Design and Implementation of Node-RED–Based Dashboards for Monitoring and Control of IoT Devices

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Abstract: - Smart campus environments increasingly rely on IoT platforms to provision, configure, monitor, and control devices across multiple building spaces. As deployments scale, differences in communication protocols, payload structures, and data models complicate integration, monitoring, and visualization. This paper proposes a reusable room-centric configuration approach for IoT device management and monitoring, implemented in Node-RED as a visual orchestration layer. The technical contribution is a template-based method that transforms heterogeneous MQTT device payloads into unified room-level data objects reusable across similar spaces with minimal reconfiguration. The approach is validated through smart campus scenarios in a Smart Lecture Hall, covering network connectivity, energy consumption, and electricity availability. To evaluate deployment efficiency, a simulation experiment based on a real configuration session was conducted. Results show that reusing the initial room setup as a Node-RED template reduced configuration time for a five-room deployment from 70.47 to 35.47 minutes, improving the overall process by 49.66%.

Key-Words: - Node-Red, MQTT, Data models, Internet of Things (IoT), IoT devices, Smart Campus.

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1 Introduction

The concept of a smart campus is relatively new, but it is already being tested and deployed in real-world settings. Many successful implementations are built on proven technologies and approaches borrowed from other domains and then adapted to campus needs. In this context, multiple buildings, floors, and shared facilities are expected to operate together seamlessly. This transformation is driven by the expansion of Internet of Things (IoT) deployments in universities, ranging from environmental sensing and comfort control to safety monitoring and energy management. As IoT infrastructures grow, the operational effort required to keep them reliable also increases, because the number of IoT devices multiplies, data streams become continuous, and the number of interactions between physical spaces and digital services expands.

A recurring challenge in real smart campus deployments is the lack of a unified operational surface for monitoring and control. IoT environments are inherently heterogeneous due to the diversity of device vendors, data models, communication protocols, and gateway configurations. In practice, this heterogeneity affects day-to-day operations such as troubleshooting connectivity issues, validating device availability, interpreting room conditions, and performing corrective actions. Monitoring and control are often fragmented across many services. As a result, operational visibility is frequently reduced to device-level readings that are difficult to interpret in the language of facilities management, where the primary concern is whether a room is comfortable, usable, and functional.

To address these challenges, smart campus solutions require an intermediate orchestration layer capable of unifying heterogeneous IoT data streams, normalizing device-specific representations, and exposing them in a human-understandable operational view. Such a layer should support both real-time monitoring and bidirectional control, while remaining flexible enough to accommodate use cases expansion.

Motivated by these needs, this paper proposes an approach for unified monitoring and control of IoT devices, implemented and functioning in a smart university campus environment. As a reference implementation, Node-Red is used as a visual orchestration layer for normalizing heterogeneous device telemetry, aggregated into room-centric representations, and exposing it through reusable configurations. The implementation focuses on room-level operational states indicative of occupant comfort, device availability, network connectivity, and energy usage.

The proposed approach is demonstrated and validated through representative smart campus use case scenarios with a focus on managing and monitoring IoT devices in a Smart Lecture Hall, including network connectivity, energy consumption, and electricity availability status. The proposed solution demonstrates how reusable configuration templates and unified data models can reduce operational complexity while improving the readability and consistency of monitoring and control workflows.

The remainder of the paper first reviews relevant approaches and technology choices reported in the literature, then introduces the context modeling applied in the smart campus scenario, and finally presents implementation patterns and validation results derived from the real deployment.

2 Related Works

Recent research demonstrates the growing adoption of Node-RED as a central middleware for Internet of Things (IoT) applications, particularly in home automation, industrial monitoring, and smart campus environments. A low-cost IoT-based home automation system, [1] integrating Node-RED with wireless sensor networks and the MQTT protocol, has been shown to enable remote control of household devices and real-time environmental monitoring, emphasizing accessibility and affordability in smart home solutions. Similarly, [2], explored the integration of Node-RED with IoT analytics, focusing on real-time data processing and visualization, and demonstrated through an industrial case study how visual flow-based programming reduces system complexity while maintaining scalability.

In the context of industrial and energy systems, [3], proposed a web-based monitoring and control platform combining Node-RED, MQTT, and Modbus TCP on a Raspberry Pi embedded platform to support bidirectional data exchange with PLCs, enabling low-cost digital transformation for power system monitoring and energy conservation. A comprehensive narrative review of more than 70 studies, [4], examined the integration of PLCs, Node-RED, and IoT technologies, highlighting Node-RED's role as middleware bridging industrial automation with cloud and edge computing environments. Earlier work, [5], demonstrated the feasibility of real-time object control using open-source hardware and MQTT, with Node-RED used for environmental data visualization, reinforcing the viability of low-cost IoT infrastructures.

Addressing interoperability challenges, [6], examined the integration of legacy industrial equipment into a building-management system aligned with Industry 5.0 principles, emphasizing Node-RED as a flexible, open-source supervisory environment capable of bridging outdated protocols while maintaining security, resilience, and sustainability. Likewise, [7], developed a web-based IoT platform for environmental and lighting control using Node-RED, MQTT, and Modbus in an embedded Linux environment, allowing centralized monitoring and control of multiple laboratory spaces.

Communication-focused studies also highlight Node-RED's role in distributed energy systems. [8], proposed a LoRa-based communication system for microgrids, using Node-RED as a private server for secure data visualization and monitoring of current and voltage sensors across multiple IoT devices. Similarly, [9], demonstrated a low-cost SCADA system based on ESP32, Raspberry Pi, Node-RED, and MQTT for effective real-time monitoring and remote control of household environmental parameters.

Several works focus on environmental monitoring and public health applications. [10], designed an air quality and cigarette smoke detection system by integrating multiple sensors with MQTT and Node-RED dashboards, providing real-time visualization and automated audio alerts to support smoke-free environments. In smart campus contexts, [11], investigated IoT motion detection sensors for attendance monitoring, with Node-RED used as an integration and debugging layer connecting MQTT data streams to databases, while visualization was handled through Grafana. A smart home automation solution, [12], using Node-RED and MQTT, has also been proposed with a focus on smoke detection and device status control via a dashboard interface.

