

IoT Integration in Educational Institutions for a Green and Digital Transition Case Study at POLITEHNICA University of Bucharest

Maria Elena ENACHE

National University of Science and Technology POLITEHNICA Bucharest,

*Corresponding author, enachemariaelena@gmail.com

ORCID ID 0009-0006-6973-4813

Bogdan TIGĂNOAIA

1. National University of Science and Technology POLITEHNICA Bucharest, Romania

2. Academy of Romanian Scientists, Ilfov 3, 050044 Bucharest, Romania

ORCID ID 0000-0002-7251-9165

bogdan.tiganoaia@upb.ro

Alexandru-Ionuț PETRIȘOR

1. Doctoral School of Urban Planning, "Ion Mincu" University of Architecture and Urbanism, Bucharest, Romania;

2. Department of Architecture, Faculty of Urban Planning and Architecture, Technical University of Moldova, Chisinau, Moldova; 3. National Institute for Research and Development in Constructions, Urbanism and Sustainable Spatial Development URBAN-INCERC, Bucharest, Romania

ORCID ID 0000-0002-2159-4034

alexandru_petrisor@yahoo.com

Georgiana MOICEANU

National University of Science and Technology POLITEHNICA Bucharest, Romania

ORCID ID 0000-0002-9483-0894

georgiana.moiceanu@upb.ro

Andrei NICULESCU

National University of Science and Technology POLITEHNICA Bucharest, Romania

ORCID ID 0000-0002-3544-2605

andrei@niculescu.ro

ABSTRACT: This article investigates the implementation of IoT technologies in educational institutions, aiming to understand their role in supporting infrastructure digitalization and achieving sustainability objectives. The case study highlights initiatives developed at the POLITEHNICA University of Bucharest to illustrate practical applications in the academic environment. The research offers practical examples for educational institutions aiming to adopt IoT-based digital solutions to optimize resources and reduce their environmental footprint. The case study provides transferable models that can be replicated in similar educational contexts. This paper is grounded in a real-world case study, documenting IoT initiatives within a Romanian university. It examines concrete applications such as environmental monitoring, process automation, and green energy projects, offering insights into sustainable digital transformation in higher education.

KEYWORDS: IoT, educational institutions, digitalization, sustainability, case study

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Introduction

Higher education institutions are currently positioned at the intersection of two major global imperatives: digital transformation and sustainable development. In recent years, the need for a simultaneous "green and digital transition" has become a defining theme in both European policy and institutional practice. On the one hand, rapid advancements in information technology compel organizations to digitalize their processes and services; on the other hand, they face growing pressure to reduce their environmental footprint and adopt sustainable practices.

The Internet of Things (IoT) technology plays a significant role in this context by enabling communication between devices through an intelligent network that allows real-time process regulation. The IoT paradigm allows

any electronic device or sensor to become part of an interconnected ecosystem, opening new opportunities for automation and data-driven decision-making. Through the use of IoT technologies, educational institutions can evolve into smart campuses that enhance resource management efficiency and academic life quality, while also contributing to the achievement of sustainability goals [1], [2].

In this framework, the digitalization of infrastructure—including through IoT—emerges as a "technological bridge" between digital innovation and environmental responsibility, which is essential for the dual transition within the education sector. At the European level, the integration of digital technology in education is supported by major strategies, such as the European Commission's Digital Education Action Plan 2021–2027. At the national level, Romania is also taking steps toward aligning education with the digital transition, although comprehensive IoT-specific strategies in education are still emerging. This plan calls on education systems to adapt sustainably to the digital era, emphasizing the need for robust digital infrastructures, the development of digital skills, and the promotion of innovative technologies (e.g., IoT) in education [3].

European initiatives stress that the digital transition must be aligned with sustainability objectives and that institutions should assess their digital maturity in order to plan concrete steps for improvement [3], [4], [5]. At the same time, human and cultural factors are recognized as essential determinants of successful digital transformation, highlighting the need to invest in the digital training of academic and administrative staff [6], [7]. Current approaches in the scientific literature emphasize the combination of favorable policy evaluation tools with the active involvement of human resources in order to achieve a coherent transformation aligned with strategic objectives.

