A Study of Artificial Intelligence and Internet of Things in Smart Campus Infrastructure

Madhura[1], Dwani[2], Fathima Soha[3], D N Kishan[4]
Sahyadri college of Engineering & Management

I. INTRODUCTION

Over the past few decades, the world has seen a lot of development in technology, due to which the population and infrastructure has also grown significantly. As cities undergo urbanization, ensuring sustainability has become a major challenge.
Urbanization refers to the shifting of population from rural areas to cities, because of which the population in rural areas is decreasing. This shift puts a lot of pressure on natural resources like water, electricity, waste management systems, etc. Hence, it has become necessary to use smart and sustainable solutions to manage these problems. Therefore, cities are implementing the concept of smart environments with the help of digital technologies so as to ensure sustainability and improve efficiency. This is how the concept of a smart campus arose. A smart campus is a subset of smart city concepts which integrates technologies like IoT, cloud computing and data analytics to make life easier. These tools help in the monitoring and management of campus operations in real time, hence enabling better decision-making and the use of various resources to support sustainable development.Water and drainage management systems play a significant role in ensuring sustainability. Without proper drainage systems, there is a high risk of flooding and water stagnation. This can lead to environmental pollution, bad odours and transmission of various waterborne diseases. Therefore, it is important to have efficient drainage systems.By integrating technologies like IoT and AI in the water and drainage management systems, it allows authorities to monitor and detect issues before they turn into major problems. They also reduce labour and contribute to the sustainability goals of the campus.
<u>Problem statement:</u>

1. Flooding:
Flooding is caused due to heavy rainfall and blockages in the drainage systems which does not allow water to flow properly. It causes water to overflow into land, causing many problems. Due to the developing infrastructure, some of the natural drainage paths get blocked which results in the accumulation of rainwater, leading to flooding even during moderate rainfall. This makes transportation difficult, damages roads, buildings and public areas, causing a downfall in economic activity.

2. Water stagnation:
Water stagnation occurs when water is accumulated in one place for a long period of time. This leads to unhygienic living conditions and environmental pollution. Water is accumulated in these areas due to improper maintenance and it is commonly observed in gutters, empty plots and construction sites. Stagnation of water causes damage to roads, releases bad odour, affects transportation, and provides a breeding space for mosquitoes and microorganisms which contaminates the water and transmits waterborne diseases.

3. Health risk:
Unhygienic living conditions and health risks are the major problems that occur due to water stagnation and flooding. The stagnant water carries various bacteria and viruses that cause waterborne diseases like cholera and typhoid. It also provides a breeding area for mosquitoes, which carry diseases like malaria and dengue. Flood conditions also increase the chances of skin infections, allergies, and respiratory problems to the people staying in its surrounding due to poor sanitation and exposure to polluted water. These health issues affect individuals as well as create a

burden on healthcare systems. It shows the need for proper prevention and management.

Limitations of traditional systems:
The traditional drainage system has many limitations like fixed capacity. The small increase in the rain causes frequent street and basement flooding. Due to no real time control we cannot prioritise critical areas during the storms. Unplanned urbanisation also increases the waste water flow. Clogging and poor maintenance also cause the drainage to overflow with waste water. Infrastructure failures also contribute to drainage problems. Untreated discharge of water increases the risk of disease. Cost effectiveness also plays a critical role.

II. CONCEPT OF SMART AND DIGITAL SUSTAINABLE CAMPUSES

1. Smart Infrastructure:
Smart campuses are basically all in one systems which connect cloud technology and IoT devices to help institutions run on their resources efficiently. The goal is to solve problems,to make better decisions, cut wastage, and operate more sustainably (Sneesl et al., 2022).
These systems combine technology, people, and institutional policies to solve real world environmental challenges like energy uses, water conservation, and renewable resources. (Oberascher et al., 2022).

The components of smart infrastructure are usually built in four stages- IoT sensors and devices, communication networks, cloud computing and data storage systems and AI and data analytics.

- IoT sensors and devices collect real-time data related to the environment and infrastructure. 'These sensors are the core of the smart monitoring systems, as they enable continuous data collection and communication.' (Zanella et al., 2014)
  - Communication networks use wireless technologies such as GSM and cloud networks to transmit data between sensors, servers and user interfaces.
  - Cloud computing platforms provide large amounts of storage, processing power and external access to data generated by smart devices.
  - Artificial Intelligence and data analytics helps in processing collected data so as to identify and predict possible failures in the systems. Research indicates that AI enhances IoT systems by "predicting future consumption" and "detecting anomalies such as leaks."

(Angelova, M., Kiryakova, G., & Yordanova, L. (2021).

2. Digital Platforms:
Digital platforms are like computer systems that collect, process, analyze and store data from various devices and parts of a campus. These platforms help the supervisors and the users to track campus operations, envision data and receive warnings. Based on this, the personnel can make informed decisions about digital platforms and the information they provide (Sneesl et al., 2022)

The components of digital platforms include monitoring dashboards, alert and notification systems, data management systems and user interface and applications.

- Monitoring dashboards are digital interfaces that represent real-time data collected from various infrastructures. They help in tracking the usage of resources, recognizing the issues and monitoring campus operations effectively.
- Alert and notification systems trigger alerts when anomalies are detected. This helps in solving the issues before it gets out of hand.
- Data management systems are used to organize and process data collected from the sensors and other devices.They provide accurate analysis, and they can easily retrieve previous data.
- User interfaces in mobile apps and websites provide a platform for the users to interact with the administrators and the system itself, reducing communication gaps and response-time.

(Alrashed, s., & Asif, M. (2021); Angelova, M., Kiryakova, G., & Yordanova, L. (2021);Abdel-Basset, M., Mohamed, R., Sallam, K. M., & Chakrabortty, R. K. (2022); SSRN, 2023)

3. Sustainability goals:
Sustainability goals are long-term objectives that focus on meeting our needs while making sure that we do not harm the environment, society and the economy

for the future generations. ‘In digital sustainable campuses these goals focus on reducing the harmful impacts on the environment by using resources wisely and helping the earth through new technologies and responsible actions.’ (Alrashed, s., & Asif, M. (2021))

The components of sustainability goals include environmental sustainability, which focuses on the conservation of natural resources, reducing pollution etc. This can be achieved by managing waste in an efficient manner, conserving water resources and monitoring the environment with the help of IoT. Another major goal includes economic sustainability which aims to reduce the cost of operations while improving the utilization of resources. Also, social sustainability plays a key role in ensuring that everyone gets fair access to resources like healthcare, education, etc.

Role of IoT, AI and Cloud Computing:

The Internet of Things helps in connecting various devices and sensors so that data can be processed and transmitted in real time. In smart campuses, IoT can be used to monitor the drainage, environmental monitoring systems and many other systems and sensors at the same time, reducing time and labour. By using such tools, the authorities can operate efficiently, make the right decisions based on the data and ensure sustainability. (Springer, 2021).

By combining IoT with AI and cloud computing, it becomes one of the crucial technologies used in smart campuses, providing the basic structure for it. Artificial Intelligence uses deep learning and machine learning which helps in decision-making and logical thinking, and hence helps in solving real world problems. AI can analyze millions of data easily and help in improving the efficiency of the smart campuses. By integrating these technologies together, it creates a smart ecosystem where the data analysis happens in real time and based on the analysed data, the decision is taken.

The paper,*”A Greener Campus: Reusing Water, Reducing Waste and Protecting the Environment”*, provides many real-life examples of the applications of IoT in a smart campus like smart bins, elevators, shuttles, and weather stations. For example, smart bins use certain sensors to detect garbage levels and alert the authorities. This helps in managing waste efficiently.

Another example provided in this paper is smart weather stations. IoT based sensors collect data from the environment like the temperature, humidity, etc, and based on this data, the AI predicts rainfall and other environmental conditions. (SSRN, 2023).

Hence, IoT, AI and cloud computing play a major role in the concept of digital campuses.

Key objectives of efficiency, resource optimization and environmental protection:

One of the goals of digital sustainable campuses is to make operations more efficient. They do this by using systems that are all connected. These campuses use technologies like the Internet of Things, sensors, etc, to monitor infrastructure. They also help in automating tasks. This approach reduces the need for manual inspection and delays, offering faster responses to problems with the systems, hence improving efficiency.

Research shows that 'smart campus setups improve system performance by enabling real-time monitoring and data-driven decision-making. This leads to efficient management of campus facilities.'

(Alrashed, s., & Asif, M. (2021); Abdel-Basset, M., Mohamed, R., Sallam, K. M., & Chakrabortty, R. K. (2022))

Another major goal is to improve water resources, energy and waste systems. Smart campuses use sensors and data analysis to keep track of where the resources are being used and recognise areas of waste. For example, research on water campuses shows how ‘real-time data collection, intelligent monitoring systems, and predictive analysis can reduce water consumption by detecting leaks, optimizing distribution, and promoting reuse strategies’

(Sleman, A., Pitt, J., & Dimitrakopoulos, G. (2021); Oberascher et al., 2022)

Such types of systems help institutions optimize energy consumption and waste management which ensures that resources are used efficiently and sustainably.

Therefore, by integrating technologies into campus infrastructure, we can ensure efficiency and optimize resources through monitoring, predictive analysis and self-operation. This does not just reduce operational expenses but also contributes to long-term environmental sustainability.

Environmental pollution:

Environmental pollution is one of the major problems affecting sustainable development today. It includes air pollution, water pollution caused by industries, factories, vehicles and waste disposal. These pollutants harm health, damage our natural resources and reduce the overall quality of life

Pollution is increased because of rapid growth in industries and urban development especially in a developing country like India. Factories release harmful gases such as sulfur dioxide (SO_2), nitrogen dioxide (NO_2) and small harmful matter into the air while industry waste pollutes rivers and water bodies. This results in serious health issues like water upon diseases, breathing problems and even infant mortality.

Another main objective is to study whether the government regulations on environmental pollution are actually helpful or not.

