providing students with a solid technical foundation for the IoT.

DISCUSSION AND CONCLUSION

In conclusion, a comprehensive IoT learning module is presented. Student assessments, feedback, and issues have been analyzed and identified. The findings also show that there is room for improvement in future offerings of the course. Communication protocols are essential components of the IoT ecosystem. While 50% of students were found to be performing below average on this topic, it is hoped that this percentage will be significantly lower in future classes. To improve this, more detailed explanation through interactive teaching and learning methods will be addressed. Also, demonstrating the importance of the IoT communication protocols in activities such as simple hands-on project using a microcontroller; NodeMCU ESP8266 with a Wi-Fi connection as the wireless transportation protocol and MQTT as the data communication protocol to transmit information between the device and the cloud. The proposed IoT learning module is successful in providing students with diverse backgrounds with a solid foundation of IoT technology. Adding demonstrations, laboratories, and/or hands-on activities would help them further understand and learn new skills, making them even more ready for the IoT.

ACKNOWLEDGEMENT

The authors would like to thank the Universiti Kebangsaan Malaysia (UKM) for supporting this research through the Geran Galakan Penyelidik Muda GGPM-2022-064. The authors declare that they have no conflicts of interest to report regarding the present study.

DECLARATION OF COMPETING INTEREST

None

REFERENCES

Abdul Razak, Abdul Hadi, Nur Shuhada Abdullah, Syed A. M. Al Junid, Abdul K. Halim, Mohd F. M. Idros, Fairul N. Osman & Faisal Nazamuddin. 2022. "Structural Crack Detection System Using Internet of Things (IoT) for Structural Health Monitoring (SHM): A Review." *Jurnal Kejuruteraan* 34 (6): 983–98. https://doi.org/10.17576/jkukm-2022-34(6)-01.

Abichandani, Pramod, Vidhusheidhaa Sivakumar, Deepan Lobo, Craig Iaboni & Prateek Shekhar. 2022. "Internet-of-Things Curriculum, Pedagogy, and Assessment for STEM Education: A Review of Literature." *IEEE Access* 10: 38351–69. https://doi.org/10.1109/ACCESS.2022.3164709.

Ahmed, Ahmed Abdelmoamen, Kiranmai Bellam, Yonggao Yang & Michael Preuss. 2022. "Integrating IoT Technologies into the CS Curriculum at PVAMU: A Case Study." *Education Sciences*. https://doi.org/ https://doi.org/ 10.3390/educsci12110840.

Atlam, Hany F., Muhammad Ajmal Azad, Ahmed G. Alzahrani & Gary Wills. 2020. "A Review of Blockchain in Internet of Things and AI." *Big Data and Cognitive Computing 2020, Vol. 4, Page 28* 4 (4): 28. https://doi.org/10.3390/BDCC4040028.

Baiji, Youssef & Prabha Sundaravadivel. 2019. "ILoLeak-Detect: An IoT-Based LoRAWAN-Enabled Oil Leak Detection System for Smart Cities." Proceedings - 2019 IEEE International Symposium on Smart Electronic Systems, ISES 2019, December, 262–67. https://doi.org/10.1109/ISES47678.2019.00065.

Bajracharya, Biju, Vamsi Gondi, & David Hua. 2021. "IoT Education Using Learning Kits of IoT Devices." *Information Systems Education Journal (ISEDJ)*, no. 6: 19.

Bayılmış, Cüneyt, M. Ali Ebleme, Ünal Çavuşoğlu, Kerem Küçük & Abdullah Sevin. 2022. "A Survey on Communication Protocols and Performance Evaluations for Internet of Things." *Digital Communications and Networks* 8 (6): 1094–1104. https://doi.org/10.1016/J.DCAN.2022.03.013.

Das, Payali, Sushmita Ghosh, Shouri Chatterjee & Swades De. 2022. "A Low Cost Outdoor Air Pollution Monitoring Device With Power Controlled Built-In PM Sensor." *IEEE Sensors Journal* 22 (13): 13682–95. https://doi.org/10.1109/JSEN.2022.3175821.

