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Smart Campus 360: An AI and IoT-Based Intelligent Campus Monitoring and Management System using Simulation

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Abstract - A college campus uses a great deal of electricity and water, produces waste every day, copes with heavy traffic and parking demand, and is responsible for the safety of thousands of people. Even so, most campuses still handle these matters through manual rounds and separate systems that do not talk to each other. Lights and fans stay on in empty classrooms, bins overflow before anyone collects them, gardens are watered on a timer whether or not the soil is dry, and fires or bad air are often noticed only after the fact. This paper presents Smart Campus 360, an AI and IoT-based framework that lets administrators monitor and manage a whole campus from one real-time dashboard. It covers thirteen functions: smart energy management, temperature and humidity monitoring, smart parking, smart dustbins, smart water management, smart irrigation, emergency and fire safety, air quality monitoring, solar energy monitoring, campus navigation, security monitoring, AI-based analysis, and the dashboard itself. Every function is built from the same three parts, a sensing component, a rule-based decision component, and an actuation or alert component, and all of them write to a shared data layer. Readings are classified as Normal, Warning, or Critical, and an AI-based analysis layer studies the accumulated data to spot anomalies, forecast demand, and suggest actions to administrators. Installing hardware across a full campus is expensive and hard to test, so the framework is meant to be prototyped through simulation, with virtual sensors and actuators feeding a dashboard that reacts in real time. By bringing sensing, automation, alerting, and analysis together, Smart Campus 360 aims to cut waste, improve safety, and support decisions based on data. The paper also sets out how these claims should be tested, first in simulation and later in a physical pilot.

Keywords: Smart campus, Internet of Things, artificial intelligence, energy management, smart parking, waste management, air quality monitoring, simulation, real-time dashboard.

1. INTRODUCTION

A college campus works a lot like a small city. It has classrooms, laboratories, hostels, canteens, gardens, parking areas, water tanks, and administrative buildings, and thousands of people pass through it every day. Electricity and water are used without a break, cleaning staff are needed all the time, and the institution pays for all of it. The way campuses are managed, though, has barely changed. A guard walks the corridors switching off lights, a supervisor checks the bins on a fixed round, a gardener waters at the same hour every day, and a fire is usually spotted by a person and not by a system.

The effects are easy to see. A classroom stays lit and cooled for hours after the last student has gone. A bin near the canteen overflows because it was not on that day's round, while another bin on the same round is only half full. Plants get watered in the rain, or are left dry on a hot afternoon. Students drive around looking for a free parking space. Stuffy air in a crowded classroom, or pollution drifting in from nearby traffic, goes unnoticed because nobody is measuring it. Any one of these is a small problem, but together they mean wasted resources, lost time, and risks that could have been avoided.

The Internet of Things (IoT) gives us a practical way to deal with this. Cheap sensors can measure occupancy, temperature, humidity, soil moisture, water level, gas concentration, and light, and small controllers can switch devices on or off in response. Once the readings reach a common platform, they can be shown side by side, compared, and analyzed. In practice, though, most campus IoT projects tackle one problem, such as parking or lighting, and build a separate system with its own interface for it. Administrators end up switching between screens and still cannot see how one part of the campus affects another.

This paper proposes **Smart Campus 360**, a framework that treats the campus as a single environment to be monitored and managed. The name reflects the aim of giving administrators a complete, all-round view. The framework covers thirteen functions grouped into ten modules. Each module follows the same pattern of sensing, decision, and action, and all of them feed one real-time dashboard and one AI-based analysis layer. Many students and institutions cannot afford to put hardware across a whole campus, so the framework is designed to be demonstrated and tested in simulation, where virtual sensors produce realistic data and virtual actuators respond to the system's decisions.

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The paper makes the following contributions.

1. A layered architecture for campus management that brings sensing, rule-based control, alerting, AI analysis, and visualization together for thirteen campus functions in a single framework.
2. A common module pattern of sensor inputs, decision rules, and actuation or alert outputs, which makes each function easy to specify, simulate, and extend.
3. A uniform three-level status model (Normal, Warning, Critical) so that readings from very different sensors can be compared and displayed in the same way.
4. An AI-based analysis layer that detects anomalies, forecasts demand, and produces recommendations for administrators, intended as decision support and not as automatic control.
5. A simulation-based prototyping approach, along with an evaluation methodology that institutions and researchers can use to test the framework before any physical deployment.