The study shows that the policies made on air pollution have helped the pollutants like sulphur dioxide and nitrogen dioxide to reduce and improve pollution however the water pollution is not very well improved. This shows that while some regulations work well, some may not work as effectively as others. Strong implementation and monitoring is required. (Greenstone, Michael and Hanna, Rema, Environmental Regulations, Air and Water Pollution, and Infant Mortality in India (December 30, 2013))

It also highlights that poor control on environmental pollution is not only an environmental issue but also a social and economic problem. Poor air quality and water quality is gonna affect the public health and increase medical cost and reduce productivity

Therefore, controlling pollution is necessary for sustainable development.

Another important objective is to create awareness that economic growth should not happen at the cost of nature. Industries should follow rules to control pollution and the government must make sure these rules are followed strictly. People can also help by taking part and using better technology can reduce pollution too.

Efficient resource optimization and smart monitoring systems help reduce environmental pollution by controlling waste disposal and improving water management along with reducing usage of energy in industries and campuses. Using IoT sensors for pollution monitoring, smart drainage systems, recycling and reuse of water, energy efficient systems, automated waste separation and sustainable industrial practices will help us manage and reduce environmental pollution.

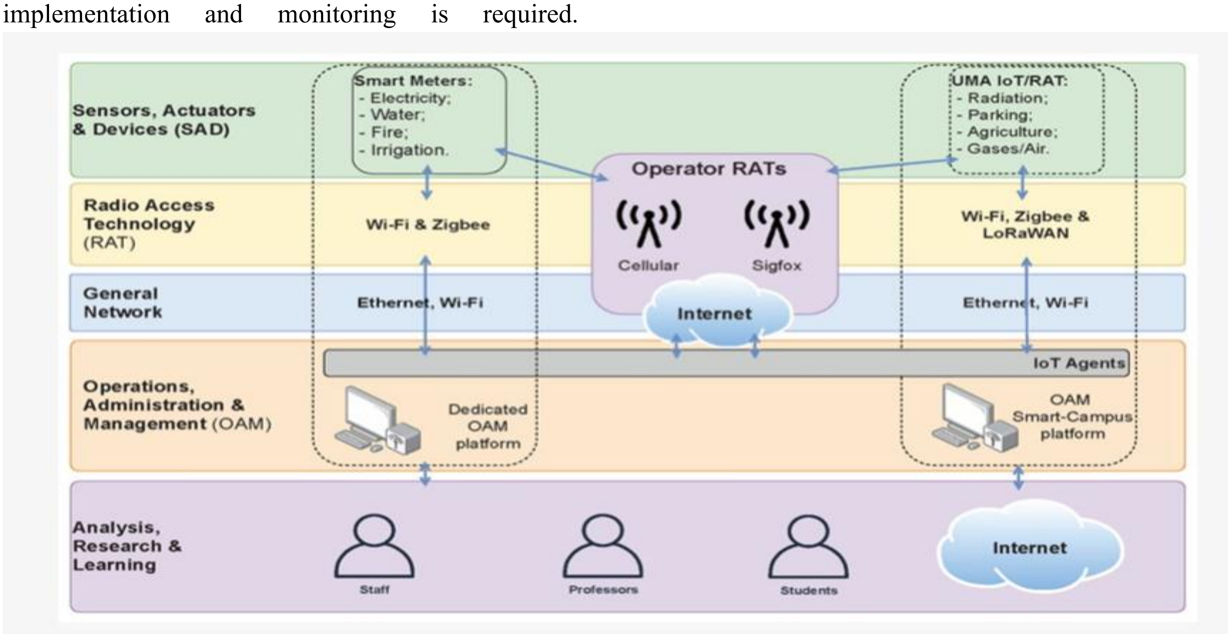

Figure 1: UMA Smart Campus framework and general ICT infrastructures.

[Martins, P., Lopes, S. I., Rosado da Cruz, A. M., & Curado, A. (2021). Towards a Smart & Sustainable Campus: An Application-Oriented Architecture to Streamline Digitization and Strengthen Sustainability in Academia. Sustainability, 13(6), 3189.]

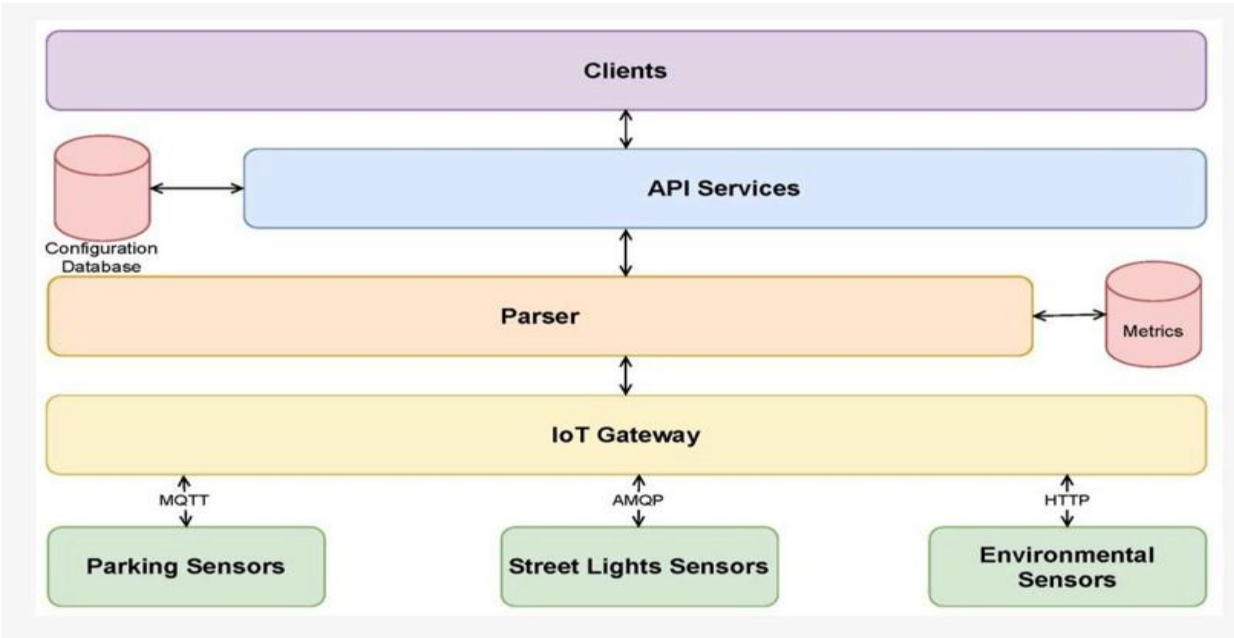

Figure 2: Smart Campus Architecture.

[Martins, P., Lopes, S. I., Rosado da Cruz, A. M., & Curado, A. (2021). Towards a Smart & Sustainable Campus: An Application-Oriented Architecture to Streamline Digitization and Strengthen Sustainability in Academia. Sustainability, 13(6), 3189.]

III. TRADITIONAL DRAINAGE MANAGEMENT SYSTEMS

Manual inspection methods:

In the traditional approach to drainage management, the drainages are checked and assessed manually by the officials. The workers go to the drainage areas and open the manholes to inspect the drains for any damage or blockages. They conduct inspections based on the water levels, condition of the drainage pipes and the drainage intensity. Based on these indicators, the drainage system was assessed. These inspections are mostly conducted during monsoon since there is a risk of flooding and blockages during this time. This approach is commonly used in Indian cities and villages.

Manual inspections often require a lot of labor and it is very time-consuming. It is also very unsanitary, and it can cause long-time health problems to the workers. Moreover, the issues can only be detected after the damage happens. Since these issues depend on periodic actions and not active situations, authorities are shifting towards an intelligent approach instead of relying on the conventional methods.

2. Complaint-Based Systems

Complaint based systems is another common traditional method of drainage management where a complaint is filed by the local residents regarding the drainage problems like blockages or overflow, and the authorities respond to it by sending officials to inspect the situation. The complaints are usually received in the form of letters or phone calls to the municipalities. However, there are several limitations to this approach. Sometimes, even if a complaint has been filed by the residents, the authorities do not respond to it on time, especially during monsoon, which actively worsens the situation of the drains. In some cases, even though the drainage issues are prevalent, citizens don't

bother reporting it to the authorities and the situation is overlooked.
A major limitation of complaint-based systems is that it does not enable real-time monitoring. Authorities come to know about the problems only when the complaint is reported, and by the time they take the necessary action, the condition of the drain is worse than before. Since there is no way for the authorities to monitor the conditions of the drains without the input from the citizens, the best approach is to implement IoT based monitoring systems which can assess the conditions of the drains continuously and predict overflows and blockages, hence alerting the authorities before the problems occur. This approach is beneficial to both the citizens and the authorities and it can help reduce environmental pollution.

3. Municipal practices
Another approach to traditional drainage management systems is municipal practices where regular inspection and maintenance of the drains is carried out by the municipalities. The officials inspect the drains to ensure that they are in a good condition, hence avoiding problems like waterlogging, blockages, etc. These practices focus on cleaning drainage, removing waste and fixing broken pipes. These maintenance schedules are based on the complaints filed by the citizens. The drainage is inspected by the sanitation workers who assess the condition of the drainages for any damages. This is labor-intensive work, and the problems are addressed only when it occurs and when the citizens report the inconvenience. The planning and maintenance of the drainage systems are made by referring to previous data. This helps engineers in identifying the areas which require immediate action. However, the authorities sometimes delay in responding and immediate action is not taken, which can make things progressively worse. (Silva et al., 2020; Santos et al., 2024)

LIMITATIONS

1.Delayed Response of Traditional Drainage Systems
Traditional drainage systems have certain limitations that come with it. One of them is delayed response to drainage issues. Since traditional drainage systems usually involve periodic checking and lack real time monitoring it is difficult to identify issues such as water stagnation, overflow, clogging or leakages. As a result, drainage problems are often found only after flooding or water accumulation has already occurred.
Since traditional systems are mostly a reactive approach, the necessary actions are not taken until the problem occurs. This can lead to overflowing of wastewater into nearby land and affect transportation, cause damage to properties and create unsanitary living conditions which increases the risk of waterborne diseases and mosquito breeding in society. Smart and digital sustainable campuses aim to overcome these limitations of traditional drainage networks by combining technologies such as IoT-based sensors, artificial intelligence and data analytics. By using these technologies, we can ensure real time monitoring which helps authorities to respond quickly to drainage issues. (Bimrah, K., & Saizen, I., 2026)

2.Lack of real-time monitoring
Lack of real time monitoring is another limitation of the conventional drainage management systems. Usually, traditional methods include periodic inspection and cleaning based on the complaints reported by the citizens. However, this does not enable real time monitoring of the drains and focuses more on a reactive approach instead of a predictive one. In some cases, the condition of the drains may go unnoticed by both the authorities and the citizens and the problem can turn severe, causing significant damage to the surrounding areas.

