

Towards Smart Sanitation: A Comprehensive Survey of IoT, AI, and ML in Public Toilet Management

Palve Priyanka Barikrao and Prof. S. P. Vidhate

Department of Computer Engineering

Viswabharti College of Engineering, Ahmednagar, India

priyankapalve94@gmail.com and sachinvacoa@gmail.com

Abstract: *This research paper presents a comprehensive review of literature surveys about the implementation of diverse technological approaches, including the Internet of Things (IoT), Artificial Intelligence (AI), and Machine Learning (ML), in the domain of public toilet monitoring systems. The study investigates the current landscape of monitoring technologies applied to public toilets, aiming to identify trends, challenges, and opportunities associated with each technique. Through an in-depth analysis of various literature surveys, the paper synthesizes the state-of-the-art advancements in IoT, AI, and ML as applied to public toilets, offering a nuanced understanding of the potential impact on hygiene maintenance, resource optimization, and real-time monitoring. The findings of this review contribute valuable insights for researchers, policymakers, and practitioners seeking to enhance the efficiency and sustainability of public toilet facilities.*

Keywords: Public Toilet monitoring, IoT, Machine Learning, AI

I. INTRODUCTION

In urban infrastructure, public toilets play a pivotal role in promoting public health, hygiene, and the overall well-being of communities. However, these facilities' effective management and maintenance pose significant challenges that demand innovative solutions. This research paper delves into the critical domain of public toilet monitoring systems, exploring the integration of technology to address the myriad issues associated with these communal amenities. Public toilets are indispensable components of urban infrastructure, catering to the basic needs of residents, commuters, and visitors alike. Despite their vital role, the efficient upkeep of public toilets often encounters obstacles such as cleanliness maintenance, resource optimization, and real-time monitoring. Recognizing the need for transformative solutions, this research thoroughly examines the landscape of public toilet monitoring systems.

The integration of advanced technologies, particularly in sensor networks, Internet of Things (IoT) devices, and data analytics, offers a promising avenue for revolutionizing how public toilets are managed. A comprehensive monitoring system enhances the hygiene and maintenance of these facilities, optimizes resource utilization, reduces operational costs, and provides valuable insights for urban planning and development.

This paper critically reviews the current state of public toilet monitoring systems, analyzing their strengths, weaknesses, opportunities, and potential threats. The research aims to contribute a nuanced understanding of the technological interventions in this domain, shedding light on the efficacy of various monitoring approaches and their implications for urban sanitation and public health. Ultimately, this exploration seeks to inform policymakers, urban planners, and researchers about the innovative avenues available to enhance the functionality and sustainability of public toilet facilities in ever-evolving urban landscapes.

II. REVIEWS OF DIFFERENT MONITORING SYSTEMS AND TECHNIQUES

2.1 Systematic Review of Monitoring System

Manual inspection is the standard method for monitoring sanitation in public restrooms. According to data from numerous cities, the manual inspection regime has systematic biases and inconsistent enforcement. Sensors that

measure the concentration of gases created as byproducts are another possible method for monitoring cleanliness. The downside is that the price of such a system goes up because sensor calibration has to be done individually for every installation. It is a hybrid solution for hygiene monitoring that uses user ratings and gas sensor auto-calibration to provide accurate results. This system generates a community benchmark hygiene rating by combining both inputs. A user app and back-end database are also established to manage the reporting and follow-ups by civic author files. [1]

By highlighting the importance of on-street public restrooms in urban sanitation, this study hopes to fill knowledge gaps and direct future studies. The literature presents a variety of answers, but one constant is the need for public sanitation to ensure that all people, especially women, transgender people, children, the elderly, and those with disabilities, have access to safe, accessible, and inclusive public spaces. Public sanitation services can be better implemented with the help of the United Nations' normative policy framework, which can direct future studies and encourage widespread participation.[2]

plan for advancing diagnostics based on precision health 23–25 by using the plethora of data often lost in bodily fluids like urine and stool. Without heavy user input, an intelligent toilet can retrieve this unused data and avoid the behavioural fatigue of frequent COVID-19 testing. Although further studies are required to determine the exact nature of the connection between faecal viral shedding, faecal-oral transmission, and total infectivity, sampling from toilets can increase the availability of COVID-19 testing and yield more specific information about infection rates and epidemics. [3]