Recent literature frequently addresses energy efficiency and building management. [13], presented an IoT-based heating management system that uses real-time data and automation rules to optimize comfort and energy costs, with Node-RED used for visualization and control of thermostatic valves. Likewise, [14], analyzed noise pollution in school environments using IoT sensor nodes, where Node-RED facilitated data flow and integration, while time-series visualization was performed using Grafana. [15], designed a comprehensive home monitoring system using Node-RED and MQTT, integrating appliance control, environmental sensing, and disaster prevention through a web-based interface.

Smart metering and energy monitoring applications further underline Node-RED's versatility. [16], developed an IoT-based smart meter system using Node-RED for real-time visualization and remote access to voltage, current, and power data, aiming to reduce human error and improve energy management.

At the campus and urban scale, [17], presented an open-source IoT platform for a smart campus, integrating Node-RED with InfluxDB, Grafana, and Home Assistant to address interoperability, scalability, and data management challenges across multiple real-world use cases. The concept of the "University of Things", [18], has also been introduced to identify opportunities and challenges associated with deploying IoT sensor infrastructures and integrating sensor data into university business processes through LoRaWAN-based communication. [19], proposed a layered IoT platform for intelligent campus buildings, employing Node-RED dashboards for real-time monitoring and control of energy consumption, environmental conditions, and building equipment, thereby demonstrating the feasibility of low-cost, open-source solutions for smart building management. Node-RED has also been applied in brain-computer interface and human-robot interaction systems. [20], proposed an IoT-oriented architecture integrating an EEG-based Emotiv EPOC+ brain-computer interface with the humanoid robot Pepper.

In this work, Node-RED was used as a gateway for communication between BCI devices, robotic APIs, MQTT-based services, and cloud-oriented IoT infrastructures. The study demonstrated how Node-RED flows can support EEG data acquisition, feature extraction, classification, and translation into machine commands for robot control. More recently, [21], developed and validated a visual node-based BCI programming framework that integrates BrainFlow and OpenBCI tools within Node-RED, highlighting the potential of Node-RED as an accessible programming environment for cross-disciplinary BCI, smart home, and assistive technology applications. [22], describes software engineering process complexity by involving the number of process steps, the relations between them, repeated cycles, and layered subprocesses. In the present implementation, these elements are visible in the configuration of multiple IoT rooms in Node-RED, which involves repeated setup steps, topic mappings, dashboard elements, and device-specific adaptations. As shown in Table 1 (Appendix), the selected IoT-based systems are presented in terms of their primary research focus, application context, and underlying technology stack.

As can be seen, Node-RED is the most commonly preferred integration and orchestration layer for heterogeneous IoT services, because it enables flow-based automation and interoperability across multiple domains. The Mosquitto MQTT broker is the next most frequent component, providing reliable pub/sub messaging between devices and services. Together, Node-RED and Mosquitto MQTT broker make a practical, standards-based pairing used in many IoT deployments. Most studies use Node-RED end-to-end for configuration, control, and dashboard monitoring, while a smaller set uses Node-RED mainly for device onboarding/configuration and relies on tools like Grafana or Home Assistant for visualization and control.

After defining the main components of the most widely used technological stack, Table 2 (Appendix) presents the IoT devices employed in different use case scenarios and the metrics used to visualize conditions in different building spaces. The control functions used to operate devices and manage the monitored spaces are shown in Table 3. These studies confirm the practical role of Node-RED as a flexible orchestration layer for IoT-based monitoring and control systems. The review shows that many implementations are use-case specific.

Table 3. Summary of controlled parameters and operational modes in selected IoT-based systems

№	Controlled parameters
[1]	Light (ON/OFF), Fan (ON/OFF), Fan speed (set number)
[3]	Air conditioner (ON/OFF)
[4]	PLC analog input (0–100 set number), PLC digital input (ON/OFF)
[7]	Lighting: per-group and per-unit ON/OFF, dimming setpoints, lighting modes; HVAC: per-unit ON/OFF; Ventilation: auto/force ON-OFF; Curtains: open/stop/close
[9]	LED light remote control (ON/OFF)
[12]	Smoke sensor arm/disarm
[13]	Thermal heating command, Electric heating command, Combined heating command, Radiator ON/OFF
[15]	Lights, HVAC, heating, exhaust fan, electric door lock, siren, webcam capture
[19]	Smart plug control (ON/OFF), illumination control, and desktop computer control
[20]	Pepper robot posture: (wake up/rest); Pepper robot navigation; Pepper tablet interaction; Pepper speech/interaction behavior
[21]	Robotic arm gripper activation; Robotic arm lifting movement; Concentration threshold; Mindfulness value

Source: created by the authors

The summary serves as a practical reference point for identifying which device types, monitor and control parameters, approaches, and technologies are most commonly adopted across different scenarios and use cases. In the following chapter, the study presents the results of applying the key insights & lessons taken from the reviewed literature.

3 Modeling a Smart University Campus Context with a Focus on Main Use Cases

This section of the paper will present objects and their relational structures used to model the context of a Smart Campus. Since standard data models are based mainly on very general characteristics of the respective objects, it is necessary to adopt more technical characteristics to model the context in a more complete form, according to the use cases. In the present context, a total of 5 template objects are used as the basis for the scenario Table 4.