Recent studies regarding drainage management shows that real time information about the water flow, drainage performance and the conditions of the surrounding areas are important in managing drains efficiently. However, the traditional methods do not follow this, mainly relying on inaccurate information and previous data instead of considering the active situation. The paper, "Data collection and information management for urban drainage systems: Current status and perspectives", describes how certain urban drainage systems face challenges in managing the drainages due to outdated and unreliable data and lack of real time monitoring, which negatively affects the ability of the municipalities to make quick decisions.

3.Human Dependency
Traditional methods heavily rely on human dependency. Municipal officials do most of the work manually, like assessing complaints from the

residents, inspecting drains for blockages and cleaning and fixing broken pipes. Their main source of input are the complaints received by the citizens who report noticeable problems like overflows and bad odour, and based on these reports, they take the required action which is extremely inefficient.
The municipalities face several challenges due to their reliance on manual methods since it is often time consuming, labor-intensive and unsanitary for the workers. It takes a lot of skill and even then, there's a high probability of making errors or overlooking some problems which can damage the drains in the long run. Due to this, the municipalities are shifting more towards the digital approach.

4.Inefficiency in human dependency
Conventional drainage management systems are inefficient when dealing with large campuses and institutional environments composed of extensive and complex networks of infrastructure. The domain of the universities usually comprises a number of colleges, hostels, laboratories, stadiums and plenty of greenery connecting with lengthy drain pipelines; Little under screen channels; And storm water system. Manually inspecting a network this large is not only time consuming, but also resource-heavy. As the campus grows physically, Facilities personnel have a harder time inspecting each area on a regular basis and tracing potential larger issues before they get out-of-hand.(Silva et al., 2020).
Another challenge of drainage maintenance is the requirement of professionals to solve different issues. Studies show that large campuses generally employ experts across various fields to make things easier. However if there is a lack of a centralized information system and everything depends on manual reports, communication between all those specialists will be delayed. Consequently, conventional drainage management techniques cannot be effectively used at universities. (Silva et al., 2020)

COMPARISON TABLE

FEATURES	TRADITIONAL DRAINAGE SYSTEM	SMART DRAINAGE SYSTEM
Monitoring methods	Manual checking carried out by employees.	Real-time monitoring through the use of IoT.
Problem identification	Issues identified only upon occurrence of congestion or flooding.	Early detection of problems.
Response time	Ineffective response.	Effective response.
Human involvement	High involvement of manpower and citizens.	Low involvement of humans.
Maintenance approach	Maintenance is done only after the issue occurs.	Predictive and preventive maintenance.
Data management	Data maintained manually using paper records.	Digitalized information management.

IV. DIGITAL COMPLAINT-BASED SYSTEMS (CASE STUDY APPROACH)

Digital complaint-based systems provide an online platform for users to report their issues and grievances regarding the environment. It is different from the traditional complaint-based systems, and it takes on an online approach which improves communication between the users and the authorities and creates a sense of transparency between them. These systems are gaining popularity in smart campuses, cities and various institutions as it is much more convenient than the traditional method. Here, complaints are reported through a user-friendly website or app, and the collected data is assigned to the respective municipal departments based on its nature and the status of the problem. In the modern version of the digital complaint systems, users can upload images of the problem and the location, which makes tracking more efficient. These systems also help in reducing the delay in response time and support real time monitoring.

Concept of User-Driven Platforms
In user-driven platforms, the users can monitor, track and report issues conveniently via an app or through websites. These platforms also help in promoting public participation and ensure smooth communication between the authorities and the users. They play a vital role in detecting developmental issues, leakages, drainage issues, property damage, complaints and other administrative tasks. They also promote transparency and build trust among the citizens and the authorities.

Features of Digital Complaint-Based Systems

1.Issue Reporting
The foundation of any complaint management system is the reporting of issues. The users can file complaints in various areas like drainage, transportation, security and many other services. The users log in to the website or app and fill out a complaint form stating the subject, nature and severity of the problem they are facing. Based on this, the complaints are categorized and assigned to the respective departments. In modern systems, AI is incorporated in the system which helps in categorizing the issues easily, ensuring faster response.

Case Study Example:
A real-world example for digital complaint-based systems is the "Campus Care Intelligent Grievance Redressal System", which uses AI to categorize the complaints and also uses a level-based escalation mechanism to handle complaints from students effectively.

2.Image Upload
These platforms also allow users to upload images of the problems, making it easier for the authorities to analyze the problem and handle it effectively. For example:

- Pothole pics
- Blocked drain pictures
- Classroom equipment is broken
- Photos of water leak
- Proof of garbage dumping

The reporting supported by image increases the speed of verification and avoids false complaints. Research on civic issue platforms has found that photo evidence makes the process more transparent and administratively efficient.

Case Study Example:
The "Street Sense Civic Issue Reporting Platform" allowed users to upload images with civic complaints like damaged streetlights, garbage issues and drainage failures.

3.Location Tagging
Location tagging is done by either GPS or map integration to know the exact location of a complaint. This feature is very important in smart city and smart campus systems as authorities can directly find the issue area without any confusion.
Advantages of location tagging:

- More rapid issue recognition
- Precise complaint routing
- Improved mapping visualization
- Field inspection simple
- Enhanced crisis response

Most platforms utilize geospatial technologies and live maps for complaint visualization.

Illustration of Case Study:
The "Civic Pulse platform" and "Street Sense system" both employed GPS-enabled location tracking and map-based complaint visualization to improve civic issue management.

4.Status Tracking
The status tracker enables users to keep track of the progress made concerning their complaints once they are submitted. Every complaint is assigned a

complaint ID number to aid in monitoring the process of redressing the same.
Some of the typical complaint statuses include:

- Submitted
- Under Review
- In Progress
- Escalated
- Resolved
- Closed

Real-time alerts and dashboards increase accountability and transparency. Other systems even track the SLAs (Service Level Agreements) to ensure complaints are resolved within the required period of time.

Case Study illustration:
The “Smart Campus Grievance Management System” offered real-time tracking, automatic escalation and centralized dashboards to make grievance resolution more efficient.

V. IOT BASED DRAINAGE AND ENVIRONMENTAL MONITORING SYSTEMS

What is IoT (Internet of Things)?
The Internet of Things (IoT) is a network of interconnected physical objects that includes sensors and actuators which help in gathering data about the environment and then transmit it through the internet or other communication networks. They help in keeping track of the surroundings, processing data and organizing responses to various changes without the intervention of authorities. (Perera et al., 2014; Abdel-Basset et al., 2022).

IoT can ensure the continuous monitoring of parameters such as water level, water flow rate, gas content and temperature in terms of drainage systems and environmental factors. The gathered data is sent to cloud-based platforms in order to analyze it and report any issues like clogging, leakage, flooding, or the presence of toxic odor (Sleman et al., 2021).
These solutions alert the authorities about the situation so that they can react in an efficient manner.

Components of Internet of Things-Based Drainage Monitoring and Environmental Monitoring System
1. Sensors:
The sensors serve as the fundamental data collection components in any IoT-based system. These sensors record various physical parameters such as water level, water flow rate, gas content, and temperature. The sensors collect real-time data of drainage and pass it to the control system (Perera et al., 2014).

2. Microcontrollers:
It is the most important component in IoT. It helps in processing of the data which is received from the sensors and then transfer it from one device to another. Examples of microcontrollers are Arudino and ESP32.

3. Communication Systems:
Devices such as Wi-Fi, GSM, LoRa and Zigbee are responsible for transferring the data obtained from the microcontroller to other servers.
This enables the simultaneous flow of communication and monitoring (Angelova et al., 2021).

4. Cloud Computing Platform:
The cloud computing platform stores, processes, and analyses data received from sensors and enables users to access their data remotely. It can also be used for further analysis purposes (Abdel-Basset et al., 2022).

5. Data Analytics and Artificial Intelligence
Data analytics and artificial intelligence algorithms find trends in the collected data, anomalies, and predict any failure that may occur, such as leakage and overflow issues (Sleman et al., 2021).

6. User Interface
The web dashboard and application can be used to view the data obtained from the system.

Working of an IoT-Based Drainage and Environmental Monitoring System:
The process of operation for an IoT-enabled drainage and environmental monitoring system is based on constant monitoring, data transfer, intelligent processing, and automated mechanisms for responding. Such solutions can be used to identify the occurrence of drainage problems like overflow, blockage, leakages, gas poisoning, and abnormal flow. IoT solutions will increase efficiency and decrease reliance on manual inspection procedures (Sleman et al., 2021).

1. Data Collection

The process of data collection represents the initial phase within the workflow process of the system using sensors attached to drainage channels, water storage tanks, sewer systems, and the environment itself. The data collected will include the environmental parameters such as levels of water and water flow, gas presence and concentration, as well as ambient temperature.

IoT sensors are used as a tool for collecting data from the environment continuously. Research notes that IoT-based devices can be used for "information collection about the environment" and monitoring relevant parameters (water and infrastructure systems) (Sleman et al., 2021).

The data collected by sensors can help identify problems like:

- Water level increase
- Water stagnation
- Pipeline blockage
- Gas leakage
- Flow abnormalities

Continuous collection of data eliminates the need for constant inspection and ensures early problem identification.

2. Data Transmission

Once the data is obtained, it is transmitted to the microcontrollers and cloud devices through the medium of Wi-Fi, GSM, etc. Through these communication mediums, real-time connectivity is achieved between the sensors/monitors and the control system.