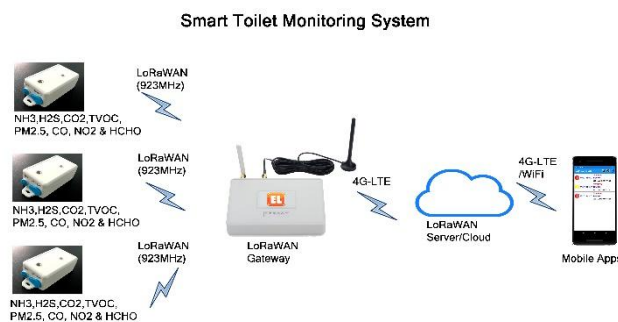


Fig.1 Smart Monitoring System

Early disease identification, faster medical care delivery, and better patient outcomes for a wide variety of public health-related medical disorders are all possible results of regular health monitoring. Technology is still a huge need to change the current healthcare model from reactive to proactive, evidence-based, and patient-centred. To this end, it would be ideal if there were platforms that could detect various indicators for health and illness and be seamlessly incorporated into people's everyday lives. However, people routinely dispose of urine—a biological fluid produced in large quantities daily, can be collected painlessly, does not interfere with people's daily routines, and contains the highest concentration of biologically active substances—into sewers without processing or monitoring it. Smart toilets, connected to data servers through the Internet of Things, could provide preventative continuous health monitoring in the comfort of the user's home, allowing for the early detection of illnesses. Furthermore, machine learning techniques can aid doctors in better and faster data classification, quantification, and interpretation than they were before. As they wait for smart toilets to become more widely used, they must address concerns about their usability, privacy, and the optimal frequency of tests. Tasoglu explains continuous urine-based health monitoring from this perspective, discusses the creation and use of equipment and procedures that will redirect medicine's attention to human health, and reviews smart toilets now on the market.[4]

The field of accessible and inclusive public restroom technology is growing at a quick pace, so it is essential to remember the general criteria that make a system accessible. The socio-spatial context of the technology's application is even more crucial in determining the nature of accessibility and inclusion. The review is desk-based, which is a limitation. This paper also identified the need for further investigation into accessible technologies for public restrooms about specific accessibility indicators, such as "tolerance for error" and "cultural appropriateness," using additional case studies. Possible next steps based on this paper's findings include understanding each indication and how it applies and

creating rating criteria for evaluating technology that improves accessibility and inclusion in public restrooms. Ultimately, this will help put existing technology in context for the Indian ground scenario, enhancing the current state of public toilets in India. [5]

The authors devised a workable business solution to the problem of dirty public restrooms in this study. The user-friendly app facilitates communication between patrons, maintenance workers, and public restrooms, and it is simple to install. Public restrooms equipped with this technology are more accessible to keep clean and sanitary. Thanks to its top-notch data display, the mobile app is a breeze. The IoT device is affordable and lightweight. As advances, this work could be improved by introducing sophisticated sensors that generate more precise data. Machine learning enhances prediction accuracy through the examination of sample data and the gathering of more test data. After this plan is widely implemented, India's public restrooms will dramatically improve. [6]

see smart toilets as a technological advancement that will allow for the automated, low-cost, and exact measuring of human excrement at high frequencies. Furthermore, intelligent toilets should make it easier to conduct clinical studies remotely and recruit a more diverse group of patients. This is a significant improvement over current methods because conventional trials skew toward individuals who can afford to miss work and travel to study sites. Smart toilets and passive monitoring could revolutionize precision health in the future, but how they affect healthcare now is highly dependent on upcoming technical developments and other variables. Investigating possible economic models within an acceptable ethical framework, making sure users are on board, and outlining the benefits over the risks (such as privacy invasion) are all critical considerations. Among these, developing smart toilets for passive health monitoring should prioritize establishing an ethical foundation for precision health. [7]

Products offered by service providers are not the primary indicator of public service execution. Additionally, the accessibility of facilities facilitates the efficient operation of every employee. Workers in government offices require access to restrooms to defecate and urinate while performing office duties. Anyone visiting a government office is subject to the same rules. Having a clean and functional restroom is, thus, crucial. It is clear from the state of cleanliness and the availability of facilities that government offices' toilet sanitation management has been lacking up until now. Most restrooms in government buildings are unfit for human use and must meet basic hygiene requirements. There is no designated department whose sole purpose is to ensure the cleanliness of restrooms at all times, which leads to ineffective administration of this aspect of facility maintenance. An assigned task force is essential for managing restroom hygiene in public buildings. The government can collaborate with private companies using an outsourcing mechanism for cleaning services to make it easier to organize work units. The government will have an easier time providing adequate restrooms and meeting health standards supporting public services through outsourcing cleaning services. [8]