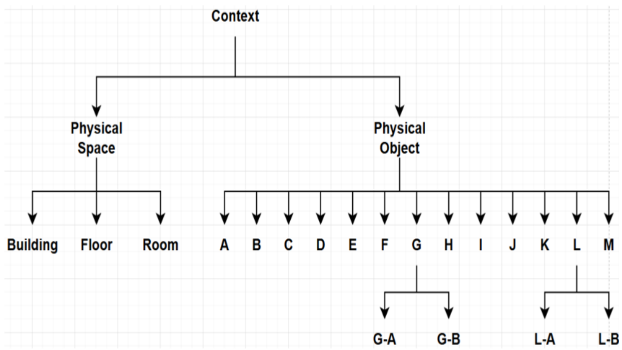
Table 4. Basic Data Models of the scenarios considered

Object	Type	Data Model Link https://smartdatamodels.org
Smart building	Physical space	dataModel.Building/Building
Smart floor	Physical space	dataModel.ZEB/Storey
Smart room	Physical space	dataModel.ZEB/Room
Sensor	Physical object	dataModel.SAREF/Sensor
Actuator	Physical object	dataModel.S4BLDG/Actuator

Source: created by the authors

The following context of the scenario consists of a smart building, a smart floor, a smart room, a sensor, and an actuator. These objects are separated as child nodes of the context, representing two groups of physical space and physical objects. As shown in Figure 1, physical objects represent a group of sensors and actuators, while physical space is a group that consists of a building, floor, and a room. Sensors and actuators are represented in the following diagram with codes. Two members of the physical objects group with codes G and L consist of child elements, in this case, sensors that measure different electrical metrics. In this case, G is an object represented as an Electrical box containing an RTD temperature transducer and a Zigbee bridge, while L is an object representing a floor distribution board containing a 120A three-phase electricity meter and a 50A two-channel single-phase electricity meter.

Since individual IoT devices are used to represent different metrics in the context of the scenario, this part of the paper will focus on three separate sub-scenarios for modeling management and monitoring of a Smart Lecture Hall environment, Network connectivity and operational status of IoT devices, and energy consumption and electricity availability. The proposed scenarios are modeled using individual relational data models representing physical spaces and physical devices. Since the characteristics of each individual object in the scenario are interdependent, diagrams illustrating their relationships will be used.



Code	ObjectName
A	Light Switch
B	Thermostatic Valve
C	Outdoor T&H Sensor
D	Motion Sensor
E	Indoor T&H Sensor
F	Indoor Illuminance Sensor
G	Electric Box
G-A	RTD
G-B	Zigbee Bridge
H	Noise Sensor
I	Outdoor Illuminance Sensor
J	Contact Sensor
K	Air Quality Sensor
L	Floor Distribution Board
L-A	Three-phase electricity meter 120A
L-B	Two-channel single-phase electricity meter
M	Smoke Sensor

Fig. 1: Context structure for Smart Campus

Source: created by the authors.

3.1 An Implementation Scenario of a Smart Lecture Hall

Creating a comfortable learning environment for students and lecturers is one of the main challenges facing smart building modeling in the context of a Smart Campus. There are many factors that can challenge the learning process, causing discomfort during lectures and exercises in lecture halls for both students and lecturers. The main parameters that characterize some of these factors in the following scenario are: temperature, humidity, lighting levels, noise levels, smoke detection, and air quality. These parameters are represented respectively by sensors for light, temperature and humidity, noise, presence, smoke, and air quality. Since the above-mentioned characteristics are largely dependent on windows and doors, contact sensors for their open and closed status are included in the scenario. Lighting and heating are controlled by a smart relay installed behind the lamp switches and a smart thermostatic valve for the radiator. The above-mentioned characteristics are used to enrich the core model of a room, with sensor values and control statuses, as can be seen on the relational diagram shown in Figure 2. The illustration is limited to the representation of the role of sensors and actuators in the physical space of the room.

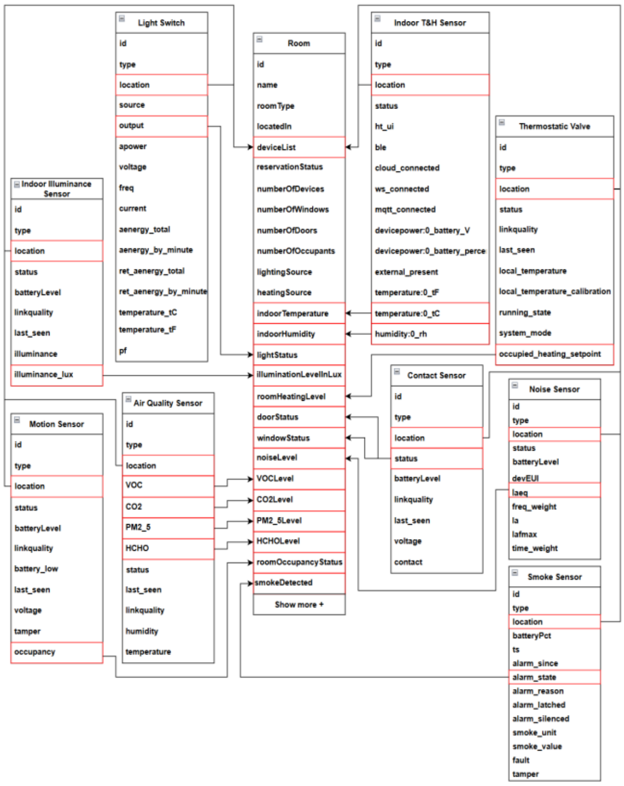


Fig. 2: Relational Data Model of IoT devices and their connectivity in the context of a smart lecture hall

Source: created by the authors.

3.2 A Scenario for Monitoring Network Communication of IoT Devices in a Lecture Hall

Ensuring reliable network communication monitoring for IoT devices is among the key factors for the effective functioning of the IoT infrastructure in a Smart Campus. In this scenario, the focus is on modeling the network connectivity between the individual components of physical spaces and objects. Each lecture hall is located on a specific floor along with its IoT devices and the status of their network connection, as shown in the Figure. 3. The relational logic is the same for the entire building, with the lists of the respective devices, their statuses, and spaces being transferred to a new list that corresponds to them at the floor and then on the building level. The data model of the building has two floor lists, one for the ground floors and one for the upper floors, with each floor assigned to one of them, according to their real location in the physical building.