Research on smart campuses shows that these communication channels allow for "real-time data acquisition and transmission" as well as "interaction" between the intelligent devices and the management system (Angelova et al., 2021).

The received data is accessible by the administrators remotely via cloud dashboards and applications.

3. Data Processing and Analytics

After collecting the data at the cloud platform/server, analysis of the data is done by employing data analytics and Artificial Intelligence (AI). The purpose of this stage is to analyze the collected data and make some predictions regarding abnormalities.

With artificial intelligence-based processing, it is possible to:

Detect leaks and clogs

Predict potential overflows

Detect any abnormal drainage behavior

Evaluate resource consumption patterns

According to Sleman et al. (2021), using AI systems it is possible to predict future resource consumption and detect abnormal behavior and leaks.

The final data can be visualized through the help of various graphs and dashboards.

4. Action and Alert System

In cases where the system senses any abnormal situation, for example, when there is excess flow, high concentration of gases, or drainage obstruction, automatic notification messages are automatically sent to the relevant authorities or departments.

The message can be received using any of the following methods:

- Mobile apps
- Text messages
- Email messages
- Dashboard notifications

A few sophisticated systems may have an automated system response that triggers actions such as:

- Starting of pumps
- Opening of drainage gates
- Activation of warning systems
- Arranging maintenance schedules

Types of Sensors Used in IoT-Based Drainage Monitoring Systems

1. Water Level Sensors

These devices determine the volume of water in drainage, tanks, and sewage pipes. These sensors help in determining cases where there is flooding, overflow, and stagnation of water.

The problem of flooding or overflow is determined when the water volume exceeds the preset limits.

Uses:

- Monitoring of Floods
- Monitoring of Sewage Water
- Water Tank Management

2. Flow Sensors

The flow sensor helps determine the speed and quantity of water flow through drainage pipelines. They play an important part in establishing abnormal

water flow, which could be due to leakage or damages in the pipe.
The presence of an abnormal increase or decrease in flow rate could be an indication of:

- Blockage in the Pipe
- Water Leakage
- Overflowing of Water

Flow sensors are very crucial in monitoring water flow.

3. Gas Sensors
Gas sensors are used to sense any harmful and toxic gases released from sewers and drains, including:

- Methane (CH_4)
- Hydrogen sulfide (H_2S)
- Carbon monoxide (CO)

These gases may cause harm and danger to people working in the area as well as the surrounding population. Gas sensors constantly monitor the air quality and sound an alarm when the concentration of gases surpasses the safe threshold.
According to some research papers, environmental monitoring systems have sensors installed for measuring "temperature, humidity, and carbon dioxide level" (Sleman et al., 2021).

4. Blockage Detection Sensors
Blockage detection sensors are employed to locate the presence of any obstacle or garbage within drainage pipes. The sensors help avoid water clogging, water overflow, and any damage to pipelines due to obstruction in the water flow.
The system can send notifications to the maintenance team regarding any blockages.

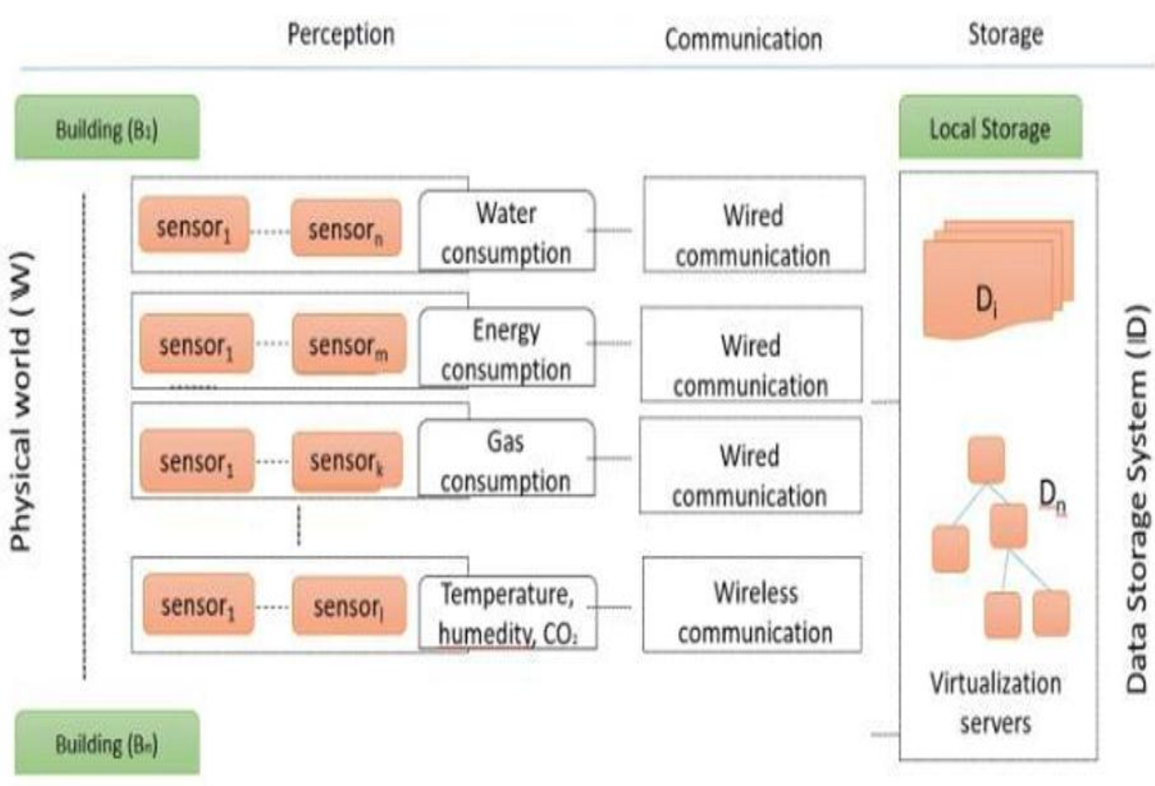

Figure 3: Sensor network architecture.

[Barroso, S., Bustos, P. & Núñez, P. Towards a cyber-physical system for sustainable and smart building: a use case for optimizing water consumption on a Smart Campus. *J Ambient Intell Human Comput* **14**, 6379–6399 (2023).

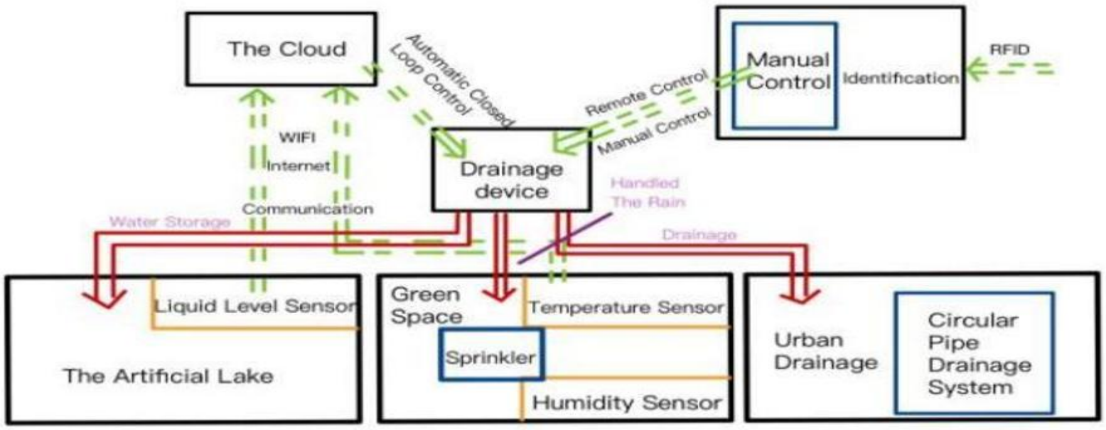

Figure 4: Smart drainage pipeline monitoring

[Tong, L. (2020). A Intelligent Campus Based on the Internet of Things--Campus Intelligent Drainage System.]

VI. CLOUD COMPUTING AND DATA MANAGEMENT

Cloud computing and data management provide several important benefits in smart, digital and sustainable campuses. These help institutions manage large data collected from IoT devices, sensors, online learning platforms and monitoring systems.

Cloud based systems improve the efficiency, flexibility and connection between campus operations by supporting real time monitoring, centralized data storage and smart decision making. Some of the major benefits of cloud computing and data management include scalability, accessibility and data integration, which help campuses become more sustainable, efficient and advanced.

1. Scalability:

Cloud computing and data management in smart, digital and sustainable campuses provides several benefits. One of the most important is scalability.

Campus produce huge amount of data through IoT devices, sensors, learning platforms, energy systems, transportation systems and security applications. Cloud platforms allow institutions to effectively organize their data without having to rework physical infrastructure over the period of time. According to the research paper, "*Application of a Big Data Framework for Data Monitoring on a Smart Campus*", use of a Big Data Framework for Data Surveillance on Smart Campus, big data technologies and cloud computing frameworks allow campuses to continuously monitor data from various surveillance systems in environments where there is less or poor storage. As the number of users, devices and services increases, scalable cloud systems enable facilitation to support universities' growing cloud environment.

New smart applications and IoT devices can be sent smoothly on the existing cloud platform. The paper, "*Towards a Smart & Sustainable Campus: An Application-Oriented Architecture to Streamline Digitization and Strengthen Sustainability in Academia*" explains that FIWARE based cloud architectures enable flexible and scalable smart campus environments through modular system combination. This allows campuses to remain flexible wherever the directions technology may take them in their precautions and processes around resources, efficiency and sustainability.

2. Accessibility:

Cloud computing improves smart campus accessibility by providing easy access to data and digital services at any time and from anywhere.

Whether computers, tablets or smartphones, students, teachers, researchers or administrators can access cloud-based platforms independently of the office or any other fixed location.

Cloud based dashboards and digital management systems offer real time information that supports faster and better decision making. Accessibility is especially important in today's educational institutions because it helps with online learning, digital communication and monitoring the campus.

Administrators are provided with real time dashboards of energy consumption, occupancy levels, water systems and environmental conditions on cloud platforms. It's also easier for students to access learning materials and campus services through centralized digital
platforms.