The rest of the paper is organized as follows. Section 2 reviews related work, and Section 3 states the problem and objectives. Section 4 presents the Smart Campus 360 framework. Section 5 describes the design of each module, Section 6 covers the rule-based control and status model, and Section 7 describes the AI-based analysis layer. Section 8 discusses the dashboard and wider system design issues. Section 9 explains the simulation setup and evaluation methodology, Section 10 discusses implications and limitations, and Section 11 concludes the paper.

2. RELATED WORK

2.1 Smart Cities and the Internet of Things

The smart city idea joins digital technology with the people and institutions that use it. Nam and Pardo describe smart city initiatives as having technological, human, and institutional dimensions, which means that technology alone cannot improve a city [1]. Caragliu et al. likewise tie smart cities to investment in human capital, infrastructure, and participatory governance [2]. On the technical side, Gubbi et al. set out a vision of IoT in which sensing, communication, and cloud-based analytics come together as services [3]. Zanella et al. discuss the architectures and protocols behind urban IoT systems and how they apply to services such as waste collection, air quality monitoring, and street lighting [4], while Al-Fuqaha et al. survey the technologies and protocols that make such systems possible [5]. A campus can be seen as a small, controlled version of a city, which makes it a convenient place to try out smart city ideas at a manageable scale.

2.2 Domain-Specific IoT Solutions

Much of the existing work looks at one campus or building function at a time. On energy, Weng and Agarwal argue that sensing and actuation in buildings can improve efficiency by matching lighting and cooling to actual occupancy [6]. On parking, Lin et al. survey smart parking solutions and identify sensing space occupancy and guiding drivers as the core tasks [7]. On waste, Medvedev et al. describe waste management as an IoT-enabled service in which fill-level sensors let collection follow need and not a fixed schedule [8]. For agriculture and landscaping, Kim et al. show how irrigation can be sensed and controlled remotely using distributed wireless sensors that measure soil conditions [9]. For environmental monitoring, Kumar et al. discuss the growth of low-cost sensors for managing urban air pollution, noting both their promise and their limited accuracy [10].

Together these studies show that each function is technically feasible. They are usually presented as stand-alone systems, though, each with its own sensors, interface, and data store.

2.3 Messaging and Data Collection

Lightweight publish-subscribe messaging is widely used for IoT telemetry. The MQTT protocol, standardized by OASIS, was designed for constrained devices and unreliable networks. It lets many sensors publish readings to named topics, which other components then subscribe to [11]. That model fits a campus well, since many small devices have to report to just a few consumers, such as the dashboard and the analysis service.

2.4 Analytics and Anomaly Detection

Raw sensor data is only useful once it has been analyzed. Chandola et al. survey anomaly detection techniques and describe how unusual readings, such as a sudden spike in consumption or a sensor that stops changing, can be told apart from ordinary variation [12]. On a campus, these techniques could help find a leaking pipe, a faulty sensor, or a device that has been left running, all of which are hard to catch by inspection alone.

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2.5 Research Gap

Earlier work shows that individual campus and city functions can be sensed and controlled with IoT, that lightweight protocols exist for collecting the data, and that anomaly detection can be applied to sensor streams. What is harder to find, especially in a form that students and smaller institutions can reproduce, is a single framework in which many campus functions share one data layer, one status model, one dashboard, and one analysis layer, and which can be demonstrated and tested through simulation without physical hardware. Smart Campus 360 is proposed to fill this gap by specifying how these pieces fit together.

3. PROBLEM STATEMENT AND OBJECTIVES

3.1 Problem Statement

Campus resources and facilities are mostly managed through manual inspection and isolated systems. The results are wasted electricity and water, overflowing bins, poorly used parking, late detection of fire, poor air quality and other hazards, and no consolidated picture for administrators. The problem, then, is how to design a unified framework that senses the condition of the campus, automates routine control actions, alerts staff to abnormal conditions, analyzes the accumulated data, and presents everything in one real-time view, in a form that can be prototyped and tested through simulation.