Since the main network connection of IoT devices depends on the components of the Electric box, where the Zigbee bridge is located, the connections in the diagram are directed from left to right. RTD is a platinum temperature sensor used to monitor the temperature of the network devices inside the electric box.

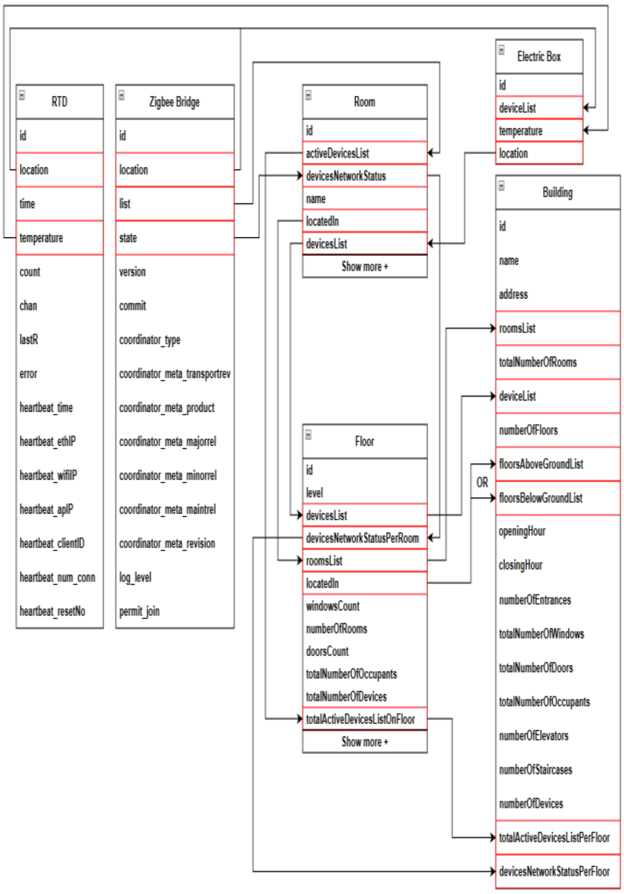


Fig. 3: Relational Data Model of IoT device network communication in the context of Smart Campus

Source: created by the authors.

The key values that represent the devices' network connection status in the lecture hall are listed, and state, where list contains a list of all active IoT devices in the hall, and state represents the status of the Zigbee bridge, which determines whether those devices will have an internet connection or not. The value "list" is passed from the sensor to the room object, then from the room object to the floor object, and finally from the floor object to the building object. At each step, the information is aggregated, so every subsequent list includes the data from the previous level. In this way, the hall object receives an updated list of all active devices in the room, then on the floor, and in the end, for the entire building. The same logic applies to the lists with devices, their statuses, rooms, and floors.

3.3 A Scenario for Monitoring Power Distribution and Energy Consumption of IoT Devices

Both previously presented scenarios, used to model the smart lecture hall and the IoT device network communication, are dependent on a third scenario that models the system's power distribution and energy consumption. Without electricity in the lecture halls, IoT devices would not be able to send or receive data, because the element enabling their network communication is dependent on the power distribution in the building due to the lack of a UPS in the physical installation. The core object in this scenario is the floor distribution board, which contains a three-phase electricity meter responsible for the sockets in a room, as well as a two-channel single-phase electricity meter responsible for the lighting in a room. The key characteristics of a lecture hall are the availability of power distribution to the sockets and lighting, as well as data on their energy consumption, both current and for a selected historical period.

As shown in the diagram in Figure 4, the three-phase electricity meter responsible for the sockets in a room uses:

• The value "emdata:0_total_act" to observe their total electricity consumption from the moment of installation in the floor distribution board;

• The value "em:0_total_act_power" visualizes the currently recorded consumption from sockets in a room;

• The value "em:0_total_current" presents the availability of electricity reaching sockets in a room;

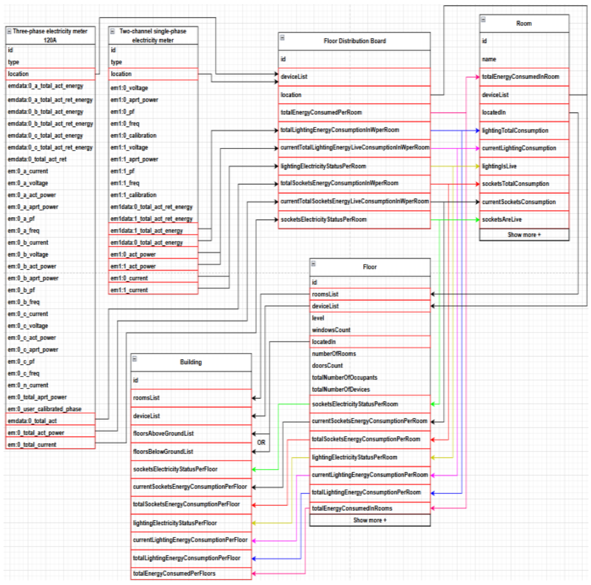


Fig. 4: Relational Data Model for the power distribution of IoT devices in the context of Smart Campus

Source: created by the authors.

The two-channel single-phase electricity meter uses variables with the same names and is modeled in a similar way in the scenario, with the difference that the above-mentioned parameters in this case are responsible for a separate lighting groups, and each group has a separate variable per meter, making them six in total. To summarize the information provided, three specific values are used on the floor distribution board, with the individual data for each group combined into one of these three values. The floor distribution board provides a separate list showing the status of lighting and sockets for each room on the floor. The current electricity consumption of the lights and sockets, as well as their historical consumption in a given room, are also stored in separate lists on the floor object. Similarly to the previous scenario, the information is also added to a separate list by floor in the building, thus determining the values of given parameters for the entire building.