Dey, Mitra Tithi, and &Punyasha Chatterjee. 2022. "Covid Waste Management Using IoT: A Smart Framework," 923–31. https://doi.org/10.1007/978-981-16-5655-2_88.

Franco, Patricia, Jose Manuel Martinez, Young Chon Kim & Mohamed A. Ahmed. 2021. "IoT Based Approach for Load Monitoring and Activity Recognition in Smart Homes." *IEEE Access* 9: 45325–39. https://doi.org/10.1109/ACCESS.2021.3067029.

Fuller, Aidan, Zhong Fan, Charles Day & Chris Barlow. 2020. "Digital Twin: Enabling Technologies, Challenges and Open Research." *IEEE Access* 8: 108952–71. https://doi.org/10.1109/ACCESS.2020.2998358.

Ha, Quang Phuc, Santanu Metia & Manh Duong Phung. 2020. "Sensing Data Fusion for Enhanced Indoor Air Quality Monitoring." *IEEE Sensors Journal* 20 (8): 4430–41. https://doi.org/10.1109/JSEN.2020.2964396.

Hansen, Emil Blixt & Simon Bøgh. 2021. "Artificial Intelligence and Internet of Things in Small and Medium-Sized Enterprises: A Survey." *Journal of Manufacturing Systems* 58 (January): 362–72. https://doi.org/10.1016/J.JMSY.2020.08.009.

Harika, G Lakshmi, Haritha Chowdary & T. Satya Kiranmai. 2020. "Cloud-Based Internet of Things for Smart Water Consumption Monitoring System," July, 967–72. https://doi.org/10.1109/ICCES48766.2020.9138074.

Hashim, Khalid Asaad, Hamzah Hadi Qasim, Abdulwahhab Essa Hamzah, Ola Alkharasani Hasan & Mustafa Al-Jadiri. 2023. "Door Lock System Based on Internet of Things and Bluetooth by Using Raspberry Pi." *Bulletin of Electrical Engineering and Informatics* 12 (5): 2753–62. https://doi.org/10.11591/eei.v12i5.5134.

Inmarsat Research. 2022. "Skills Shortages Remain the Top Barrier to Industrial IoT Adoption, Inmarsat Research Reveals." Inmarsat. 2022. https://www.inmarsat.com/en/news/latest-news/enterprise/2022/skills-shortage-iot-adoption-research.html.

Islam, Md Rakibul, Abdul Matin, Md Saifullah Siddiquee, Fahim Md Sifnatul Hasnain, Md Habibur Rahman & Tonmoy Hasan. 2020. "A Novel Smart Gas Stove with Gas Leakage Detection and Multistage Prevention System Using IoT Lora Technology." *2020 IEEE Electric Power and Energy Conference, EPEC 2020*, November. https://doi.org/10.1109/EPEC48502.2020.9320109.

Jia, Mengda, Ali Komeily, Yueren Wang & Ravi S Srinivasan ME Rinker. 2019. "Adopting Internet of Things for the Development of Smart Buildings: A Review of Enabling Technologies and Applications." *Automation in Construction* 101: 111–26. https://doi.org/10.1016/j.autcon.2019.01.023.

Karimi, Reyhaneh, Leila Farahzadi, Samad M.E. Sepasgozar, Sharifeh Sargolzaei, Sanee M. Ebrahimzadeh Sepasgozar, Mohsen Zareian & Akram Nasrolahi. 2021. "Smart Built Environment Including Smart Home, Smart Building and Smart City: Definitions and Applied Technologies." In *Advances and Technologies in Building Construction and Structural Analysis*. IntechOpen. https://doi.org/10.5772/intechopen.95104.

Khan, Faheem, Ilhan Tarimer & Whangbo Taekeun. 2022. "Factor Model for Online Education during the COVID-19 Pandemic Using the IoT." *Processes* 10 (7). https://doi.org/10.3390/pr10071419.

Kim, Dongsu, Yeobeom Yoon, Jongman Lee, Pedro J. Mago, Kwangho Lee & Heejin Cho. 2022. "Design and Implementation of Smart Buildings: A Review of Current Research Trend." *Energies* 15 (12). https://doi.org/10.3390/EN15124278.