3.2 Objectives

The framework is designed to meet the following objectives.

- **O1, resource saving:** reduce electricity wastage by switching lights and fans according to occupancy, and cut water wastage by controlling watering according to soil and tank conditions.
- **O2, environmental awareness:** monitor temperature, humidity, and air quality in classrooms and open areas so that unhealthy conditions are identified.
- **O3, facility efficiency:** show free and occupied parking spaces, bin fill levels, and campus locations so that users and staff spend less time searching and servicing.
- **O4, safety:** detect emergencies and fire conditions, raise alarms and alerts without delay, and support security monitoring.
- **O5, renewable energy visibility:** track solar generation and compare it with consumption.
- **O6, unified visibility:** present all campus information on one real-time dashboard with a consistent status model.
- **O7, decision support:** analyze accumulated data with AI techniques to detect anomalies, forecast demand, and recommend actions.
- **O8, reproducibility:** allow the complete system to be built and tested through simulation.

3.3 Scope and Assumptions

The framework targets a single campus with a reliable power supply and a local network or internet connection. It assumes that sensors and devices can be installed, or simulated, in each zone, that administrators and maintenance staff act on the alerts they receive, and that data collection follows the institution's privacy policy. Life-critical response, such as fire fighting and medical emergencies, remains the job of trained personnel and emergency services. The framework offers early detection and alerting; it does not replace them.

4. THE SMART CAMPUS 360 FRAMEWORK

4.1 Overview

Smart Campus 360 is organized into five cooperating layers: sensing and actuation, communication, data, intelligence, and application. The sensing and actuation layer holds the sensors that measure the campus and the devices that act on it. The communication layer carries readings and commands. The data layer stores current values, history, and events. The intelligence layer applies rule-based control and AI-based analysis. Finally, the application layer provides the real-time dashboard, the alerts, and the navigation interface.

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Table 1. Layers of the Smart Campus 360 framework

Layer	Main responsibility	Typical elements
Sensing and actuation	Measure campus conditions and carry out control actions	Occupancy, temperature, humidity, soil-moisture, gas, level, and light sensors; relays, pumps, buzzers
Communication	Transport readings and commands between devices and the platform	Wi-Fi or local network, publish-subscribe messaging
Data	Store current state, history, events, and alerts	Time-series and event database
Intelligence	Apply control rules and AI analysis	Threshold rules, anomaly detection, forecasting, recommendations
Application	Present information and accept user actions	Real-time dashboard, alerts, navigation, administrator views

4.2 The Thirteen Functions and Ten Modules

The thirteen functions are grouped into ten modules so that related functions can share sensors and logic. For example, smart energy management, which switches lights and fans, is carried out by the Smart Classroom module together with the Energy Management module, which calculates consumption. Table 2 shows the full mapping.

Table 2. Campus functions and the modules that implement them

No.	Function	Module	Core sensing and action
1	Smart energy management	Smart Classroom, Energy Management	Occupancy detection; automatic light and fan control
2	Temperature and humidity monitoring	Environment Monitoring	Temperature and humidity sensors in classrooms
3	Smart parking	Smart Parking	Occupancy sensors per parking slot
4	Smart dustbin	Smart Waste	Fill-level sensor in each bin
5	Smart water management	Smart Water	Hand-wash tap control; tank level; usage monitoring
6	Smart irrigation	Smart Garden and Irrigation	Soil-moisture sensor; automatic watering
7	Emergency and fire safety	Emergency and Security	Flame, smoke, or gas detection; alarm and alert
8	Air quality monitoring	Environment Monitoring	Particulate and gas sensors
9	Solar energy monitoring	Solar Energy	Generation and usage measurement
10	Campus navigation	Campus Dashboard (navigation view)	Location directory of classrooms, departments, parking, facilities
11	Security monitoring	Emergency and Security	Entry and motion events; camera feeds
12	AI-based analysis	Intelligence layer	Anomaly detection, forecasting, recommendations
13	Real-time dashboard	Campus Dashboard	Unified display, alerts, status indicators

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4.3 The Common Module Pattern

Every module follows the same four-step pattern. First, one or more sensors publish readings to a named topic, either at regular intervals or when a value changes. Second, a decision component compares each reading with the configured thresholds and the device's current state, and assigns a status. Third, depending on that status, the module either acts, for example by switching a device, or raises an alert. Fourth, the reading, the status, and any action are stored with a timestamp. Because the pattern is uniform, a new function can be added by defining its sensors, thresholds, and actions, without changing the rest of the framework.