The research set out to accomplish three things. Mainly to build an IoT administration platform. The pros and cons of current systems are examined in literature reviews. Secondly, recommend predictive maintenance to help anticipate when plumbing fixtures will fail. The last step was to employ a scheduling algorithm to ascertain the optimal number of janitors. To offer future suggestions, evaluate the model's performance. Infrared, temperature, and humidity sensors make a connected bathroom possible. Researchers have looked at sensors to see how they may be adjusted in private, sanitary restrooms. A more robust research and development effort could lead to more cost-effective and accurate sensors. As it reliably forecasts time series lags, the Auto-Regressive Integrated Moving Average (ARIMA) model is well-suited for predictive maintenance. Since LSTM excels in making time series predictions, it is reasonable to draw parallels between them. By adjusting the Moving Average, apply the ARIMA model to RUL prediction methods (MA)[9]

The project's primary goal is to improve the sustainability and efficiency of restrooms by using Internet of Things (IoT) technologies. The authors aim to tackle the problems with resource management that come with traditional toilets by introducing clever solutions. A thorough analysis of the project's execution is given in the technical report, which delves into the particular Internet of Things (IoT) technologies used and how they optimized resource usage in restrooms. The detailed insights in the technical paper contribute to the larger conversation on resource optimization through technology breakthroughs. The Smart Toilet project is an example of how the Internet of Things (IoT) may be used to make everyday things more beneficial and help with more effective use of resources. [10]

Preventing the spread of disease and keeping odours under control—a social indicator of cleanliness—requires regular toilet hygiene maintenance. Since new viruses like SARS-CoV-2 have emerged, it is more important than ever to clean and disinfect thoroughly. Despite the significant improvement of flush toilets, pathogens might survive due to insufficient cleaning and proper hand hygiene. A potential health concern is flushing a toilet or sink with biofilm since it might house germs and smells. Automatic toilet bowl cleaners reduce the discharge of pathogens. Toilet rims can harbour Salmonella for as long as fifty days. When cleaning, there is a higher risk of illness since bacteria can be transferred to surfaces, utensils, and sinks. Although it increases energy and water use, ventilation and flushing reduce odours in restrooms. Interventions must be based on accurate quantification of infection risks.[11]

An automated toilet monitoring system was developed by utilizing electronic sensors, including ultrasonic sensors, gas detectors, and an Arduino controller, which offers several benefits over the current system. It lessens the likelihood of infectious diseases spreading due to inadequate sanitation practices. Additionally, the system combines power efficiency and water reduction measures. The system makes efficient use of technological devices and is user-friendly for everyone. [12]

2.2 Internet of Things

Due to overcrowding, lack of sanitation facilities, or poor maintenance, open defecation and public urination are common in many Indian slums and villages. The government spends substantial resources to keep these public restrooms in good repair. Still, nothing is being done because there is no centralized mechanism to check how well the public restrooms are being cleaned. Therefore, it would be good to implement a system that allows centralized monitoring of all the restrooms and gives the cleaner an interface to resolve this issue. An easy-to-understand toilet monitoring system that makes use of the Internet of Things and machine learning is the goal of this article. The system comprises a web server, many Internet of Things devices, and a cleaner-specific mobile app. The administrator and the person cleaning the toilet can use the system to track different metrics related to cleanliness and even predict how the toilet will look using historical data. [13]