Literature review

Theoretically, the core element of any IoT infrastructure is the smart sensor. An IoT sensor can be defined as "an electronic device that detects physical stimuli and converts raw data into a form readable by machines or humans" [8]. According to IBM, the IoT is viewed as "the network of physical objects... embedded with sensors, software, and network connectivity, enabling them to collect and share data," and "sensors are devices that can detect changes in the environment, such as temperature, humidity, light, motion, or pressure" [9]. In other words, IoT networks interconnect billions of such sensors that continuously generate massive volumes of data. As we move toward an IoT-centered society, the number of distributed sensors worldwide is growing rapidly, fueling real-time data analytics systems [8].

For example, Badshah et al. [10] emphasize that in smart environments (such as smart homes or campuses), any electrically equipped device can have its own sensors. Advances in sensor technology have made these devices increasingly smaller, more powerful, and more affordable [8], enabling large-scale IoT deployments and generating what is now known as big data. The data collected from sensors must be analyzed and interpreted in order to be effectively utilized, and emerging technologies such as cloud computing and artificial intelligence facilitate this process.

The literature identifies numerous application domains for IoT sensors that support both digital and sustainability objectives. IoT systems allow real-time monitoring and control of environmental and operational parameters within a campus (energy consumption, air quality, humidity, etc.), generating useful data for smart decision-making—from smart grids and air quality monitoring to urban agriculture [8]. For instance, energy sensors can track building consumption; environmental sensors can monitor air or water pollution; and other types of sensors can automate lighting, ventilation, or security systems based on space occupancy. Studies show that the use of IoT data leads to optimized resource usage, reduced waste, and increased comfort on a campus-wide scale, contributing significantly to sustainability goals [11], [12].

The integration of IoT in education has also been analyzed by researchers who highlight its positive impact on teaching and learning. IoT can support innovative pedagogical methods (smart labs, real-time simulations, automated assessments), improving both the learning experience and institutional management [10]. At the same time, the literature warns that the success of IoT implementations depends on human factors: the acceptance of technology by teachers and students, as well as their digital readiness, is crucial for project effectiveness [13]. Institutions that invest in digital culture and staff training tend to achieve faster and more consistent benefits, while avoiding the risk of glorifying technology without real-world applicability [7].

In conclusion, both academic and policy sources highlight the potential of IoT to facilitate the "green and digital" transition by linking educational infrastructures with the physical environment and energy resources. Leading authors and critics [9], [10], [11], [12] suggest that sensor networks can transform educational buildings and spaces into intelligent ecosystems that simultaneously support ecological and digital decision-making. This theoretical foundation provides the framework for the practical implementation analysis conducted at POLITEHNICA University of Bucharest.

Methodology

This study employs a qualitative case study approach, focusing on the analysis of IoT technology integration into the educational infrastructure of POLITEHNICA University of Bucharest. The study covers the period between 2020 and 2024, corresponding to the implementation timeline of IoT-based projects at POLITEHNICA University of Bucharest. The research methods applied include: analysis of institutional documentation (internal projects, strategies, and technical reports from UPB), direct evaluation of active IoT systems (LoRaWAN networks, sensors, cloud platforms, and software applications), and interpretation of the data generated by these systems within the campus.

The methodological process was carried out in three main stages:

- (1) identifying institutional needs regarding digitalization and the green transition;
- (2) documenting the IoT solutions already implemented at the campus level and the corresponding infrastructure;
- (3) analyzing the impact of these solutions by correlating quantitative data (energy consumption, environmental indicators) and qualitative data (feedback from users and technical teams).

For validation and contextualization, the findings were cross-referenced with scientific literature and relevant public policy sources in the field [1–9].

This approach provides a coherent framework for understanding how IoT technologies can contribute to the green and digital transition in the university environment, emphasizing the transferability of the UPB model to other higher education institutions interested in sustainability and technological innovation [3][6][8].