Cloud systems also enhance collaboration of different department by providing a secure platform for data sharing and communication. Therefore, accessibility by cloud computing results in higher operational efficiency, better user experience and promotes the development of campuses.

3. Data Integration:

Another significant advantage of data management and cloud computing in smart campuses is data integration. Smart campuses use variety of technologies including IoT sensors, environmental monitoring systems,
security systems, smart classrooms, transportation systems and drainage monitoring systems. All these different sources of data can be put into one central system on cloud platforms. The research paper "*Application of a Big Data Framework for Data Monitoring on a Smart Campus*" states that cloud computing frameworks assist in combining large volumes of structured and unstructured data produced by a variety of campus devices and applications. Integrated data systems allow for better real time monitoring and decision making as all critical or important information can
be viewed through a single dashboard interface. Also, the paper explains that IoT devices and FIWARE cloud platforms improve the interconnection of different campus applications and services. This combination enables
institutions to better manage their energy consumption, water resources, transportation systems and infrastructure.

Data integration also improves sustainability by cutting down on resource waste and facilitating automated campus management systems. Therefore, integrated cloud-based data systems form the core of smart, digital and sustainable campuses.

Hence, cloud computing and data management technologies play a major role in the development of smart, digital and sustainable campuses.

Through real time monitoring, scalable cloud systems, integrated data platforms and dashboard-based management, institutions can improve efficiency of operations, sustainability, safety, and overall campus management.

(Martins et al., 2021; Villegas-Ch et al., 2019; Van Der V oordt et al., 2021)

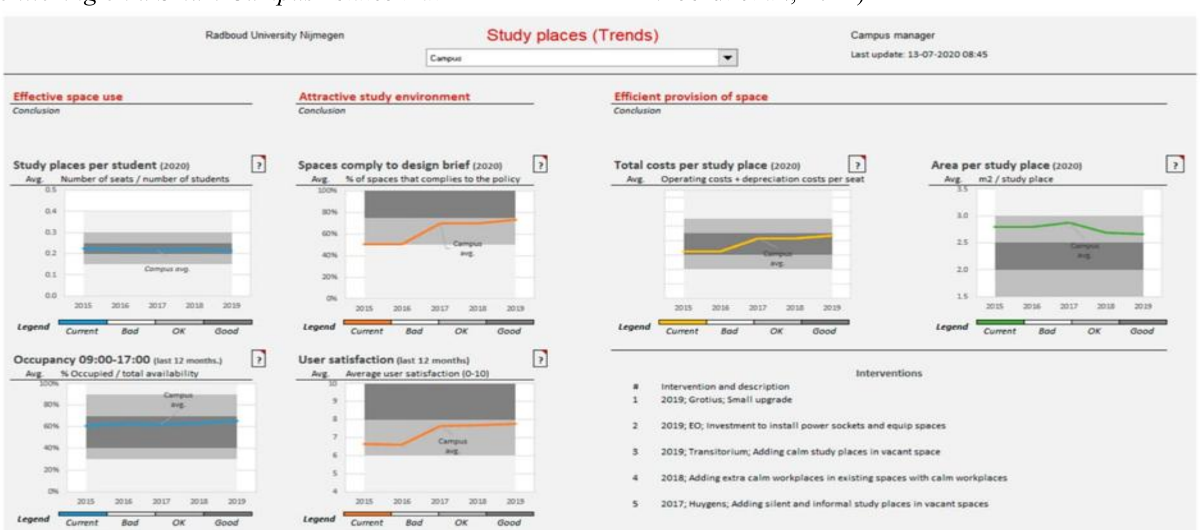

Figure 5: Drainage status dashboard

[Valks, B., Arkesteijn, M., Koutamanis, A., & Den Heijer, A. (2021). Towards smart campus management: Defining information requirements for decision making through dashboard design. *Buildings*, *11*(5), 201]

VII. DATA ANALYTICS AND PREDICTIVE MAINTENANCE

Data analytics and predictive maintenance have emerged as essential
tools in today's smart city infrastructure. Data analytics refers to the collection, structuring and analysis of data to get valuable insights. It enables entities to understand system performance, recognize issues and predict future occurrences. The use of IoT sensors, artificial intelligence (AI), machine learning (ML) and cloud computing technologies
allows for analysis of historic as well as live data which helps in predicting system problems. This is useful in cutting down costs, enhancing efficiency and avoiding any system breakdown in various sectors including waste removal, sewage, transportation, and flood control.

Categories of Data Analytics:
1.Descriptive Analytics:
Descriptive analytics is concerned with providing information on what has taken place based on past data.

Features:
- Based on historical data sets and reports
- Shows trends in the system performance

Examples:
- Number of drainage blockages in the previous months
- Frequency of garbage overflow in different urban locations
- Variation in water levels in monsoon seasons

Uses:
Urban planners can analyze previous sewer overflow data to identify high-risk areas.

2. Predictive Analytics
Predictive analytics is the use of past and present data to predict future outcomes with the help of machine learning algorithms.

Properties:
- Predicts potential failures
- Utilizes statistical analysis and artificial intelligence
- Offers advance warning alerts

Example:
- Flood prediction based on rainfall pattern
- Potential pipe obstruction detection
- Equipment maintenance needs forecasting

Predictive analytics examines existing and past data to predict future occurrences.

3. Prescriptive Analytics
Prescriptive analytics recommends suitable actions after analyzing predictions.

Features:
- Proposes corrective action
- Optimizes maintenance plans
- Enhances resource planning

Examples:
- Deploying sewage-cleaning robots at risk-prone locations
- Sending maintenance staff before machinery break downs
- Optimization of garbage pickup routes

The intelligent management system will notify the concerned authorities on its own about the need for an action.

How Previous Data is Helpful for Prediction:
Previous data holds significant importance in any predictive system. Analyzing past data will allow AI machines to forecast future occurrences based on their pattern.

1.Prediction of Blockages
Blockages can be predicted from the past sewage flows, garbage levels, and drainage performances.
Process:
- Water level and waste accumulation data are collected by sensors
- Cloud services retain past data records
- Patterns are analyzed by machine learning algorithms
- Abnormal cases trigger an alert to authorities

Example:
In case there is frequent observation of raised water levels in drainage pipes during rain, the system predicts blockages.

2. Flood Prediction Systems
Such systems analyze the history of rainfall, trends in water level, moisture content in soil, records of drainage performance

Advantages:
- Early flooding warnings
- Proactive disaster management
- Minimized property losses
- Improved public safety

Internet-of-things devices monitor environmental variables for predicting floods.

3. Prediction of Maintenance Requirements
In predictive maintenance, sensor-based data including:
- Temperature
- Pressure
- Vibration
- Humidity
- Power consumption

It indicates small discrepancies in the machine indicating potential breakdowns in the future. Machine learning algorithms make use of data obtained currently compared with failure data to make predictions regarding maintenance requirements.

Benefits:
- Increased uptime
- Low repair costs
- High machine lifetime
- Efficiency

Techniques Used in Predictive Maintenance:

1. Introduction to Machine Learning
A Machine Learning algorithm enables the computer to learn through data analysis without being explicitly programmed. Categories of ML:
- Supervised Learning
- Unsupervised Learning
- Reinforcement Learning

Machine learning techniques analyze historical sensor data to predict future failures to make optimization of resource utilization possible.
Popular Machine Learning Algorithms:
- Random Forest
- Support Vector Machine (SVM)
- Neural Networks
- K-Means Clustering

2. Pattern Recognition
Pattern recognition involves the identification of repeating patterns in data.

Examples:
- Patterns of overflow in drainages
- Patterns in vibration before the motor fails
- Trends in seasonal flooding events

Pattern recognition systems make use of sensor data compared with historical patterns for prediction purposes.

3. Anomaly Detection
Anomaly detection is used to detect any abnormal activities.

Examples:
- Abrupt rise in water level
- Abnormal vibrations in machinery
- Unusual garbage build-up

Such AI-enabled anomaly detection systems keep analyzing the data stream and raise alerts when any abnormal activity is detected.

Sample Case: Smart City Drainage Monitoring System in India
Let us consider a drainage monitoring system in a smart city. The steps involved are:

1.IoT sensors monitor:
- Level of water
- Speed of water flow
- Intensive raining in the area

This data is transmitted to:
- Cloud services
- Data analytics system
- Machine Learning analyzes:
- Floods in previous years
- Rainfall data

History of pipe performance:

- Prediction: A high chance of clogging is detected in the drainage pipeline.
- Course of Action: City authorities receive an alert message. The cleaning robot is redirected immediately. An emergency maintenance crew is dispatched.
- Result: Flooding is avoided, public safety is increased and the maintenance cost is low.

Such AI enabled predictive maintenance approaches to increase the efficiency of smart cities. Hence, data analytics and predictive maintenance play an important role in developing smart infrastructures and smart cities. Using IoT sensors, cloud computing, Artificial Intelligence and Machine Learning, the authorities can be alerted about blockages, flood hazards, and other maintenance needs even before any failures occur.

VIII. INTEGRATION OF COMMUNITY PARTICIPATION

Importance of public involvement:
Public participation is crucial for creating a smart, digital and sustainable campus. The effectiveness of a smart campus is enhanced by active participation of students, faculty, staff and other members of the university community in all decisions and activities on the campus. Public participation will lead to more successful implementation of smart campus initiatives since it enables connecting technology with human needs. Many studies indicate that the "voice" of citizens will enhance engagement levels and enable social sustainability. Through tools such as mobile applications, members of the university community will be able to communicate their complaints regarding matters like security, waste disposal, water leakage, damage in equipment and public health issues and as a result appropriate measures will be taken. This increases participation awareness regarding sustainability issues. It also promotes good communication and cooperation within the community. This causes the community to become committed to the development projects within the campus when they realize that their views matter. Thus, engagement of the public in the development process plays a very important role in creating an efficient and human-oriented smart campus.