4.4 Stakeholders and Roles

Four roles interact with the framework. **Administrators** view the full dashboard, configure thresholds, and review analytical reports. **Maintenance and housekeeping staff** receive alerts about bins, water, and equipment and act on them. **Security staff** receive emergency and security alerts. **Students and visitors** use the navigation and parking views. Role-based access makes sure each user sees only what is relevant to them.

5. Module Design

5.1 Smart Energy Management (Smart Classroom)

Each classroom has an occupancy sensor, such as a passive infrared sensor or a people counter at the door, and optionally a light-level sensor. When someone is detected, the lights come on, and the fans start if the room temperature is above a comfort threshold. When no one has been detected for a configured delay, the lights and fans go off. The delay is there so that devices are not switched off while students are still in the room but sitting still. If daylight is sensed, the lights can stay off in a bright room. The module records how long the lights and fans run, and this feeds the Energy Management module, which calculates consumption per room, building, and period from device ratings and run time.

5.2 Temperature and Humidity Monitoring

Temperature and humidity sensors in classrooms report to the platform at regular intervals. The values are compared with comfort ranges, and a room outside its range is shown with a Warning or Critical status. The readings also play a control role, because the fan logic in the Smart Classroom module depends on temperature, and they support the analysis layer, which can compare comfort conditions across rooms and times of day.

5.3 Smart Parking

Each parking slot has an occupancy sensor, such as an ultrasonic or infrared sensor, that reports whether the slot is free or taken. The module counts free and occupied slots in each parking zone and shows the counts on the dashboard and in the navigation view, so drivers can head straight for a zone with space. A zone with very few free slots is shown as Warning, and a full zone as Critical. Historical occupancy can be used to study peak hours.

5.4 Smart Dustbin

A fill-level sensor, usually ultrasonic, measures the distance from the lid to the surface of the waste, and the module converts this into a fill percentage. A bin above the Warning threshold is flagged for upcoming collection, and a bin above the Critical threshold triggers an alert to housekeeping staff. Bins are listed in descending order of fill level, so collection rounds follow need and not a fixed route. Bins that keep filling quickly point to places where more bins, or more frequent collection, are needed.

5.5 Smart Water Management

The Smart Water module looks at two aspects of water use on campus. The first is the hand-wash tap, which opens only when it detects a hand and closes by itself, so less water is left running. The second is the overhead tank. A level sensor reports the water level and, where a pump is available, the pump starts at a low level and stops at a high level, which prevents both shortage and overflow. Usage totals are recorded, and an unusual rise in consumption, for example overnight, is flagged by the analysis layer as a possible leak.

5.6 Smart Irrigation

Soil-moisture sensors in gardens and planted areas report the moisture level. When it drops below a configured dryness threshold, the module starts the watering pump or valve, and it stops once the level reaches a target value. Watering is therefore driven by what the plants need and not by a timer. If a rain indication is available, it suspends watering. Each watering event and its duration are recorded, so water used for gardens can be reported separately from other uses.

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5.7 Emergency and Fire Safety

Flame, smoke, and gas sensors are placed in selected locations such as laboratories, kitchens, and electrical rooms. When a sensor crosses its threshold, the module marks the location as Critical, sounds a local alarm such as a buzzer, and sends an alert with the location to security staff and administrators through the dashboard and, where configured, through messages. A manual emergency button can raise the same alert. To limit false alarms, a single marginal reading only produces a Warning. A Critical state needs either a strongly elevated reading or confirmation from a second sensor or a repeated reading.