3.4 A Summarized Data Model for Monitoring IoT Devices in Smart Campus

Based on the proposed three Smart Campus scenarios, it can be concluded that the objects describing the physical spaces, after their unification, have the following characteristics, presented in Table 5 (Appendix). The proposed features for enriching the base data models could be considered as a comprehensive example of modeling the building's IoT Device infrastructure in the context of a Smart Campus. These additional features are provided by the actual sensors and actuators installed in lecture halls 207, 210, and 309, located in building 2 of ULSIT University, Sofia. Bulgaria. As can be seen, some of the parameters of the proposed models are static, which means they will have fixed values, while those in the diagrams above are dynamic and change in real time.

3.5 A Reusable Configuration Approach for IoT Devices in Smart Campus

To implement unified data object models and the main Smart Campus scenarios, this paper proposes a reusable, room-centric configuration approach for IoT devices. Each building space, in this case a lecture hall, is treated as a "room object" that represents the room's current physical state and controllable functions. Instead of exposing many heterogeneous device streams, the approach maps selected device data into one semantically consistent, room-level representation that can be directly consumed by context-aware applications, as can be seen in Figure 5.

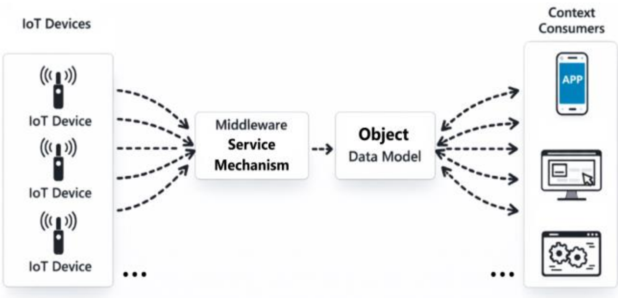


Fig. 5: Reusable IoT device simplification data approach as a single contextual object
Source: created by the authors.

The core idea is to extract only the relevant metrics from all devices in a room, for example, occupancy, temperature, lighting state, air quality, normalize them into consistent attribute names and units, and aggregate them into a single real-time room topic. Configuration is done through a template per room, where device streams are grouped by their physical placement, unnecessary vendor-specific fields are ignored, and the selected values are unified into one room data object model. The same template can then be reused for other rooms by changing only room-specific identifiers. This approach improves clarity and integration: applications and stakeholders work with one understandable room state, not multiple device topics and raw identifiers. The proposed approach also supports control by defining standardized room-level command topics that can be used across different spaces.

The next part of the paper presents the Node-RED implementation of the proposed configuration for IoT device management and visualization, focusing on real-time target values required by the Smart Campus use-case scenarios.

4 Implementation of IoT Device Management Configurations using Node-RED

To validate the proposed solution, a demonstration will be conducted on the real system for connecting, managing, and visualizing IoT devices in the second university building, focusing on Room 207.

4.1 Configuration of IoT devices in Room 207

Deployed sensors and actuators publish measurements and status messages to a Mosquitto MQTT broker using device-specific topics and payload formats. In Node-RED, an MQTT input node forwards these messages to a function node that normalizes them into a single, room-centered topic namespace. The following workflow in Figure 6 shows the Node-RED workflow used for the IoT devices configuration.

Fig. 6: IoT device configuration workflow in Node-Red

Source: created by the authors.

The function checks the incoming msg. topic, extracts the relevant value from msg. payload (either a single field or several fields when the payload is a compound object), and republishes the result under standardized nested topics with the following structure: „Building_2/Floor1/Room207/...". Each output topic corresponds to the most important room features, provided by the IoT devices, in this case: roomOccupancyStatus, illuminationLevelInLux, doorStatus, windowStatus, HCHOlevel, VOClevel, CO2level, PM2_5level, roomHeatingLevel, noiseLevel, indoorTemperature, indoorHumidity, lightStatus, devicesNetworkStatus, activeDevicesList, currentSocketsConsumption, currentLightingConsumption, socketsAreLive, lightingIsLive, socketsTotalConsumption, lightingTotalConsumption, and smokeDetected.

For measurements reported across multiple channels, the function temporarily stores partial values in context, computes combined totals, in this case, summed lighting consumption, and visualizes simple live ON and OFF states based on thresholds. This topic mapping step converts heterogeneous device telemetry into consistent feature streams, enabling downstream storage and analysis to operate on stable semantic topics rather than on changing device identifiers. The practical outcome of the proposed configuration is illustrated in Figure. 7.

The proposed control configuration focuses on the IoT devices that support direct actuation in the Smart Lecture Hall scenario. Unlike passive sensors, which only publish measurements, these devices receive commands through predefined MQTT topics and change the physical state of the room. In the current implementation, the actuation layer includes lighting control and radiator heating control. These functions are sufficient to demonstrate how the unified room-oriented model can support monitoring, and also bidirectional interaction with the environment.

Fig. 7: MQTT Explorer screenshot of the room topic unification

Source: created by the authors.

The command structure follows the same reusable logic applied in the monitoring flows. Each controllable device is associated with a standardized MQTT command topic, while the payload defines the requested action or parameter value. This makes the control configuration easier to replicate in other rooms, because only the room-specific topic prefix and device identifiers need to be modified. The main actuation topics and payload structures used in the Node-RED and MQTT configuration are summarized in Table 6.

Each IoT device uses a specific topic to activate a given action or event. Since the lamp switch can be turned on or off, the topic used for communication is only one: "Switch_Command." An object with the corresponding value for the on or off position is submitted on this topic. The valve for the thermostatic valve, on the other hand, can perform 3 separate actions: turning the radiator on and off, setting a temperature to maintain, and setting the temperature offset. The first command uses the same object as for the lamp switch, while the second and third use an object with a value and represent only one active state, which means that there is no inactive state.