Citizen reporting systems:
Citizen reporting systems form a vital element of citizen engagement in digital and sustainable campuses. Individuals including students, teachers, and other members of staff are enabled to participate actively by reporting issues as well as sharing information concerning campus facility services, safety, cleanliness, and sustainability. As suggested in the research paper titled *"Campus@5.0: Digitalization and Sustainability to Serve an Intelligent Campus – Mobile App Concept and Prototype,"* citizen involvement is a significant component for enhancing smart campus strategies through the combination of technology and needs of the campus.
In the study, the researchers propose the creation of a mobile application, which serves as a citizen reporting system allowing its users to report on problems such as broken lights, water leakages, overflowed waste containers, foul odors, unsafe conditions, as well as campus security. Through the system, users are able to submit pictures alongside the reported issues and monitor their status.

The study also emphasizes the point that a lot of respondents have found problem-reporting features highly important since these contribute to better communication between the administration of the university and the surrounding community. With the help of such a participatory mechanism, the individuals become actively involved in various initiatives of development and sustainability in the campus. This way, citizen reporting contributes to social sustainability, community involvement, and smarter campus operations.

Hybrid model
The hybrid model of including community participation in the development of a smart campus involves combining elements of human intervention along with the use of technology. The paper, "Campus@5.0: Digitalization and Sustainability to Serve an Intelligent Campus – Mobile AppConcept and Prototype" notes that when technology combines with the participation of students, educators and other

members of the community, the success of smart campuses is achieved. The combination will result in efficiency and sustainability on campus. Human intervention involves reporting campus-related issues, providing feedback, decision-making and ensuring sustainability. On the other hand, automation involves such technological tools as mobile applications, IoT, smart sensors and cloud computing for collecting, processing and managing data efficiently and reliably. A mobile application prototype shown in the research paper will enable the users to make reports such as faulty lightbulbs, water leakage, waste issues and security concerns. The report automatically goes to the respective department along with allowing the user to track the progress of his/her problem report. It is also highlighted in the research paper that the society wants to make use of technology not just rely on machines. So by involving the community in a blended approach, communication improves, problems get solved more effectively, things become more sustainable and we end up with a smarter, stronger community.

Benefits:
The benefits of community participation integration is very important in the creation of a digital campus. A sustainable campus can never be created using technological aspects alone, there has to be involvement of community members. As stated in the research paper, "*Understanding Social Sustainability for Smart Cities*", social sustainability requires citizens involvement, participation and inclusion. Smart technologies perform better in cases where people take part in planning, decision-making and reporting issues about campus. Participation by the students and other staff will help the university to know the needs of the university community better and solve its issues. The students and the faculty could report various issues like water leakage, broken equipment, waste management problems, security, among others. This is because when there is involvement in the community, the university management becomes more accountable due to increased sharing of opinions by the community and communication lines are opened up between management and the people using the campus facilities. The article discusses social sustainability in terms of inclusion, equity, and quality of life. When there is involvement of students, teachers, and other campus workers in campus sustainability practices, the campus becomes more people-centered. Thus, community participation will contribute towards digital governance and sustainability in the universities.

IX. SYSTEM ARCHITECTURE OF SMART DRAINAGE MODEL

The architecture of the intelligent drainage system presented in the image shows how the combination of IoT technologies, sensors, cloud servers, and intelligent monitoring systems can help in monitoring drainage status and managing waste. The role of the architecture is to detect any blockage, monitor the wastewater flow, analyze the drainage status, and provide notifications to the authority.

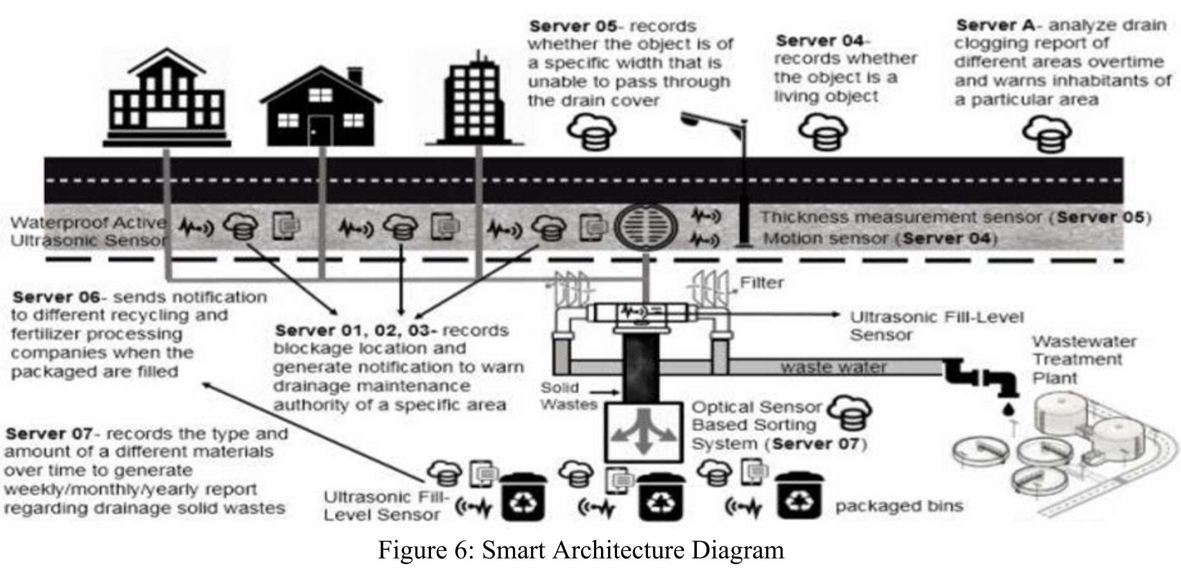

Figure 6: Smart Architecture Diagram

[*T. Zaki, I. T. Jahan, M. S. Hossain and H. S. Narman, "An IoT-Based Complete Smart Drainage System for a Smart City," 2021 IEEE 12th Annual Information Technology, Electronics and Mobile Communication Conference (IEMCON), Vancouver, BC, Canada, 2021, pp. 0553-0558, doi: 10.1109/IEMCON53756.2021.9623149.*]

1. Data Collection Layer
The first layer of the architecture consists of a number of sensors that have been placed in the drainage pipelines system. These sensors are used to monitor various parameters such as the velocity of the effluent, pipeline blockage, amount of solid waste, among others.

Components used include:
- Waterproof active ultrasonic sensors
- Ultrasonic fill-level sensors
- Motion sensors
- Thickness measurement sensors
- Optical sensors

The ultrasonic fill-level sensors check the wastewater level within the drainage pipeline for instances of overflows. The motion sensors detect movement within the pipes while the thickness measurement sensors determine if any solid material is too bulky to move through the drain cover. Finally, the optical sensors are useful in distinguishing types of solid waste materials. By continuous monitoring, the authorities can detect drainage issues such as blockage and overflow effectively.

2. Communication Layer
The collected information is then transferred to cloud-connected servers through IoT communication techniques. The proposed design utilizes interconnected servers which continuously share information and exchange messages with the maintenance departments.

Some of the features of the communication technology used include the following:

- Real-time monitoring
- Remote access to drainage data
- Instant alert transmission
- Cloud connectivity

The wireless communication between sensors, servers, and clouds enables the authorities to monitor the drainage data from remote locations.

3. Processing and Analytics Layer
There are several servers within the processing layer responsible for analyzing the drainage data and executing certain operations.

These operations are performed by the following servers:
- Registering the positions of the blockages
- Determining the nature of the object
- Discovering oversized waste items
- Monitoring the patterns of clogged drainage
- Providing reports on the accumulated waste

For instance:
- Servers 01, 02, and 03 register the positions of the blockages and notify the authorities of drainage maintenance.
- Server 04 determines whether the object within the drainage system is alive.
- Server 05 finds out whether the size of the object is too big for the drainage cover.
- Server A analyses clogging reports and warns the people residing close by.

The processing layer makes intelligent analysis possible.

4. Waste Management and Sorting System
The architecture also features a sorting mechanism using optical sensors which segregates the solid waste products obtained from the drainage system. The segregated waste material is transported to the packaged bins for recycling purposes.

These functions include:

- Waste classification
- Segregation of waste
- Tracking waste quantities
- Reporting on waste buildup

Server 07 keeps track of the quantity and type of waste materials and provides reports on waste from the drainage system weekly, monthly, and annually. This increases the effectiveness of the waste management process and enhances environmental sustainability.

5. Application and Alert Layer
This level of the network offers notification alerts and monitoring services to the maintenance department as well as the residents. Whenever there is an issue with the drainage, alerts are generated automatically by the network.

This application level includes:
- Real-time alerts
- Monitoring the state of the drainage
- Control functions remotely
- Automatic warning messages
- Scheduling of maintenance

This network helps prevent flooding, stagnant water, and drainage malfunction.

Overall System Flow:
The flow of the process in the smart drainage system involves the following stages:

Sensors → Data Collection → Information Transmission using Radio Frequency → Cloud Computing → Information Analysis → Monitoring/Notification → Maintenance
It is through the implementation of IoT devices, cloud computing, and information analysis that this process flow becomes possible.

X. ADVANTAGES OF SMART DRAINAGE SYSTEMS

1. Real-Time Data Collection:
The use of IoT sensors, WSNs, edge devices, and cloud computing technology makes it possible to measure and analyze such variables as the level of water, flow rate, gases, and blockages present in drainage pipelines. In this way, any risk of an overflow or problems with the system can be detected right away without the need for regular monitoring by municipal authorities. According to research, ultrasonic, flow, and gas sensors can transfer data to cloud computing services and apps for immediate use. (Misra et al., 2022; Sonawane et al., 2018)
For example, the Hong Kong experience of using smart drainage systems showed how such solutions leverage IoT, sensors, and Raspberry Pi controllers together with Artificial Neural Networks (ANN) to get real-time data about the environment. (Keung et al., 2018)

2. Reduced Flooding Risks:
Another advantage of implementing smart drainage technology is mitigating risks associated with flooding. Conventional drainage infrastructure may not function effectively under circumstances where there is heavy rain, and blockages, as well as water overflow, are not identified in advance. This problem is solved by the implementation of smart drainage technologies. (Misra et al., 2022)

Furthermore, edge-enabled stormwater drainage systems can be implemented to predict and mitigate potential overflow issues before flooding occurs. In a study that was carried out on catchments within cities, it was revealed that smart drainage systems could achieve an accuracy of about 92.4% for predicting overflow and a decrease in the detection period by 35%. (Veerappan, 2024)

Real-time control (RTC) smart drainage systems can decrease peak flood flows by up to 50%. (Malik et al., 2018)

3. Enhanced Hygiene and Public Health:
Smart drainage systems enhance hygiene in urban areas by reducing the risk of overflowing sewage, wastewater stagnation, and release of dangerous gases. Drains are one of the primary sources of water-borne infections and cause contamination of the environment. Systems equipped with Internet of Things (IoT) technology sense toxic gases like methane (CH_4), sulfur dioxide (SO_2), and carbon monoxide (CO), allowing precautionary measures to be taken before any incident happens. (Sonawane et al., 2018)
In addition, the systems minimize the dangers to humans caused by sewer work by limiting the need for manual inspections and cleaning. According to a study, hundreds of people die every year because of unsound methods used when cleaning sewers; hence, smart monitoring systems would considerably mitigate these hazards. (Misra et al., 2022).