Kumar, Sachin, Prayag Tiwari & Mikhail Zymbler. 2019. "Internet of Things Is a Revolutionary Approach for Future Technology Enhancement: A Review." *Journal of Big Data* 6 (1): 1–21. https://doi.org/10.1186/S40537-019-0268-2/FIGURES/9.

Laghari, Asif Ali, Kaishan Wu, Rashid Ali Laghari, Mureed Ali & Abdullah Ayub Khan. 2022. "A Review and State of Art of Internet of Things (IoT)." *Archives of Computational Methods in Engineering* 29 (3): 1395–1413. https://doi.org/10.1007/S11831-021-09622-6/METRICS.

Leong, Ying-Mei & Chockalingam Letchumanan. 2019. "Effective Learning in Higher Education in Malaysia by Implementing Internet of Things Related Tools in Teaching and Introducing IoT Courses in Curriculum."

Lombardi, Marco, Francesco Pascale & Domenico Santaniello. 2021. "Internet of Things: A General Overview between Architectures, Protocols and Applications." *Information 2021, Vol. 12, Page 87* 12 (2): 87. https://doi.org/10.3390/INFO12020087.

Malik, Praveen Kumar, Rohit Sharma, Rajesh Singh, Anita Gehlot, Suresh Chandra Satapathy, Waleed S. Alnumay, Danilo Pelusi, Uttam Ghosh & Janmenjoy Nayak. 2021. "Industrial Internet of Things and Its Applications in Industry 4.0: State of The Art." *Computer Communications* 166 (January): 125–39. https://doi.org/10.1016/J.COMCOM.2020.11.016.

Mircea, Marinela, Marian Stoica & Bogdan Ghilic-Micu. 2021. "Investigating the Impact of the Internet of Things in Higher Education Environment." *IEEE Access* 9: 33396–409. https://doi.org/10.1109/ACCESS.2021.3060964.

Mu'Amar Wildan, F. A.R., Eki Ahmad Zaki Hamidi & Tutun Juhana. 2020. "The Design of Application for Smart Home Base on LoRa." In *Proceedings - 2020 6th International Conference on Wireless and Telematics, ICWT 2020*. Institute of Electrical and Electronics Engineers Inc. https://doi.org/10.1109/ICWT50448.2020.9243648.

Nelke, Sofia Amador & Michael Winokur. 2020. "Introducing IoT Subjects to an Existing Curriculum." *IEEE Design and Test*. IEEE Computer Society. https://doi.org/10.1109/MDAT.2020.3005358.

Nguyen, Son Thanh, Bich Ngoc Le & Quy Xuan Dao. 2021. "AI and IoT-Powered Smart University Campus: Design of Autonomous Waste Management." *Proceedings - 2021 International Symposium on Electrical and Electronics Engineering, ISEE 2021*, April, 139–44. https://doi.org/10.1109/ISEE51682.2021.9418672.

Perumal, Thinagaran, E. Ramanujam, Sukhavasi Suman, Abhishek Sharma & Harshit Singhal. 2022. "Internet of Things Centric Based Multi-Activity Recognition in Smart Home Environment." *IEEE Internet of Things Journal*. https://doi.org/10.1109/JIOT.2022.3209970.

Reddy SP, Vijaya Vardan, Jagadeeswari B, Jaya Soundariya M B, Jeevitha M & Deepika Y. 2023. "The Implementation of the Virtual Reality Technology in the Hotel Marketing Management Using IoT," January, 1067–72. https://doi.org/10.1109/ICAISS55157.2022.10011068.

Ronoh, Kennedy, Elizabeth Muli, Edwin Ngwawe & Sam Njuki. 2021. "Internet of Things Learning Methodologies, Teaching Tools and Teaching Platforms." International Conference on Electrical, Computer, and Energy Technologies, *ICECET 2021*, no. December: 1–6. https://doi.org/10.1109/ICECET52533.2021.9698711.

See-To, Eric W.K., Xiao Xi Wang, Kwan Yeung Lee, Man Leung Wong & Hong Ning Dai. 2022. "Deep Learning-Driven Proactive Maintenance Management of IoT-Empowered Smart Toilet." *IEEE Internet of Things Journal*, February. https://doi.org/10.1109/JIOT.2022.3211889.