Table 6. Actuation of IoT devices in Node-Red, MQTT

IoT Device	MQTT Topic:	Active	Inactive
Light Switch	/lampSwitch1/cmd/Switch_Command	obj	obj
		{value: "on"}	{value:"off"}
Thermostatic Valve	/thermostaticValve1/cmd/Switch_Command	obj	obj
		{value: "on"}	{value:"off"}
Thermostatic Valve	/thermostaticValve1/cmd/Temperature_Value	{occupied_heating_setpoint: Number}	n/a
Thermostatic Valve	/thermostaticValve1/cmd/Temperature_Offset	{local_temperature_calibration: Number}	n/a

Source: created by the authors

The Node-RED flows, illustrated in Figure 8, are designed as simple, modular device setup blocks where each light switch/thermostatic parameter is mapped to its own MQTT in/out node and a corresponding dashboard control block. In operation, the dashboard triggers publish commands to the corresponding MQTT topics, while subscribed MQTT messages feed back device state values to update the UI.

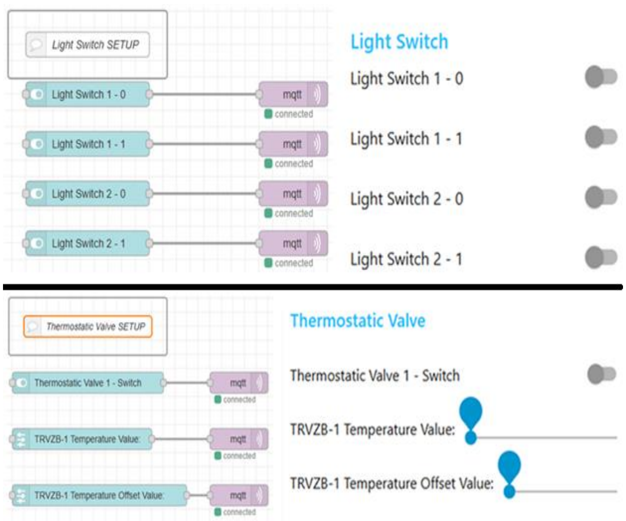


Fig. 8: Node-RED Dashboard UI for light switches and thermostatic valve operation
Source: created by the authors.

4.2 Visualization of IoT Device Measurements

The unified room topics introduced in the previous section are consumed by the Node-RED Dashboard to present IoT device measurements and states, reflecting the real-time condition of Room 207. The user interface components are implemented using the node-red-dashboard library, version 3.6.5. Each room feature published under the MQTT topic "Building_2/Floor1/Room207/" is visualized using the configuration pattern shown in Figure. 9.

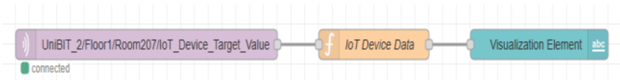


Fig. 9: A generic Node-RED visualization flow
Source: created by the authors.

The visualization flow consists of three nodes:
(1) an MQTT input node that subscribes to the selected device measurement topic;
(2) a function node that converts the incoming payload into a dashboard-ready format;
(3) a dedicated dashboard UI node component;

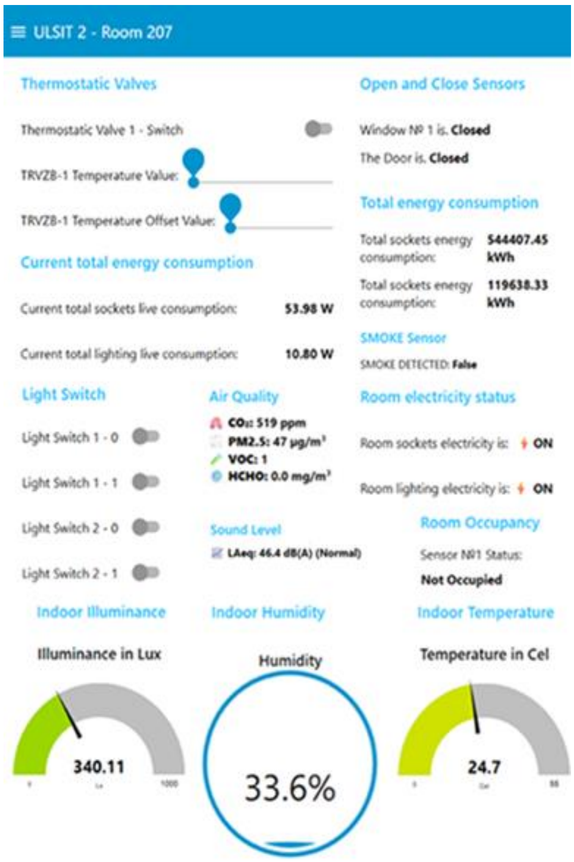


Fig. 10: Node-RED Dashboard used for monitoring and control in Room 207
Source: created by the authors.

Using this mapping, the final design of Room 207 is presented through a dashboard visualization. The dashboard combines several key environmental measurements, including temperature, humidity, and illuminance, displayed as gauges, with operational and safety information. This includes thermostatic valve settings, window and door status (open/closed), lighting control switches, occupancy; energy consumption, the main air-quality indicators, sound level, and smoke-detection status. The resulting Node-RED Dashboard for Room 207 is shown in Figure. 10.

Dashboard visualization config is summarized in Table 7 (Appendix). The table specifies each IoT device feature, the standardized MQTT topic, and Node-RED dashboard element responsible for data visualization. This summary provides a complete, compact dashboard configuration, reusable across other rooms that include the same IoT device set, fully or partially.

4.3 Evaluation of the Operational Complexity Reduction Achieved by the Proposed Approach

The use of configuration time as an evaluation indicator is also supported by prior work on time-related factors in software delivery. [23], shows that changes in delivery-cycle duration can influence both defect resolution time and delivered quality, suggesting that time-based process measures are relevant when evaluating software engineering improvements. The reduction of configuration time is interpreted as an indicator of lower operational effort and reduced configuration complexity. To evaluate the reduction of operational complexity, a simulation experiment was conducted using the real configuration session of Room 207 as a reference time model for a five-room deployment in total. The experiment includes only the IoT devices from the Smart Campus context model.