Incorporation of waste management systems into the drainage system helps avoid clogging caused by plastics, biodegradable waste, among others. (Zaki et al., 2021)

4. Cost Efficiency (Long-Term):
Even though it is necessary to invest in sensors, communication equipment, and cloud-based services to establish a smart drainage system, significant savings can be made over time. Smart drainage systems eliminate the requirement for costly inspections, maintenance activities, and flood management. (Misra et al., 2022)
According to studies on smart urban drainage systems, smart monitoring and maintenance can save money as well as minimize the damage caused to the infrastructure. Furthermore, by optimizing the flow of water and minimizing unnecessary inspection times, smart drainage systems become more efficient. (Keung et al., 2018)
It is significantly cheaper and scalable to build smart drainage systems using smart retrofitting solutions, such as IoT, LoRa, and NB-IoT technologies, compared to the construction of new infrastructure.

5. Sustainable Water Management:
Effective drainage systems help in sustainable urban growth through efficient stormwater management and adaptable management of drainage systems. Using edge computing technology and artificial intelligence-based analytics, systems can reallocate rainwater among various drainage systems.
These modern drainage systems further help in climate change resilience and goal 11 of Sustainable Development Goals – Sustainable cities and communities, by effective urban flood management and minimization of environmental impact. (Veerappan, 2024)

Moreover, waste-management systems facilitate in segregating and recycling waste, which may be a hindrance to drainage pipes, leading to sustainable urban sanitation and clean water systems. (Zaki et al., 2021)

XI. CHALLENGES AND LIMITATIONS

1. High initial Cost:
During the implementation of smart, sustainable digital campuses, the problem of high costs involved. First there is the need for installation of advanced technologies like Internet of Things (IoT), Artificial Intelligence (AI), cloud computing, smart classrooms, renewable energy sources and cyber security among others. These involve large amounts of financial investment and the university in many developing countries would have challenges finding sufficient funds.

2. Technical complexity:
The smart campuses are based on technologies like IoT, AI, big data, cloud computing and smart energy. Integrating the technology and managing the system would increase technical challenges as the devices might come from different vendors hence compatibility challenges. Furthermore, there will be the requirement of advanced software and experts to analyze data coming from the sensors in real time.

3. Data Security issues:
The security of data collected from sensors and other means is one of the most important aspects of a smart campus. Smart campuses gather plenty of data from both students and their environment using sensors, surveillance cameras and other technology. Being connected to the Internet makes them susceptible to hacker attacks. Hence, universities need strict cybersecurity measures.

4. Maintenance of Sensors:
As mentioned above, sensors are an essential part of the work of a smart campus. They are used to monitor the campus's consumption of energy and environmental conditions. Yet, sensors may become ineffective because of power failure, malfunctioning or communication errors. Maintenance of sensors demands extra cost for software and hardware updates.

5. Need for skilled personnel:
Smart campus implementation necessitates the involvement of specialists such as IT professionals, engineers, cybersecurity experts, and data analysts. The universities lack qualified manpower in many cases and hiring them results in extra expenses. Guidance is also required for efficient utilization of smart campus technologies.

XII. FUTURE SCOPE AND INNOVATIONS

The future developments in technology could incorporate the use of smart drainages and environmental monitoring systems that apply advanced technological innovations for greater automation, sustainability, precision, and improved decision-making. The emerging technologies that could be used as smart campuses include the application of artificial intelligence, digital twinning, blockchain, and advanced sensors.

1. AI-based autonomous systems:
One of the promising innovations involves the implementation of intelligent autonomous systems based on artificial intelligence. Artificial Intelligence can evaluate the data provided by sensors that monitor IoT in real-time to detect any problems including drainage system blocks, water spillage and leaks. Intelligent systems are also capable of performing predictive maintenance which allows predicting any failures of the drainage system and reducing maintenance costs. Machine learning systems will constantly learn from the past experiences and increase efficiency by using data about drainage and the environment (Villegas- Ch et al., 2019).

2. Smart city integration:
Today, smart campuses are seen as prototypes of smart cities because they also involve interconnected systems responsible for water, transportation, energy resources, waste disposal and environmental protection. Combining smart city structures, smart campuses are capable of supporting communication, information exchange, emergency response, and environmentally- friendly urban planning (Martins et al., 2021).

3. Digital twins for campuses:
Another important development is the idea of digital twins for use in smart campus management. The digital twin of an asset refers to computer simulation technology that records real-time information for the particular asset. A digital twin could be developed to simulate and analyze the performance of drainage systems, water systems, buildings, and the overall environment for a smart campus. We can identify any possible issues and test out the solutions available without affecting the real world by this idea.

4. Advanced sensors:
In future more advanced sensors would be used to monitor smart drainage systems. Currently sensors in IoT technology can detect and record variables such as water level, water flowrate, toxic gases, humidity, temperature and the conditions inside pipes. Advanced sensor technology means that cheaper and wireless sensors are available and capable of gathering information faster than previous iterations.

5. Blockchain for data security:
A new area in smart campuses is blockchain technology and its application for enhancing data security and transparency. It is important to manage all the information safely as consequences of collecting sensitive data in smart campus systems. This goal can be achieved by leveraging blockchain technology which provides data security by decentralizing and securing the information. Blockchain technology may increase transparency, reliability and trust in digital monitoring tools because it allows one to record any data without the possibility of tampering with it.

Hence, technological developments for future smart campuses must involve the creation of intelligent environment monitoring systems which must be not only automatic but also integrated. The use of the latest technology such as artificial intelligence (AI), Internet of Things (IoT), cloud computing, digital twins, sensors, and blockchain technology will ensure the effectiveness and sustainability of smart campus drainage systems.

XIII. CONCLUSION

The rapid development of processes related to urbanization and the innovation of technologies raises the necessity for very efficient and sustainable infrastructural system management at a very high level. One solution to this problem could be to implement smart campuses by means of the use of digital technologies, environmental control systems and intelligent decisions when making decisions in campus activities. The implementation of IoT technologies, cloud computing, sensor technologies, artificial intelligence and digital community reports will help campuses efficiently monitor their infrastructure and deal with the challenges. IoT and AI technologies have significant importance in terms of increasing the efficiency of smart drainage and environmental monitoring systems. IoT devices and sensors gather real-time data about water levels, conditions of drainage, and waste buildup. Further the analysis performed with the help of AI allows identifying problems, predicting potential failures, and facilitating automated decisions. Along with that, the digital reporting systems used by students and other people connected with campus facilities improve the process of communication between users and authorities. Intelligent drainage monitoring systems can also prove to be useful from an environmental perspective where intelligent prediction and monitoring help to reduce water wastage, prevent drainage overflow and minimize pollution levels. Waste management systems and intelligent monitoring help create a healthy campus environment in addition to reducing costs. These systems also help in creating sustainable environments which utilize water, energy and other resources carefully within the campuses. The future use of smart campus technologies will give several advantages such as cost reduction on maintenance, efficiency improvement, environmental protection and effective decision making. The following innovations will further strengthen the efficiency of campus technologies in coming decades and include advancements like digital twins, advanced sensing technologies, and autonomous AI systems that help secure communications of smart cities. A sustainable and resilient environment and infrastructure will become essential requirements in future as campus evolves into digital ecosystems.

REFERENCES

[1] Eltawil, A., Mostafa, N.A., Matsushita, Y. (2021). Toward a Smart and Sustainable Campus: Future Vision, Opportunities, and Challenges. In: Ujang, N., Fukuda, T., Pisello, A.L., Vukadinović, D. (eds) Resilient and Responsible Smart Cities. Advances in Science, Technology & Innovation. Springer, Cham.

[2] Islam, Md. Motaharul and Nafiz Ahmed, Talukder, A Greener Campus: Reusing Water, Reducing Waste and Protecting the Environment (May 25, 2023). IN4OBE Global Virtual Summit 2022 Transforming Education and Empowering Learners (IN4OBE 2022), Available at SSRN: https://ssrn.com/abstract=4458674 or

[3] Wang, X., Cai, Q., Li, D., Hong, L., Ma, Z., Zhu, W., Qian, L., Sun, J., Fan, Z., & Xie, C. (2025). From Concept to Reality: The Practical Implementation of a Laboratory-Based Smart Water Campus Model. Sustainability, 17(1), 221.

[4] Barroso, S., Bustos, P. & Núñez, P. Towards a cyber-physical system for sustainable and smart building: a use case for optimising water consumption on a SmartCampus. J Ambient Intell Human Comput 14, 6379–6399 (2023).

[5] Plaiasu, Wolfgang Rauch, Robert Sitzenfrei; Smart water campus – a testbed for smart water applications. Water Sci Technol 1 December 2022; 86 (11): 2834–2847.

[6] Skaggs, R. W., Fausey, N. R., & Evans, R. O. (2012). Drainage water management. Journal of Soil and Water Conservation, 67(6), 167A-172A.