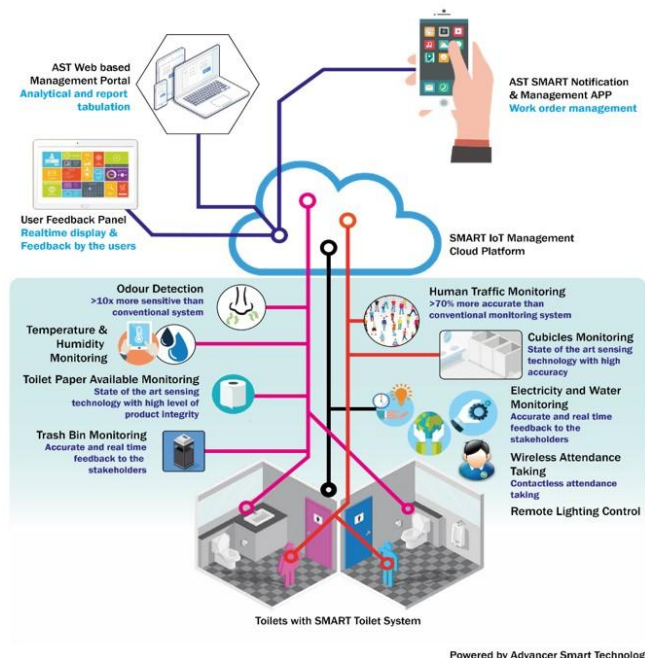


Fig.2 App-based system

found the existing problems with the e-toilet installations and devised a well-planned solution. Furthermore, it suggested cross-platform software and utilized cloud technology to make the solution omnipresent. In addition to making the e-toilet system more user-friendly, the proposed system automates several processes, which relieves some of the burden on local authorities. [14]

One major issue with public restrooms is their need for upkeep, but this solution will fix that. The restrooms are usually not clean because employees clean most without notice. This method monitors their actions efficiently, allowing higher-ups to keep tabs on them in real-time. Due to this, there will be less effort and more efficiency in the labour force. Eventually, toilet usage will rise since more people can use the regularly cleaned toilets. Incorporating mecha-electronic components into this system in the future will allow it to automate cleaning in response to sensor outputs completely. [15]

This study delves into the effects of the Internet of Things (IoT) on several industries, focusing on how it has revolutionized augmented reality, video streaming, and autonomous vehicles. It stresses the importance of low latency, increased bandwidth, and faster data rates. Key technologies, including MIMO, CRAN, and D2D communication, are discussed, emphasizing 5G as a driver for the evolution of the IoT. Addressing issues like high data rates and the necessity of edge computing in 5G-IoT deployment, the paper also discusses new use cases fueled by AI and deep learning. [16]

While technological progress has unquestionably increased in today's society, the country's hygiene state is jeopardized. Providing clean and hygienic toilets is the main idea behind this paper. Every public restroom needs to be spotless and hygienic. Our nation's government has instituted a programme known as "Swachh Bharat" (Clean India). One of the goals of the Clean India initiative is to ensure that the restrooms are accessible from contamination. Supporters of the Clean India initiative may find this helpful document. Eventually, it will be able to reveal the crucial role of the Clean India programme. Their sole concern under an existing system is finding the filth in the restrooms. They are settled in cleaning the restrooms as part of the suggested system by monitoring the sweeper's operations. Many syndromes can be avoided. Toilet management may become more widely known as a result. Thus, work is focused on utilizing safe and clean toilets. Various sensors, including olfactory, infrared, acoustic, and radio frequency identification readers, form the basis of this paper's image processing and Internet of Things (IoT) ideas. [17]

Utilizing innovations in the Internet of Things (IoT), the Intelligent Toilet Management System aims to improve restroom facilities' overall efficiency and user experience. In their detailed description of the system's design and execution, the authors shed light on how the Internet of Things (IoT) technology revolutionized traditional toilet administration. To improve resource utilization, maintenance, and user pleasure, the project intends to integrate toilet facilities into the IoT ecosystem and implement features that do just that. The conference paper provides a thorough summary that helps readers better comprehend the system's features, technical details, and possible uses. Overall, the Intelligent Toilet Management System project showcases the authors' dedication to creating novel consumer electronics solutions while significantly impacting the crossroads of the Internet of Things (IoT) and facility management. [18]



Fig.3 Health Monitoring Smart toilet

Using the Internet of Things (IoT) and integrated sensors, the primary goal of this project is to revamp conventional restrooms completely. The writers provide a comprehensive review of the sensor devices used and how they are integrated into the intelligent toilet system, delving into the technical details of the implementation. In addition to improving the user experience, this initiative is working toward making sanitation more efficient and sanitary. The

extensive analysis presented in the journal adds to the current scholarly conversation on the Internet of Things (IoT) and its potential uses in cutting-edge scientific and technical fields. Technical advancements can revolutionize and enhance fundamental parts of everyday lives, and implementing the Smart Toilet project is a prime example of this. [19]