The real session for the first room required 29.83 minutes and was used as the baseline reference for the simulated experiment. The initial setup included subscribing to the MQTT topics of the installed devices, inspecting the incoming payloads, identifying the most relevant values for monitoring, creating the required Node-RED flows, implementing the extraction logic, and configuring the visualization elements. The most time-consuming part was understanding the device payloads and selecting the relevant values. This effort was not equal across devices, since simpler sensors were faster to interpret, while more complex devices, such as the electricity meters and the Zigbee Bridge, required more effort to understand and configure.

Based on this real session, the experiment simulated the deployment of five lecture halls with similar installations. The first room was treated as the reference room, fully configured from scratch. For the remaining rooms, two rollout strategies were compared. In the first strategy, the configuration was rebuilt manually for each additional room, but using the knowledge already obtained from the first real setup. In the second strategy, the first room was reused as the main Node-Red template, after which only the room-specific MQTT topic paths were updated, and the branches for missing devices were removed. For the manual rebuild strategy, the estimated times for the additional rooms were based on the repeated configuration steps that remain necessary after the first room has been completed. These include creating MQTT input nodes, assigning room-specific topics, reconnecting the processing logic, and recreating dashboard elements. For the template reuse strategy, the Room 207 configuration is treated as a reusable Node-RED flow template. The existing MQTT nodes, function nodes, dashboard components, and topic structure are preserved. Only the room identifiers are changed, and the branches for missing devices are removed. In this way, the comparison focuses on the effect of configuration reuse under the same five-room deployment scenario. The measured times used as quantitative evaluation metrics are presented in Table 8.

Table 8. Simulated deployment time for five rooms using the real Room 207 session as a reference

Room	Installed device set	Manual rebuild with prior knowledge (min)	Template reuse (min)
Room 207	Full set	29.83	29.83
Room 210	Full set without 1 device	10.15	1.41
Room 214	Full set	10.6	1.44
Room 218	Full set without 4 devices	9.27	1.34
Room 220	Full set	10.6	1.44
Total	—	70.47	35.47

Source: created by the authors

The simulated results show that, when the real Room 207 session is used as the reference setup and then extended to five rooms, the total deployment time is reduced from 70.47 min to 35.47 min when template reuse is applied. This corresponds to an improvement of 49.66% in the overall setup configuration process.

5 Conclusion

This paper introduces a reusable, template-based configuration approach implemented in Node-RED. The results demonstrate that the proposed approach has the potential to significantly reduce deployment and maintenance complexity, allowing the same configuration logic to be replicated across multiple rooms and buildings with minimal changes. The implementation was validated in the context of a smart campus by integrating use case scenarios for managing and monitoring IoT devices in a Smart Lecture Hall, including network connectivity, energy consumption, and electricity availability status. The results from the experiment showed that reusing the initial room setup as a Node-Red template reduced the total configuration time from 70.47 min to 35.47 min, corresponding to an improvement of 49.66% in the overall deployment process. As a result, the solution is transferable and adaptable to other smart campus environments, similar smart building scenarios, and setups.

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APPENDIX

Table 1. Summary of application contexts and main research focuses of selected IoT-based systems

Context and Use Case	**Ref. №**	**Main focus of the works**
Smart Home & Residential IoT	[1], [9], [12], [15], [21]	Low-cost smart home automation; real-time environmental monitoring; SCADA-like household control; smoke detection; appliance control; web dashboards; EEG-based BCI control for smart home automation using Node-RED/OpenBCI.
Building Management, Energy Efficiency & HVAC	[6], [7], [13]	Integration of legacy industrial equipment into BMS; Industry 5.0 alignment; environmental monitoring and lighting control; IoT-based heating optimization for comfort and energy savings
Smart Energy, Power Systems & Microgrids	[3], [8], [16]	Web-based PLC monitoring and control; energy system visualization; LoRa-based microgrid monitoring; smart metering; household and PV energy management with bidirectional measurement
Industrial IoT & Digital Transformation	[2], [4], [5]	Node-RED and IoT analytics for industrial use; survey of PLC–IoT–IIoT integration; feasibility of real-time object control with open-source hardware
Smart Campus & University IoT	[11], [17], [18], [19]	IoT-based campus attendance; open-source smart campus platforms; interoperability and scalability in real deployments; conceptual “University of Things”; layered campus-building IoT platforms
Public Health & Environmental Monitoring	[10], [14]	Air quality and cigarette smoke detection with alerts; noise pollution monitoring in schools using IoT nodes and time-series visualization
Laboratory, Robotics & Specialized Indoor Spaces	[7], [20]	Multi-lab environmental monitoring and lighting control via web-based IoT platforms; EEG-based BCI communication with a humanoid robot in an IoT environment using Node-RED and MQTT.

Source: created by the authors

Table 2. Summary of IoT devices employed and metrics used for monitoring conditions in building spaces

Ref. №	**IoT Device/s**	**Visualized metrics**
[1]	Light switch, Fan	Fan speed
[2]	BME280 sensor	Temperature, Humidity, Pressure
[3]	SMB350 multi-circuit power meter, Air Conditioner	Electrical metrics (220V & 110V): voltage, current, active/reactive/apparent power, power factor, demand (real-time & 15-min), energy (kWh, kvarh); Device status: Air Conditioner
[4]	MicroLogix 1400 PLC	PLC analog outputs, PLC digital outputs
[5]	Temperature and Humidity sensor, Gas sensor	Temperature, Humidity, Gas level
[6]	No specific IoT Device mentioned (PAC equipment)	Input/output temperature and relative humidity; outside temperature
[7]	CO_2 sensors, Temperature and humidity sensors, Illuminance sensor, Luminometer; LED luminaires, Whiteboard and Blackboard lights, Spot lights, Electric curtains, Air conditioners, Ventilation system, Relay modules, PLCs	Environmental: temperature, humidity, CO_2, illumination; Lighting: LED dimming level (0–32767), luminaire status indicators
[8]	LoRa node with voltage and current sensor, RAK831 LoRa concentrator	Voltage, Current (per device)
[9]	BME280, LDR	Temperature, Humidity, Pressure, Light value, LED status
[10]	DHT22 sensor, MQ-2 gas sensor, PM2.5 air quality sensor, DFPlayer Mini module	Temperature, Humidity, PM2.5, CO concentration, ISPU index
[11]	PIR sensor	Motion detection (time-series by time slots)
[12]	MQ-2 Gas sensor, Buzzer	Smoke detection status
[13]	Smart thermostatic valves, Smart temperature and humidity sensor, Smart Wi-Fi plug	Thermal: current temperature, target temperature, heat call state; Actuators: radiator status
[14]	Acoustic Signal Sensor; Temperature and Humidity sensors (DHT11, AHT10)	Noise level (dB), Temperature, Humidity
[15]	Quad 3V relay module, USB webcam, environmental and safety sensors, and an electric door	Environmental: temperature, humidity, illumination; Safety: fire, gas (MQ-2/4/9), motion; Trends: temperature over time