5.8 Air Quality Monitoring

Air quality sensors measure particulate matter and gases such as carbon dioxide, and the module turns the readings into a simple air quality category for each monitored area. In classrooms, high carbon dioxide points to poor ventilation and can prompt staff to open windows or run the ventilation. In open areas, high particulate levels suggest pollution from traffic, construction, or burning. Low-cost sensors have limited accuracy [10], so the framework treats their values as indicators and recommends calibrating them periodically against reference instruments.

5.9 Solar Energy Monitoring

Where a campus has solar panels, current and voltage sensors measure the power generated, and the module records generation over time. By comparing it with the campus consumption measured by the Energy Management module, it shows what share of consumption is met by solar power and how much energy is drawn from the grid. A drop in generation in bright conditions is flagged, since it may mean dirty panels or a fault.

5.10 Campus Navigation

The navigation function helps users find classrooms, departments, parking zones, and other facilities. The framework stores a directory of campus locations with coordinates on a campus map, along with building and floor information. A user picks a destination and sees its position and a route on the map. The navigation view is tied to live data, so it can show, for example, which parking zone has space or which restrooms and facilities are available right now.

5.11 Security Monitoring

The security function collects entry and motion events at selected gates and restricted areas and, where cameras are installed, gives authorized staff access to the feeds. Events outside permitted times, such as motion in a locked laboratory at night, raise a Warning or Critical alert. Cameras capture images of people, so the framework limits access to authorized staff, logs who views the feeds, and applies a retention period, as discussed in Section 8.4. In the simulation, the camera feed is represented by event messages and not by real video.

6. Rule-Based Control and Status Model

6.1 Threshold Rules

Most control actions in the framework are written as simple rules that compare a reading with a threshold. Table 3 gives representative examples. The numerical values are configuration parameters and not fixed constants, because they depend on the climate, the building, the sensors used, and institutional policy.

Table 3. Representative control and alert rules

Module	Rule (condition)	Action
Smart Classroom	Occupancy detected	Lights ON; fans ON if temperature above comfort limit
Smart Classroom	No occupancy for the configured delay	Lights and fans OFF
Smart Parking	Slot sensor detects a vehicle	Slot marked occupied; zone count updated
Smart Waste	Fill level above Warning / Critical threshold	Flag for collection / alert staff
Smart Water	Tank level below low / above high limit	Pump ON / pump OFF
Smart Irrigation	Soil moisture below dryness threshold	Watering ON until target moisture reached

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Module	Rule (condition)	Action
Environment	Temperature, humidity, or CO2 outside range	Warning or Critical status; ventilation prompt
Emergency	Flame, smoke, or gas above threshold	Alarm ON; alert with location
Solar Energy	Low generation during bright conditions	Warning for inspection

6.2 Status Classification

To compare very different sensors, each reading is mapped to one of three statuses. **Normal** means the value is within the expected range and nothing needs to be done. **Warning** means the value is nearing a limit or is outside the preferred range, so attention may be needed soon. **Critical** means the value has crossed a limit and needs immediate action. Each module defines the mapping with two thresholds. For a value x that should stay below a limit, the status is Normal if x is below the warning threshold T_w, Warning if x lies between T_w and the critical threshold T_c, and Critical if x is at or above T_c. For values that must stay above a limit, such as tank level, the comparison is reversed. Devices also carry an ON or OFF state, which the dashboard shows next to the status.

6.3 Preventing Unstable Switching

A rule with a single threshold can cause rapid on-off switching when a reading hovers around the limit. To avoid this, the framework uses hysteresis, with different thresholds for switching on and switching off, together with minimum on and off times for devices such as pumps and fans. For occupancy-based control, a delay before switching off stops the lights from going out during short periods of stillness. These measures protect the equipment and spare users the annoyance.

6.4 Energy and Saving Calculations

The energy used by a device over a period is calculated from its rated power and the time it was on. For a set of devices d, with rated power P_d (in watts) and on-time t_d (in hours), the consumption is:

$$E = \Sigma (P_d \times t_d) / 1000 \quad (kWh)$$

The saving achieved by automation in a given room and period is estimated by comparing consumption under automatic control with a baseline, in which devices run for the scheduled class hours or follow observed manual behavior:

$$Saving (\%) = (E_baseline - E_automatic) / E_baseline \times 100$$

In the same way, the share of consumption met by solar power is the ratio of solar energy used to total consumption in the same period. These simple measures let the Energy Management and Solar Energy modules report results that administrators can easily understand and verify.