The selected case studies correspond to relevant, institutionally validated projects already implemented at POLITEHNICA University of Bucharest, as part of its green and digital transition strategy.

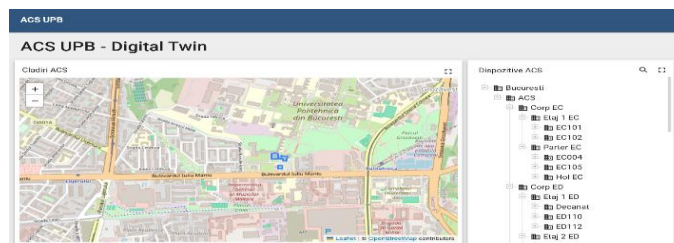
Results and further discussions

LoRaWAN networks and IoT sensors in the PRECIS and ACS buildings

Monitoring environmental parameters and optimizing resource use in large university campuses requires efficient wireless sensor networks with low energy consumption. In this context, POLITEHNICA University of Bucharest has opted for the implementation of LoRaWAN technology, known for its wide coverage and extended device autonomy. Two strategic buildings—the Research Center for Intelligent Products and Systems (PRECIS) and the Faculty of Automatic Control and Computers (ACS)—were selected for the deployment of a demonstrative project.

Figure 1 illustrates the visualization of the LoRaWAN network architecture and the IoT devices implemented in the ACS-UPB buildings, as displayed in the Digital Twin platform.

Figure 1. Visualization of the LoRaWAN digital network and IoT devices in the ACS-UPB buildings, as displayed in the Digital Twin platform



Source: POLITEHNICA University of Bucharest – Digital Twin Platform <http://digitaltwin.upb.ro>

This implementation is part of the CloudPrecis project, which aims to develop a smart campus model capable of collecting and analyzing real-time data on the internal and external environment of educational buildings. The Digital Twin platform enables real-time visualization of the network and sensors, facilitating automated decisions regarding air conditioning, ventilation, lighting, or space management [13], [14], [16].

As shown in Table 1, the technical architecture includes two LoRaWAN gateways (indoor and outdoor) and over 50 sensors strategically distributed across offices, laboratories, classrooms, and outdoor areas. These sensors collect data on temperature, humidity, CO₂ levels, presence, lighting, weather conditions, and parking occupancy.

Table 1. IoT devices installed in the UPB campus – PRECIS and ACS buildings

Device type	Quantity	Location	Main function
LoRaWAN outdoor gateway	1	ACS rooftop	Extended wireless coverage
LoRaWAN indoor gateway	1	PRECIS building	Indoor network connectivity
Elsys ERS-Eye sensors	10	Classrooms, offices	Light, motion, temperature, humidity monitoring
Elsys ERS-CO ₂ sensors	5	Laboratories, offices	CO ₂ level monitoring
Elsys ERS-VOC sensors	5	Enclosed spaces	Detection of volatile organic compounds (VOC)
Libelium Smart Parking sensors	10	Campus parking areas	Parking occupancy monitoring
Libelium Smart Security stations	3	Waste bin areas	Waste bin fill level monitoring
Libelium Smart Agriculture PRO stations	4	PRECIS yard / green areas	Soil humidity, temperature, plant parameter monitoring
Libelium Smart Agro Extreme station	1	Outdoor – weather area	Advanced weather data collection
SensMax people counting sensors	20	PRECIS and ACS entrances/exits	People counting, traffic flow analysis

Source: Authors' own research.

The devices are connected to a cloud-based infrastructure that enables the integration and automated analysis of data. The collected data contributes to the assessment of indoor comfort, air quality, and space occupancy levels, and can support policies aimed at improving energy efficiency, reducing emissions, and promoting sustainable campus management [17].

Photovoltaic Systems with IoT Monitoring

Enhancing campus sustainability requires the in-situ production of green energy to reduce both operational costs and carbon emissions. European funding through the Modernization Fund, managed by the Ministry of Energy, enabled an ambitious project for the installation of solar panels on the buildings of POLITEHNICA University of Bucharest. The main objectives include covering a significant portion of the university's energy consumption through renewable sources and improving the continuity of power supply.