[7] Gondane, S., Shirpurkar, T., Raut, S., & Mistry, A. (2021). Automated drain cleaning system under Swachh Bharat Abhiyaan. Journal of Research in Mechanical Engineering, 7(5), 1–9.

[8] Martins, P., Lopes, S. I., Rosado da Cruz, A. M., & Curado, A. (2021). Towards a Smart & Sustainable Campus: An Application-Oriented Architecture to Streamline Digitization and Strengthen Sustainability in Academia. Sustainability, 13(6), 3189.

[9] Sneesl, R., Jusoh, Y. Y., Jabar, M. A., & Abdullah, S. (2022). Revising Technology Adoption Factors for IoT-Based Smart Campuses: A Systematic Review. Sustainability, 14(8), 4840.

[10] Oprea, S.-V., Bâra, A., Ifrim, G., & Marcu, A. (2021). Smart campus as a microcosm of smart cities: A review. arXiv.

[11] Zanella, A., Bui, N., Castellani, A., Vangelista, L., & Zorzi, M. (2014). Internet of Things for smart cities. IEEE Internet of Things Journal, 1(1), 22–32.

[12] Alrashed, S., & Asif, M. (2021). Smart campus architecture and sustainability: A case study. Sustainability, 13(6), 3189. https://doi.org/10.3390/su13063189

[13] Starzec, M., & Dziopak, J. (2020). A Case Study of the Retention Efficiency of a Traditional and Innovative Drainage System. Resources, 9(9), 108.

[14] Santos, F., & Jamandre, C. A. (2024). A review of approaches to drainage system management: Current status and future research directions. International Journal of Advanced Engineering, Management and Science, 10(1), 1–12.

[15] V. S. Gawali, M. Pande, M. Sayyad and R. S. Bhadade, "IoT Based Real Time Drainage Monitoring System," 2024 International Conference on Emerging Smart Computing and Informatics (ESCI), Pune, India, 2024, pp. 1-6, doi: 10.1109/ESCI59607.2024.10497198.

[16] Zulkifli, C. Z., Garfan, S., Talal, M., Alamoodi, A. H., Alamleh, A., Ahmaro, I. Y. Y., Sulaiman, S., Ibrahim, A. B., Zaidan, B. B., Ismail, A. R., Albahri, O. S., Albahri, A. S., Soon, C. F., Harun, N. H., & Chiang, H. H. (2022). IoT-Based Water Monitoring Systems: A Systematic Review. Water, 14(22), 3621.

[17] Eggimann, S., Truffer, B., Maurer, M., & Narayanamurthy, V. (2020). Data collection and information management for urban drainage systems. Resources, 9(4), 48.

[18] Narman, H. S., Ariyapala, K., Islam, S., & Pulli, P. (2021). A smart sewer management system using IoT and cloud computing. In 2021 IEEE 12th Annual Ubiquitous Computing, Electronics & Mobile Communication Conference (UEMCON) (pp. 1–7). IEEE.

[19] Kotwal, S., Dheepak, K., Teja, E., & Satyagnani, C. (2026). A digital platform for community issue reporting and monitoring. International Journal of Scientific Research and Engineering Development (IJSRED), 9(2), 3169–3185.

[20] Aramide, O. O. (2025). Smart infrastructure: Leveraging IoT and AI for predictive maintenance in urban facilities. SAMRIDDHI: A Journal of Physical Sciences, Engineering and Technology, 17(2), 34–37.

[21] Karthikeyan, S., Pravin, S., Keerthivasan, V., Prabhu, V., & Dhanasekaran, M. (2025). Smart campus grievance management system. International Journal of Research Publication and Reviews, 6(11), 1446–1454.

[22] Anbazhagan, T., Balaji, M., & Mothishwar, M. (2019). Design and fabrication of automatic drain cleaner (Project Report). Department of Mechanical Engineering, Faculty of Engineering and Technology, SRM University.

[23] Misra, D., Das, G., & Das, D. (2022). Artificial intelligent based smart drainage system [Preprint]. Research Square.

[24] Apsara, B. (2024). Project report on drain care system (Project Report). Department of Computer Applications, St. Teresa's College (Autonomous), Ernakulam.

[25] Veerappan, S. (2024). Edge-enabled smart stormwater drainage systems: A real-time analytics framework for urban flood management. Journal of Smart Infrastructure and Environmental Sustainability, 1(1), 52–59.

[26] Barroso, S., Bustos, P., & Núñez, P. (2023). Towards a cyber-physical system for sustainable and smart building: a use case for optimising water consumption on a SmartCampus. Journal of Ambient Intelligence and Humanized Computing, 14(5), 6379–6399.

[27] Malik, H., Kändler, N., Alam, M. M., Annus, I., Le Moullec, Y., & Kuusik, A. (2018, March). Evaluation of low power wide area network technologies for smart urban drainage systems. In Proceedings of the 2018 IEEE International Conference on Environmental Engineering (EE).

[28] T. Zaki, I. T. Jahan, M. S. Hossain and H. S. Narman, "An IoT-Based Complete Smart Drainage System for a Smart City," 2021 IEEE 12th Annual Information Technology, Electronics and Mobile Communication Conference (IEMCON), Vancouver, BC, Canada, 2021, pp. 0553-0558, doi: 10.1109/IEMCON53756.2021.9623149.

[29] Keung, K. L., Lee, C. K. M., Ng, K. K. H., & Yeung, C. K. (2018). Smart city application and analysis: Real-time urban drainage monitoring by IoT sensors: A case study of Hong Kong. In Proceedings of the 2018 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM) (pp. 1433–1437). IEEE.

[30] S. Sivakumar, A. Agastin, A. Aswini, P. Pukazhya, and V. Ram, "CampusCare – Intelligent Grievance Redressal System," International Journal of Engineering Research & Technology (IJERT), vol. 15, no. 03, 2026

[31] N. Li, T. D. Palaoag, H. Du, and T. Guo, "Design and Optimization of Smart Campus Framework Based on Artificial Intelligence," Journal of

Information Systems Engineering and Management, vol. 8, no. 3, 2023.
[32] R. Sameera, D. S. Mastan Bi, S. Chaitanya, and S. Hruthik, “Smart Campus Grievance Management System,” International Journal of Research Publication and Reviews, vol. 6, no. 11, pp. 1446–1454, 2025.
[33] A. Maramreddy, N. R. Kancharla, S. K. Lelloul, and P. G. R. S. Nischith, “StreetSense: Civic Issue Reporting Platform with Real-Time Safety Heatmaps,” International Research Journal of Engineering and Technology (IRJET), vol. 13, no. 04, 2026.
[34] C. Perera, A. Zaslavsky, P. Christen, and D. Georgakopoulos, “Sensing as a Service Model for Smart Cities Supported by Internet of Things,” Transactions on Emerging Telecommunications Technologies, 2014.
[35] S. Kotwal, K. Dheepak, E. Teja, and C. Satyagnani, “A Digital Platform for Community Issue Reporting and Monitoring,” International Journal of Scientific Research and Engineering Development (IJSRED), vol. 9, no. 2, 2026.
[36] Anbazhagan, T., Balaji, M., & Mothishwar, M. (2019). Design and fabrication of automatic drain cleaner (Project Report). Department of Mechanical Engineering, SRM University.
[37] Sengupta, N., & Chinnasamy, R. (2020). Designing of cleaning system for garbage and sewage of smart city with cloud based predictive analytics. International Journal of Computing and Digital Systems, 9(6), 1079–1089.
[38] Marinescu, I., & Dumitrescu, E. (2024). Enhancing smart city ecosystems through 5G technologies: Security, predictive maintenance, and network optimization challenges and opportunities. International Journal of Data Science and Intelligent Applications, 8, 1–20.
[39] Gupta, D. (2025). AI-powered predictive maintenance in smart city IoT systems. Research Annals of Industrial and Systems Engineering, 2(1), 19–26.
[40] Syadida, M. H., & Faqih, A. (2025). Performance analysis and implementation of a real-time based robotic system in clean water filtration. Journal of Artificial Intelligence and Engineering Applications, 4(3), 2170–2177.
[41] Chagnon-Lessard, T., Gosselin, L., Barnabé, S., Bello-Ochende, T., Fendt, S., Goers, S., da Silva, L. C. P., Schweiger, B., Simmons, R., Vandersickel, A., & Zhang, P. (2021). *Smart campuses: Extensive review of the last decade of research and current challenges*. *IEEE Access, 9*, 124200–124234.
[42] Greenstone, Michael and Hanna, Rema, Environmental Regulations, Air and Water Pollution, and Infant Mortality in India (December 30, 2013). MIT Department of Economics Working Paper No. 11-11, HKS Working Paper No. RWP11-034.
[43] Bimrah, K., & Saizen, I. (2026). The evolution and decline of traditional water management systems: A case study of Jaipur, India. Water History.
[44] Villegas-Ch, W., Molina-Enriquez, J., Chicaiza-Tamayo, C., Ortiz-Garcés, I., & Luján-Mora, S. (2019). Application of a big data framework for data monitoring on a smart campus. Sustainability, 11(20), 5552.
[45] Van der Voordt, T., Jensen, P. A., & Coenders, J. L. (2021). Towards smart campus management: Defining information requirements for decision making through dashboard design. Buildings, 11(5), 201.
[46] Magalhães, C., Mota, F., Ribeiro, G., Cordeiro, M., Bastos, T., & Teixeira, L. (2025). Campus@5.0: Digitalization and sustainability to serve an intelligent campus – Mobile app concept and prototype. Procedia Computer Science, 263, 183–190.
[47] Chen, T., Gil-Garcia, J. R., & Gasco-Hernandez, M. (2022). Understanding social sustainability for smart cities: The importance of inclusion, equity, and citizen participation as both inputs and long-term outcomes. Journal of Smart Cities and Society, 1(2), 135–148.
[48] Chagnon-Lessard, T., Gosselin, L., Barnabé, S., Bello-Ochende, T., Fendt, S., Goers, S., da Silva, L. C. P., Schweiger, B., Simmons, R., Vandersickel, A., & Zhang, P. (2021). *Smart campuses: Extensive review of the last decade of research and current challenges*. *IEEE Access, 9*, 124200–124234.