7. AI-Based Analysis and Decision Support

7.1 Purpose and Positioning

Threshold rules respond to the current reading. They cannot recognize patterns over time, or unusual behavior that stays below a threshold. The AI-based analysis layer complements the rules by looking at history. It is positioned as decision support: it explains and recommends, while critical control actions, especially those involving safety, stay under transparent rules and human decision.

7.2 Analytical Tasks

The analysis layer performs four kinds of tasks.

1. **Anomaly detection.** Statistical or machine-learning methods flag readings that depart from the usual pattern for a given sensor and time of day, such as water use at night, a classroom drawing power while empty, or a sensor that keeps reporting the same value [12]. Simple methods, such as comparing a reading with a moving average and standard deviation, are enough for a first implementation.
2. **Forecasting.** Time-series models estimate near-term values such as hourly parking demand, daily electricity consumption, or the time at which a bin will be full. Forecasts let staff prepare, for example by scheduling bin collection before the predicted overflow.

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3. **Pattern discovery.** Aggregation and clustering reveal relationships, such as rooms that stay hot, bins that fill fastest, or parking zones that are always the first to fill up.
4. **Recommendation generation.** Results are written as short, plain-language recommendations, such as "Block C Room 204 has been occupied for fewer than two hours per day but consumes the most electricity" or "Bin 7 is expected to be full by 3 p.m."

7.3 Indicators for Administrators

Table 4. Principal analytical indicators

Indicator	Definition	Planning use
Energy per room or building	Consumption by period, from device ratings and run time	Identify high consumers; verify savings
Automation saving	Reduction compared with baseline (Section 6.4)	Measure benefit of automation
Solar share	Fraction of consumption met by solar generation	Renewable energy planning
Water use by category	Taps, tank, and irrigation use per period	Leak detection; water budgeting
Bin fill rate	Average time for a bin to reach Critical	Placement and collection frequency
Parking utilization	Occupied share of slots by zone and hour	Allocation of space; peak management
Comfort index	Share of time temperature and humidity are in range	Ventilation and cooling planning
Air quality category share	Share of time in each air quality category	Health and ventilation measures
Alert count and response time	Number of alerts and time to acknowledgment	Safety readiness and staffing

7.4 Explainability and Human Oversight

Every recommendation shows the data it is based on, so administrators can check it and override it. Anomaly flags are presented as suggestions for inspection and not as proven faults, because unusual readings can come from legitimate events such as an examination, a function, or maintenance work. The thresholds used for flagging can be adjusted, and administrators can mark flagged items as false alarms, which gives feedback for tuning.

8. Dashboard and System Design Considerations

8.1 The Real-Time Dashboard

The dashboard is a single page that summarizes the condition of the campus. At the top, summary tiles show how many items are in the Normal, Warning, and Critical states, along with key figures such as free parking slots, bins needing collection, current solar generation, and active alerts. Below these, each module has a panel showing its current readings, device states (ON or OFF), and status colors. An alert list shows recent events ordered by severity and time, and a map view places alerts at their location on campus. Administrators can open a module to see its history and adjust its thresholds. The dashboard updates automatically as new readings arrive, so nobody has to reload the page.

8.2 Architecture

Smart Campus 360 can be built as a conventional layered application. Sensors and controllers, real or simulated, publish readings to a message broker using a lightweight publish-subscribe protocol [11]. A backend service subscribes to the topics, applies the rules, stores readings and events in a database, sends commands to devices, and exposes interfaces for the dashboard. The analysis layer runs as a separate service that reads historical data, so models can be changed without touching the control logic. The dashboard is a web application that receives live updates from the backend.

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8.3 Core Data Model

Table 5. Main entities of the data model

Entity	Key attributes
Zone	Identifier, name, type (classroom, parking, garden, and so on), building, floor, map coordinates
Device	Identifier, zone, type (sensor or actuator), module, current state (ON or OFF)
Reading	Device identifier, value, unit, timestamp
Event	Identifier, zone, module, status (Normal, Warning, Critical), message, timestamp, acknowledgment
Action	Device identifier, command, cause (rule or user), timestamp
Threshold	Module, parameter, warning value, critical value, hysteresis margin
User	Identifier, role, access rights
Recommendation	Identifier, text, supporting data reference, timestamp, administrator response

Keeping every reading, event, and action, instead of overwriting the current value, gives an audit trail and is the basis for the analytical indicators in Section 7.3.