Ref. №	IoT Device/s	Visualized metrics
[16]	ACS712 current sensor, LCD Display	Voltage, Current, Power
[17]	Aranet4 PRO CO_2 sensor; Aranet PRO base station; Develco Zigbee devices; BACnet controller; RadonEye Plus2; PV inverters; energy controllers; power meters	Environmental: CO_2, radon, indoor/outdoor temperature; Energy: heating energy, gas usage; Electrical: voltage, current, power, frequency, power factor; PV: production, consumption, import/export, savings
[18]	Pycom sensor nodes; Pycom LoPy4; Kerlink gateways; CO_2 sensor	Temperature, Humidity, Air pressure, CO_2, particulates, light level, GPS, accelerometer data, RFID/NFC
[19]	Sonoff POW R2; PZEM-004T-100A; photovoltaic monitoring node; Dragino sensors; weather station	Voltage, Current, Active/Reactive/Apparent power, Energy, Frequency, CO_2, Humidity, TVOC, Temperature
[20]	Emotiv EPOC and EEG BCI device; Pepper humanoid robot	EEG data features and classification outputs; BCI-generated robot control commands; Pepper posture/control states; publish-subscribe topic values for brain-robot communication in IoT
[21]	OpenBCI Cyton and Daisy boards; TinkerKit Braccio robotic arm	EEG frequency-band metrics: θ, α, β2, γ; Mindfulness/Concentration value; ERS bursts; θ/γ synchrony; robotic arm activation status

Source: created by the authors

Table 5. Summary of objects used to model the Smart Campus context

Building	Floor	Room
id	id	id
name	level	name
address	locatedIn	roomType
type	numberOfRooms	locatedIn
totalNumberOfFloors	roomsList	reservationStatus
totalNumberOfFloorsAboveGround	windowsCount	numberOfDevices
floorsAboveGroundList	doorsCount	deviceList
totalNumberOfFloorsBelowGround	totalNumberOfDevices	numberOfWindows
floorsBelowGroundList	deviceList	numberOfDoors
openingHour	peopleOccupancy	numberOfOccupants
closingHour	dateCreated	lightingSource
numberOfEntrances	dateModified	heatingSource
totalNumberOfWindows	socketsElectricityStatusPerRoom	peopleCapacity
totalNumberOfDoors	currentSocketsEnergyConsumptionPerRoom	peopleOccupancy
totalNumberOfOccupants	lightingElectricityStatusPerRoom	dateModified
totalNumberOfRooms	totalSocketsEnergyConsumptionPerRoom	dateCreated
numberOfElevators	currentlLightingEnergyConsumptionPerRoom	indoorTemperature
numberOfStaircases	totalLightingEnergyConsumptionPerRoom	activeDevicesList
numberOfDevices	totalEnergyConsumedInRooms	currentLightingConsumption
deviceList	totalActiveDevicesListOnFloor	lightingTotalConsumption
peopleOccupancy	devicesNetworkStatusPerRoom	lightingIsLive
peopleCapacity	peopleCapacity	socketsTotalConsumption
dateCreated		socketsAreLive
dateModified		currentSocketsConsumption
location		devicesNetworkStatus
roomsList		totalEnergyConsumedInRoom
devicesNetworkStatusPerFloor		roomOccupancyStatus
totalActiveDevicesListPerFloor		PM2_5Level
totalEnergyConsumedPerFloors		HCHOLevel
totalLightingEnergyConsumptionPerFloor		CO2Level
currentLightingEnergyConsumptionPerFloor		VOCLevel
lightingElectricityStatusPerFloor		noiseLevel

Building	Floor	Room
totalSocketsEnergyConsumptionPerFloor		windowStatus
currentSocketsEnergyConsumptionPerFloo r		doorStatus
socketsElectricityStatusPerFloor		roomHeatingLevel
		illuminationLevelInLux
		lightStatus
		indoorHumidity

Source: created by the authors

Table 7. Mapping of Room 207 IoT topics to Node-RED Dashboard visualization elements

IoT Device	MQTT Topic	Visualization elements used
Air Quality Sensor	HCHOlevel	Text
	VOClevel	Text
	CO2level	Text
	PM2_5level	Text
Contact Sensor	doorStatus	Text
	windowStatus	Text
Light Switch	roomOccupancyStatus	Switch
PM50 Electricity Meter	currentSocketsConsumption	Text
	socketsAreLive	Text
	socketsTotalConsumption	Text
Smoke Sensor	smokeDetected	Text
Sound Level Sensor	noiseLevel	Text
T&H Sensor	indoorHumidity	Gauge: level
T&H Sensor	indoorTemperature	Gauge: gauge
Thermostatic Valve	illuminationLevelInLux	Switch, Slider, Slider
Thermostatic Valve	roomHeatingLevel	Text
Three phase Electricity Meter	currentLightingConsumption	Text
Three phase Electricity Meter	lightingIsLive	Text
Three phase Electricity Meter	lightStatus	Text
Three phase Electricity Meter	lightingTotalConsumption	Text
Zigbee Bridge	devicesNetworkStatus	Text
Zigbee Bridge	activeDevicesList	Table

Source: created by the authors

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