Implemented solutions: In 2024, a project titled “*Ensuring electricity supply by installing photovoltaic systems for self-consumption*” was approved, with a total value of approximately 29.4 million RON [21]. The project targets 56 buildings across the university's three main campuses: Regie, Noul Local, and Leu. The entire system—with a total installed capacity of 7.04 MW—is equipped with IoT-based technologies: internet-connected inverters, smart digital meters, and sensors for monitoring current, voltage, and power factor. Production and performance data are transmitted in real time to a centralized platform integrated with the university's cloud infrastructure [22].

This intelligent solar network (microgrid) allows technical teams to monitor the performance of each solar panel, detect potential malfunctions early (e.g., accidental shading or efficiency loss), and optimize maintenance interventions [23].

How significant is the impact and how can it be measured? The primary outcome is an estimated annual generation of approximately 7,618 MWh of green energy [21], covering a substantial portion of the campuses' electricity needs. Initial estimates indicate around 1,526 MWh/year in the Regie campus, 5,458 MWh/year in Noul Local, and 632 MWh/year in the Leu campus. These values are continuously validated through the IoT infrastructure, which enables real-time metering of energy production. The impact is assessed through objective indicators: reductions in electricity bills, decreased CO₂ emissions (estimated between 0.5–0.7 tons of CO₂ avoided per MWh of solar energy produced), and improved energy supply stability for the campuses. The monitoring platform generates automated daily reports and alerts, such as production drops exceeding 20%, which may indicate a defective panel [22].

Table 2. Estimated annual energy production across the three UPB campuses

Location (Campus)	Installed power (MW)	Estimated annual production (MWh/year)
Regie	1.526	1,526
Noul Local	5.458	5,458
Leu	0.632	632
Total UPB	7.616 (≈ 7.04 as reported)	7,618 (reference total)

Source: Authors' own research.

What could the future look like? The project envisions expanding functionalities through the integration of smart storage batteries (managed via IoT), as well as extending the photovoltaic system to additional campus buildings. Performance monitoring allows for the continuous optimization of panel orientation and types installed. In the future, POLITEHNICA University of Bucharest plans to develop a smart grid living laboratory on campus, where not only energy production but also consumption will be optimized in real time—for example, by powering electric vehicles or prioritizing critical laboratories. The resulting data will support interdisciplinary research projects in the fields of energy transition and sustainable mobility.

Urban Agriculture and Smart Greenhouse at UPB

The green and digital transition requires higher education institutions to integrate IoT technologies into sustainability initiatives, in order to reduce environmental impact and modernize the educational process [6]. POLITEHNICA University of Bucharest has assumed ambitious objectives—climate neutrality by 2040 and zero waste status by 2035—which demand innovative campus projects aimed at reducing emissions and waste [7]. One essential area is urban agriculture and productive green spaces, in response to pressing questions such as “How can urban gardens help combat climate change?”. As a result, the need arose to develop an educational and research project on the POLITEHNICA campus that combines IoT technology with sustainable agriculture, offering students a living laboratory for the green and digital transition. This approach also aligns with the academic mission of training environmentally conscious engineers—POLITEHNICA integrates sustainability topics into education to encourage responsible environmental behavior among graduates.

Solution:The university has initiated a smart greenhouse on campus—an IoT-controlled urban agriculture pilot that practically demonstrates the fusion of digitalization and sustainability. This automated greenhouse, named *Freya*, was developed by a team of students at POLITEHNICA University of Bucharest and is equipped with an interconnected network of sensors (rain, soil moisture, temperature, water level, and light) that monitor the microclimate in real time [8]. The aggregated data allows precise control of cultivation conditions, with the system automatically adjusting ventilation and irrigation to maintain optimal plant growth parameters. Users can monitor and control the greenhouse remotely via a web interface or even through voice commands, thanks to the developed IoT platform. The hardware solution is built using open-source technologies and has a scalable architecture, allowing for easy expansion with new sensors or actuators. Notably, the smart greenhouse also incorporates eco-friendly features: it collects and uses rainwater for irrigation, and energy consumption is minimized through the use of low-power electronic devices.