8.4 Security and Privacy

A campus platform controls physical devices and holds information about people, so it has to be protected. The framework uses role-based access control, encrypted communication between devices, broker, and dashboard, and hashed credentials. Device commands are accepted only from authenticated components, so an outsider cannot switch equipment or silence an alarm. Camera feeds and entry records are visible only to authorized security staff, access to them is logged, and retention rules say how long they are kept. Parking and occupancy data should be anonymous and should not identify individuals. Since the framework may handle personal data of students and staff, implementers should align their deployment with the applicable data-protection law, including India's Digital Personal Data Protection Act, 2023 [13], and with the institution's own policy.

8.5 Reliability and Fail-Safe Behavior

Sensors fail, networks drop, and power gets interrupted, so the framework plans for it. It tracks the time since each device last reported and marks a silent device as offline, which the dashboard shows, instead of quietly treating it as Normal. Safety functions such as fire alarms should have local logic that keeps working even when the network is down. For automation, a failure should lead to the safe state: lights stay usable, and pumps stop instead of running dry or overflowing a tank. Manual override switches should always remain available to staff.

9. Simulation and Evaluation Methodology

This paper presents the design of the framework. A full empirical evaluation needs either extended simulation experiments or a physical pilot, and the results of such studies are left for later work. This section describes the simulation approach used to prototype the framework and specifies how it should be evaluated, so that its claims can be tested in a reproducible way.

9.1 Simulation Approach

In the simulation, each physical sensor is replaced by a software component that generates values from a defined model, and each actuator is replaced by a virtual device whose state appears on the dashboard. Occupancy is generated from a class timetable with random variation in arrival and departure times. Temperature and humidity follow a daily cycle with random noise and rise with occupancy. Parking occupancy follows morning arrival and evening departure patterns. Bin fill levels rise at different rates in different locations, and soil moisture falls over time and rises when watering is applied. Tank levels drop with use and rise when the pump runs. Solar generation follows a daily curve with random cloud effects. Emergency and security events are injected at chosen times to test the response. The interface also lets an operator change values by hand, for example to trigger a fire reading, so the response can be demonstrated on demand.

Simulation suits this stage for three reasons. It allows all thirteen functions to be demonstrated together at almost no hardware cost, it allows rare and dangerous events such as fire to be tested safely, and it allows the same scenario to be repeated exactly. Its limitation, discussed in Section 10.2, is that simulated data reflects the designer's assumptions and not the full variability of real sensors.

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9.2 Research Questions

- **RQ1:** Does occupancy-based control reduce the simulated running time and energy consumption of lights and fans compared with a baseline of scheduled or manual operation?
- **RQ2:** Does the rule and status model classify readings correctly and trigger the intended actions and alerts, including when readings are noisy?
- **RQ3:** Does need-based control of watering and bin collection reduce water use and unnecessary collection visits compared with fixed schedules?
- **RQ4:** How quickly and reliably do the emergency functions detect injected events, and how many false alarms occur?
- **RQ5:** How accurately does the analysis layer detect injected anomalies and forecast demand?
- **RQ6:** Do administrators and students find the dashboard clear and useful?

9.3 Metrics

For energy, the metrics are device on-time, energy in kilowatt-hours, and the saving percentage defined in Section 6.4. For water and waste, they are the volume of water used, the number of watering events, the number of collection visits, and the number of bins that reached Critical before being collected. For rule correctness, the metric is the proportion of test cases in which the expected status and action were produced. For the emergency functions, the metrics are detection delay from event injection to alert, missed events, and false alarms. For the analysis layer, anomalies injected at known times serve as ground truth, and precision, recall, and F1 score are computed; forecast quality is measured by the mean absolute error against held-out simulated data. For usability, a structured questionnaire such as the System Usability Scale can be given to administrators and students after a demonstration, and the time taken to complete representative tasks, such as finding the full bins or locating a classroom, is recorded.