Artificial Intelligence

The smart toilet paves the way for practical, long-term health monitoring. There are privacy concerns regarding standard identifying solutions that rely on camera or radio-frequency identification (RFID) technologies. AI toilet showcases a triboelectric pressure sensor array, which allows for a more discreet approach, affordable software, and easy deployment. Ten textile-based triboelectric sensors make up the pressure sensor array fastened to the toilet seat; these sensors can exploit the variations in pressure distribution caused by how each person sits to deduce biometric information. Deep learning could accurately identify six users with a 90% success rate. It is also possible to track how long the person sits on the toilet using signals from pressure sensors. The technology incorporates a photo sensor that compares the synthetic urine to a urine chart and uses deep learning to determine the kinds and amounts of items. The data from the urinalysis and stool analysis, the two-factor user identification and the entire sitting time measured by the pressure sensor array were automatically transferred to a cloud system. The users could then access this data on their mobile devices to better monitor their health status. [20]

To facilitate more efficient staffing, the project succeeded in developing an affordable and user-friendly interface connecting the cleaning service with public bathrooms. Setting up this application is a breeze. Research on multiple toilets at once is possible using time series projections. This toilet condition can help maintain a clean toilet before it gets dirty. Because of the recent upgrade to the data display, using the mobile app is much simpler. This Internet of Things gadget is lightweight and cheap. More sensitive and up-to-date sensors could improve the quality of this study's findings in the future. Machine learning improves the accuracy of predictions by learning from small samples and expanding the quantity of test data. More efficient storage systems and servers in the cloud are possible with this method when applied on a massive scale. [21]

Using theoretical frameworks and practical field research, this article delves into revitalizing and renovating urban parks. Concurrently, the smart park system's potential for revitalizing and renovating city parks was investigated in light of pertinent research and investigations. Smart city research and its applications are in a relatively mature stage. Building urban parks is an integral part of city planning, so it is essential to learn about smart city applications that apply to park design so that they can be appropriately included. A multi-disciplinary system, the smart park system integrates all relevant fields. There must be more in-depth conversation and research into integrating science and technology more systematically and comprehensively to create an intelligent connection between city dwellers and parks that will better assist inhabitants in their everyday lives. Related applications of the smart park system are not thoroughly discussed or researched in this study and should be further investigated. [22]

2.3 Different Methods

The healthcare industry has also been profoundly affected by the unprecedented developments brought forth by the 2020 pandemic. The scenario prompted an increase in the total utilization of the Internet of Things. The Internet of Things (IoT) has the potential to be a game-changer in the healthcare industry, paving the way for face-free, remote patient treatment. To provide better care, these facilities can monitor patients constantly. Furthermore, real-time data clouding can be helpful in situations requiring considerable data documentation. In this study, we present LightGBM, an Internet of Things (IoT) health tracker that can intelligently predict a user's health state using a machine learning model, and it achieves a prediction accuracy of 91.12%. The gadget also has embedded temperature, heart rate, and SpO₂. A data clouding system has also been created for public and private servers, allowing users and clinicians to share data in real-time. A user-friendly strategy has been developed to help non-tech users worldwide acclimate to smart health care with the suggested technology. [23]

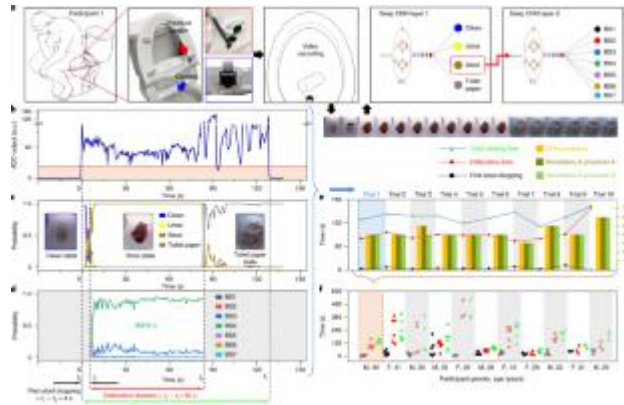


Fig.4 Mountable toilet system

Problems with healthcare are on the rise in countries with excessive populations, which means that the need for medical treatment is also on the rise. Despite falling treatment costs, the demand for high-quality care is increasing. Technological advancements allow a computer to remotely check health, providing more accurate results than human monitors. Both the reliability of complex machinery and the amount of time needed for personalized training have the potential to be enhanced. To guarantee the precision of the critical real-time signal, this study suggests an IoT-based real-time remote patient monitoring system. Through the Message Queuing Telemetry Transport (MQTT) protocol, the crucial real-time signal is transmitted from the suggested approach to the website. Reading and analyzing patients' vital signs while simultaneously reducing signal latency is the goal of this effort. [24]