Table 3 presents the types of sensors used in the *Freya* smart greenhouse, the monitored parameters, and how they interact with the IoT platform.

Table 3. Sensors used in the smart greenhouse and their associated functions

Sensor type	Measured parameter	Main function	IoT interaction
Soil moisture sensor	Water level in soil	Activates automatic irrigation	Sends data to the platform
Light sensor	Light intensity	Optimizes shading or lighting	Adjusts ventilation
Temperature sensor	Indoor climate	Regulates ventilation	Triggers alerts for critical thresholds
Water level sensor	Rainwater level	Controls irrigation water source	Activates the pump

Source: Authors' own research.

By integrating smart urban agriculture into the university environment, the POLITEHNICA initiative generates benefits on multiple levels. From an educational perspective, the smart greenhouse offers students the opportunity to apply theoretical concepts from IoT, electronics, and environmental science in practice, developing interdisciplinary skills in the emerging field of Agriculture 4.0 [7]. This learning-by-doing approach adds a valuable practical dimension to the curriculum, preparing future engineers to address the challenges of the green transition through innovative technological solutions.

At the same time, the project has demonstrated that significant gains in agriculture can be achieved through digitalization: the IoT-based greenhouse system saves resources through smart irrigation (using collected rainwater) and reduces energy consumption compared to conventional systems [8].

Complete automation of the internal climate ensures healthy plant growth regardless of external weather conditions, enabling consistent local production. From an organizational impact perspective, POLITEHNICA strengthens its reputation as a smart and sustainable campus. The greenhouse prototype has attracted the attention of the scientific community and industry, facilitating connections with potential partners and funders interested in green technologies [19].

The *Freya* greenhouse has led to actual resource savings, as illustrated in Table 4, which presents comparative estimates of water and energy consumption between the conventional system and the implemented IoT solution.

Table 4. Estimated reduction in water and energy consumption in the smart greenhouse

Resource	Conventional system	Freya IoT greenhouse	Difference
Water consumption/month (liters)	5,000	3,200	–36%
Energy consumption/month (kWh)	40	25	–37.5%

Source: Authors' own research.

The *Freya* pilot project opens the possibility for expanding smart green infrastructure. POLITEHNICA University can replicate the system as mini-greenhouses on rooftops or other available spaces, integrating them into a campus-wide Digital Twin system [7]. The platform collects essential data for optimizing resource consumption and supports applied research. The university is already investing in energy microgrids and green buildings, which can be efficiently complemented by integrating urban agriculture into this Smart Campus ecosystem [8].

Digital platforms at POLITEHNICA University of Bucharest in the digital transition

Digitalization in education involves more than just hardware technologies or integrated sensors; it also includes the development of software platforms that facilitate administrative processes, academic mobility, career guidance, and internal communication. POLITEHNICA University of Bucharest has developed a digital ecosystem composed of specialized platforms that support institutional goals for digital transformation and sustainability. These platforms contribute to process efficiency, reduction in paper usage, improved information accessibility, and the modernization of educational practices [21–27].

These platforms operate synergistically to create a coherent, accessible, and sustainable university environment adapted to current digital demands. They provide students, faculty, and administrative staff with modern tools for work and interaction, significantly reducing reliance on paper-based processes and in-person interactions, thus contributing to the reduction of the institution's carbon footprint.

The most relevant platforms are summarized in Table 5, outlining their functionalities and contributions to both the digital and green transition.