Seng, Lau Gim, Kenneth Lim Kuo Wei & Steven Joseph Narciso. 2020. "Effective Industry Ready IoT Applied Courseware - Teaching IoT Design and Validation." IEEE Global Engineering Education Conference*, EDUCON* 2020-April: 1579–83. https://doi.org/10.1109/EDUCON45650.2020.9125366.

Silvis-Cividjian, Natalia. 2019. "Teaching Internet of Things (IoT) Literacy: A Systems Engineering Approach." In Proceedings - 2019 IEEE/ACM 41st International Conference on Software Engineering: Software Engineering Education and Training, ICSE-SEET 2019, 50–61. Institute of Electrical and Electronics Engineers Inc. https://doi.org/10.1109/ICSE-SEET.2019.00014.

Spachos, Petros & Konstantinos N. Plataniotis. 2020. "BLE Beacons for Indoor Positioning at an Interactive IoT-Based Smart Museum." *IEEE Systems Journal* 14 (3): 3483–93. https://doi.org/10.1109/JSYST.2020.2969088.

Statista. 2023. "Smart Home - Worldwide." Statista Market Insights. 2023. https://www.statista.com/outlook/dmo/smart-home/worldwide.

Thaenthong, Jirawat, Varinthon Kwanjun & Phimsai Charoensuk. 2022. "Microcontroller and Internet of Things Application for Smart Restroom." Proceedings - 2022 Research, Invention, and Innovation Congress: Innovative Electricals and Electronics, RI2C 2022, 165–69. https://doi.org/10.1109/RI2C56397.2022.9910335.

Unaldi, Sibel, Nesibe Yalcin & Enes Elci. 2023. "An IoT-Based Smart Home Application with Barrier-Free Stairs for Disabled/Elderly People." *Elektronika Ir Elektrotechnika* 29 (1): 15–20. https://doi.org/10.5755/J02.EIE.30731.

Vaheed, S. K., Padmalaya Nayak, Pratap Singh Rajput, T. Uday Snehit, Y. Sai Kiran & Laxman Kumar. 2022. "Building IoT-Assisted Indoor Air Quality Pollution Monitoring System." 7th International Conference on Communication and Electronics Systems, ICCES 2022 - Proceedings, 484–89. https://doi.org/10.1109/ICCES54183.2022.9835822.

Velliyangiri, Geetha, Anbumani Venkatachalam, Manikandan Ramachandran, Ambeshwar Kumar & Murugan Subramanian. 2022. "Internet of Health Things (IoHT) Against COVID-19: A Review of Recent Development." *Computational Intelligence for COVID-19 and Future Pandemics*, 267–79. https://doi.org/10.1007/978-981-16-3783-4_13.

Villa, Valentina, Berardo Naticchia, Giulia Bruno, Khurshid Aliev, Paolo Piantanida & Dario Antonelli. 2021. "IoT Open-Source Architecture for the Maintenance of Building Facilities." *Applied Sciences 2021, Vol. 11, Page 5374* 11 (12): 5374. https://doi.org/10.3390/APP11125374.

Yuan, Shih Yi, Fong Chi Lui, Hui Chun Huang, Ting Wei Huang & Wei Sheng Liu. 2023. "IoT OS Teaching Material Development." Proceedings of the 6th IEEE Eurasian Conference on Educational Innovation 2023: Educational Innovations and Emerging Technologies*, ECEI 2023*, 175–78. https://doi.org/10.1109/ECEI57668.2023.10105261.

Yun, Seoyeon & Dusan Licina. 2023. "Investigation of Indicators for Personal Exposure and Occupancy in Offices by Using Smart Sensors." *Energy & Buildings* 298: 378–7788. https://doi.org/10.1016/j.enbuild.2023.113539.

Zualkernan, Imran A., Fadi A. Aloul, Vikram Sakkia, Hassan Al Noman, Salman Sowdagar & Omar Al Hammadi. 2019. "An IoT-Based Emergency Evacuation System." Proceedings - 2019 IEEE International Conference on Internet of Things and Intelligence System*,* IoTaIS *2019*, November, 62–66. https://doi.org/10.1109/IOTAIS47347.2019.8980381.