Creating a railway coach-specific automated bio-toilet system is the primary goal of this project. To improve the use of toilets in railway contexts, the authors delve into cutting-edge engineering and research to develop a complex solution. The journal provides a thorough account of the project's aims, methods, and results, which add significant knowledge to the area. [25]

Incorporating turbidity sensors to improve functionality, this groundbreaking idea introduces the concept of smart toilets. The authors thoroughly examine the project's goals and outcomes within the designated journal issue and volume, delving into the application of state-of-the-art technology to build an intelligent toilet system.[26]

An innovative portable flush toilet is the main focus of this project, which aims to meet the needs of the Red Cross and is designed to be easily integrated into shelters that prioritize smart design. This mobile flush toilet is a unique addition to humanitarian efforts, and the writers of the conference presentation go into depth about the design and development process to show how it came to be. The project tackles the real-world problems of providing toilet facilities in emergency shelters, showing how crucial smart design concepts are. The Red Cross Mobile Flush Toilet is an innovative and well-planned solution that utilizes technology to enhance living circumstances during emergencies. The conference paper offers a wealth of information about the project, which is excellent for people interested in humanitarian technologies. It shows how smart design can help with crucial needs, especially in emergency shelters. [27]

Creating a smart toilet is the centre of this creative effort, demonstrating the integration of electrical and electronic technology for the user's benefit. With sophisticated technologies, the initiative intends to transform the way toilets completely. The writers thoroughly describe the features of the smart toilet and go into detail about the complex design and implementation. The Smart Toilet utilizes cutting-edge electrical and electronic innovation to bring new capabilities beyond typical functioning. Readers thoroughly comprehend the project's aims, methods, and results from the insightful commentary provided in the journal. With the increasing interest in smart technologies, the publication's timeliness in May 2018 implies a current relevance. Not only does this effort add to the field's scholarly conversation, but it also shows how these technologies can be used in real life. The Smart Toilet project showcases the potential for smart solutions in standard utilities and marks an innovative leap in electrical and electronic improvements. [28]

Over four months, this cluster-randomized controlled study indicated that public school restrooms in the Philippines might be improved with bundled O&M interventions. School restrooms were found to be more usable and cleaner after receiving materials and supplies for usage, cleaning, and structural maintenance, along with training and knowledge to

help with O&M activities in schools. The long-term effects of packed O&M therapies can only be determined with more studies. The national WinS monitoring system, which DepEd has been using since 2017, is an excellent tool for schools and the education sector to help with WinS improvement areas and sector management and planning. Based on the results of this study, the DepEd's WinS programme in the Philippines could accelerate efforts to achieve WASH service levels that align with the SDG goals by implementing the packaged O&M interventions more extensively.[29] For this research, a building information model (BIM) of many ventilation systems using Autodesk Revit. Utilized computational fluid dynamics (CFD) techniques to describe the spread of pollutants in these models and modelled buildings' energy usage in DesignBuilder. Increasing the volume and number of air exchanges and managing the installation height of exhaust vents are two essential approaches identified from an architectural design standpoint for minimizing the concentration of air pollutants. Public restrooms can have their ventilation systems optimized for all-air air conditioning systems with an exhaust height of 400 mm, significantly improving indoor environmental health, reducing carbon emissions by 30,681 kg CO₂, and using 20.4% less energy.[30]

III. CONCLUSION

In conclusion, the analysis of literature surveys on IoT, AI, and ML applications in public toilet monitoring systems reveals a dynamic landscape with significant potential for transformative impact. The integration of these technologies offers promising avenues for addressing long-standing challenges associated with hygiene maintenance, resource optimization, and real-time monitoring in public toilets. The diverse literature surveys reviewed highlight the multifaceted benefits of these technological interventions, ranging from increased operational efficiency to data-driven insights for urban planning. However, successfully implementing these technologies requires a nuanced understanding of contextual factors, user behaviour, and the unique challenges public toilet facilities pose. The synthesis of these technologies can lead to holistic health. By addressing the identified challenges and building on the insights gleaned from literature surveys, future endeavours in this field have the potential to revolutionize urban sanitation practices, fostering healthier and more resilient communities.

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