Table 5. Digital platforms developed at POLITEHNICA University of Bucharest

Platform	Website	Main functionality	Contribution to the green and digital transition
Travel	travel.upb.ro	Management of internal and external academic mobility	Full digitalization of mobility processes; eliminates physical documents
Apply	apply.upb.ro	Online admission platform for applicants	Eliminates the need for physical file submission; reduces resource consumption
Mobility	mobility.upb.ro	Information about Erasmus+ scholarships and academic exchanges	Promotes sustainable transnational education
International	international.upb.ro	Presentation of the university's international academic offering	Global digital visibility; promotion of sustainable cooperation
Alumni	alumni.upb.ro	Connecting graduates with the academic community	Supports digital networking and lifelong learning
Connect	connect.upb.ro	Internal communication and student integration platform	Reduces bureaucracy and encourages paperless communication
Virtual Tour	turvirtual.upb.ro	360° virtual campus and lab tour	Promotes the campus without physical

			travel; enables digital visual education <i>Source: Authors' own research.</i>
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The analyzed digital platforms (Apply, Travel, Mobility, International, Alumni, Connect, and Virtual Tour) cover complementary areas of the university ecosystem at POLITEHNICA University of Bucharest—from admissions and academic mobility to alumni relations and campus promotion. While each platform provides robust functionalities, there are significant opportunities for improvement through enhanced interoperability, automated notifications, integration of interactive components (such as chatbots, digital signatures, and bidirectional evaluations), and optimization of user experience (including mobile usability).

Furthermore, adopting a coherent, multilingual, and user-centered design, along with automatic synchronization of data between platforms (e.g., between Mobility and International, or between Connect and Alumni), would contribute to the creation of a truly integrated digital ecosystem. Implementing mentorship features, active communities, and proactive user support would further strengthen engagement and unlock the full potential of each platform.

Table 6. Proposed improvement directions for the digital platforms developed by POLITEHNICA University of Bucharest

Platform (URL)	Proposed improvement directions
apply.upb.ro	Integrate with the alumni platform to track post-admission academic paths.
travel.upb.ro	Automate application processing; integrate with external tools (e.g., Erasmus+ management systems).
mobility.upb.ro	Introduce automated notifications and enable online signing of mobility documents.
international.upb.ro	Integrate an interactive chatbot; automatically synchronize data with mobility-related platforms.
alumni.upb.ro	Develop a formal mentoring system; establish direct connections with connect.upb.ro and mobility.upb.ro.
connect.upb.ro	Add a student–company feedback module; automatically integrate internship credits into the academic system.
turvirtual.upb.ro	Provide text-based descriptions for accessibility; update regularly; implement VR features for promotion.

Source: Authors' own research.

Study limitations

This study has several limitations. First, the analysis is based on a single institutional example, which may limit the generalizability of the conclusions. The IoT technical components analyzed are specific to the institutional context, and local conditions (infrastructure, human resources) may influence the results.

In terms of methodology, the study mainly consists of a synthesis of available documentation and data; no surveys or impact studies involving all stakeholders have been carried out yet. In addition, since the IoT projects are still ongoing, some of the effects can only be fully assessed in the long term.

Future research will aim to extend the current descriptive approach by including primary data collection through surveys and interviews with IoT users. An impact assessment study will also be designed to evaluate the perceived benefits and challenges of IoT adoption in the academic environment.

Conclusions

The integration of IoT technologies in the university environment represents a key strategic direction for achieving the sustainability and digitalization objectives set at the European level. This study, focused on the example of POLITEHNICA University of Bucharest, highlights how IoT solutions can transform a traditional campus into an intelligent ecosystem that is energy-efficient and centered on educational innovation.

The research findings demonstrated that the IoT infrastructure implemented at POLITEHNICA University of Bucharest—from LoRaWAN networks and distributed building sensors to digital monitoring platforms and the smart greenhouse “Freya”—brings real and measurable benefits, both operationally (resource optimization, emissions reduction, energy efficiency) and educationally (digital skills development, applied learning, support for interdisciplinary research).

The experience of POLITEHNICA University of Bucharest shows that smart campus projects can serve as scalable models for other higher education institutions, especially in the context of the green and digital transition. However, the success of these initiatives depends on collaboration among university administration, technical teams, academic staff, and students, as well as sustained support through public policy and European funding.

In conclusion, the green and digital transition in education is no longer merely an opportunity—it is a necessity. IoT becomes the link between infrastructure, the environment, and the educational process, and POLITEHNICA University of Bucharest demonstrates that the vision of a sustainable, intelligent, and interconnected university is already a functional reality.

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