9.4 Study Design

A recommended design is to run the simulated campus for several simulated weeks under defined scenarios: a normal teaching week, an examination week, a holiday period, a hot period, a rainy period, and a set of emergency drills. Each scenario is run once with automation enabled and once with a baseline in which devices follow fixed schedules or manual behavior, using the same random seeds so the comparison is fair. Results are reported as averages over multiple runs, with ranges or confidence intervals. At a later stage, a physical pilot should be carried out in one classroom block, one parking zone, and a few bins and garden areas, and its results compared with the simulation.

9.5 Threats to Validity

Several threats to validity should be kept in mind. Simulated data follows the assumptions of the model and may be cleaner than real sensor data. Savings in a simulation depend on the assumed baseline behavior, and a different baseline would give different numbers. Thresholds tuned on simulated data may need retuning under real conditions. Usability responses from a small group of students and staff may not represent all users. The evaluation should acknowledge these limits and, where possible, validate the results against real measurements from a pilot.

10. Discussion

10.1 Expected Benefits

The framework is expected to benefit several groups. The institution gains lower electricity and water costs, a more reliable view of resource use, and earlier warning of faults and leaks. Maintenance and housekeeping staff get work assigned by need, with locations, and are spared unnecessary rounds. Security staff receive alerts with locations and times. Students and visitors save time through the parking and navigation information, and gain from better ventilation and safer surroundings. Administrators get one consolidated record of campus conditions to support planning and reporting.

10.2 Limitations

The framework has limitations, and they should be stated plainly. First, this paper presents a design and a simulation-based prototype, so its effectiveness on a physical campus has yet to be shown. Second, simulated data reflects the designer's assumptions, while real sensors bring noise, drift, and failures that a simulation may not fully capture. Third, low-cost sensors, especially for air quality and gas, have limited accuracy and need calibration [10]. Fourth, automation saves energy only where occupancy is detected reliably, and poorly placed sensors may switch devices off while people are still present. Fifth, fire and emergency detection must be validated and certified against the applicable safety standards before anyone relies on it, and the framework should supplement

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approved fire safety systems and not replace them. Sixth, camera-based monitoring raises privacy concerns that call for policy as well as technology. Finally, the benefits depend on staff acting on the alerts and recommendations the system produces.

10.3 Ethical and Governance Considerations

Campus data can reveal things about individuals, such as when and where they are present. Clear policies should state what is collected, who can see it, and how long it is kept. Occupancy sensing should count presence and not identify people, and security data should be restricted to authorized staff. Where AI-based recommendations influence decisions, the system should stay explainable and allow human override. Savings and performance figures should be reported honestly, including false alarms and failures, because only honest reporting makes a system trustworthy.

11. Conclusion and Future Work

This paper presented Smart Campus 360, an AI and IoT-based framework for monitoring and managing a campus through a single real-time dashboard. The framework combines thirteen functions, namely smart energy management, temperature and humidity monitoring, smart parking, smart dustbins, smart water management, smart irrigation, emergency and fire safety, air quality monitoring, solar energy monitoring, campus navigation, security monitoring, AI-based analysis, and the dashboard itself. These sit within a layered architecture, a common module pattern, and a uniform Normal, Warning, and Critical status model. An AI-based analysis layer adds anomaly detection, forecasting, and recommendations on top of rule-based control, and the simulation approach allows the whole system to be built and tested without physical hardware. By turning scattered campus facilities into one connected and observable system, the framework aims to reduce wastage, improve safety and convenience, and give administrators evidence for their decisions.

Several directions remain open for future work. The first is to run the simulation experiments described in Section 9 and report their results. The second is a physical pilot in a limited area of a campus, to compare real measurements with simulated ones. The third is to replace the simple statistical methods with learned models for occupancy prediction and demand forecasting. The fourth is to integrate attendance, library, and transport systems, as well as electric-vehicle charging. The fifth is a mobile application for students and staff with personalized navigation and notifications. Finally, studies of user acceptance and privacy perceptions would help ensure that such systems are adopted responsibly.

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