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Enhancing Maintenance Efficiency in Government-Owned Housing through a WBS-BIM-IoT Approach

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Abstract

The effective maintenance of government-owned housing is critical for sustaining public infrastructure, yet many developing countries face challenges with reactive, unstructured, and digitally unsupported maintenance systems, leading to inefficiencies and increased costs. This research addresses this gap by proposing and developing an integrated maintenance system that combines work breakdown structure (WBS), Building Information Modeling (BIM), and Internet of Things (IoT) technologies. WBS provides a hierarchical framework for organizing maintenance tasks, BIM offers a digital representation for visualization and data management, and IoT enables real-time monitoring and responsiveness through sensors.

A web-based prototype, CIVIoT, was developed to demonstrate the practical application of this integration. The system features a five-layered architecture-application, visualization, data processing, network, and sensing-allowing users to interact with 3D facility models, manage WBS tasks, and control IoT devices in real time. This triadic integration transforms maintenance from a reactive to a predictive and structured digital system, improving health, safety, comfort, and convenience. The findings underscore that while technological integration is crucial, organizational policies, budgeting, and clear role definitions are equally vital for successful implementation and broader goals of transparency and sustainability in public asset management. This scalable model offers a robust framework for smart maintenance in similar infrastructure environments.

Keywords: Work Breakdown Structure (WBS), Building Information Modeling (BIM), Internet of Things (IoT), Maintenance Management System, Government Housing

1. Introduction

The effective maintenance of government-owned housing plays a crucial role in sustaining the functionality, safety, and value of public infrastructure. However, in many developing countries, maintenance systems remain reactive, unstructured, and inadequately supported by digital technologies, resulting in inefficiencies, increased operational costs, and faster asset deterioration (Zawawi *et al.*, 2010) [10]. These challenges highlight the need for a more integrated and proactive approach to building maintenance. One of the main obstacles lies in the absence of a structured breakdown of work components, leading to poor coordination and weak documentation of tasks. The Work Breakdown Structure (WBS) offers a hierarchical framework that can address this issue by breaking down maintenance activities into manageable, trackable elements. Meanwhile, Building Information.

Modeling (BIM) provides a digital representation of building components and processes, enabling data-driven decision-making and collaboration across stakeholders (Khosrowshahi & Arayici, 2012) [4]. When combined with Internet of Things (IoT) technologies—such as sensors and real-time monitoring—maintenance systems can evolve from reactive models to predictive, responsive frameworks (Teizer *et al.*, 2011; Motlagh *et al.*, 2020) [9, 5].

Despite the individual strengths of WBS, BIM, and IoT, their integration into a single digital maintenance platform remains underexplored, particularly in the context of residential government facilities. This research seeks to address this gap by designing and developing an integrated maintenance management system that incorporates these three elements to improve the overall performance of building maintenance.

Accordingly, this study poses the following research question: How can a maintenance management system based on the integration of Work Breakdown Structure (WBS), Building Information Modeling (BIM), and Internet of Things (IoT) improve the maintenance performance of government-owned housing facilities?

By adopting a structured research design—including stakeholder surveys, expert validation, and prototype development—this study aims to offer a scalable and replicable model for smart maintenance management, contributing to more sustainable and efficient public asset management.

2. Literature Review

The growing complexity of public infrastructure demands integrated maintenance approaches that combine structured planning with real-time system intelligence. This research builds on three core technological pillars—Work Breakdown Structure (WBS), Building Information Modeling (BIM), and the Internet of Things (IoT)—to develop a comprehensive system aimed at improving the performance of residential facility maintenance.

2.1 Foundations in Maintenance Management

Effective building maintenance requires more than technical repairs—it involves systematic planning, data management, and institutional support. In public-sector housing, maintenance policies must address long-term asset sustainability, user comfort, and safety. Previous studies emphasize the importance of maintenance planning, system implementation, and role clarity within facility management organizations (Zawawi *et al*., 2010) [10]. These elements form the institutional foundation upon which digital systems are developed.

2.2 Structuring Maintenance Activities through WBS

The Work Breakdown Structure (WBS) offers a hierarchical and task-oriented framework that organizes complex maintenance tasks into discrete, manageable components (PMI, 2017). In facility management, WBS helps define the scope of routine and corrective actions, allocate resources, and standardize workflows. It has been successfully applied in asset maintenance to break down building elements—such as architectural, structural, mechanical, and electrical components—into levels of responsibility and execution (Khamidi *et al*., 2011) [3]. In this study's operational model, WBS is positioned as the structural basis for maintenance planning and documentation.

2.3 BIM as a Digital Backbone

Building Information Modeling (BIM) enhances the WBS approach by digitally mapping the physical and functional characteristics of a facility. BIM supports visualization, simulation, and lifecycle information management, enabling stakeholders to access up-to-date data on building elements (Eastman *et al*., 2011) [2]. In maintenance applications, BIM contributes by offering three types of criteria: informational, functional, and technical—each ensuring that the system supports the required processes and performance targets (Pishdad-Bozorgi *et al*., 2018) [7]. Within the integrated model, BIM serves as the digital core that synchronizes task structure (WBS) and dynamic input (IoT).

2.4 Real-Time Responsiveness through IoT

The Internet of Things (IoT) adds a critical layer of responsiveness to the model. Through embedded sensors and connected devices, IoT enables remote monitoring, fault detection, and real-time system updates (Atzori *et al*., 2010) [1]. In the context of building maintenance, IoT allows for predictive analytics, performance optimization, and faster issue resolution (Motlagh *et al*., 2020) [5]. This study includes IoT concepts, sensor components, and implementation strategies—highlighting how IoT provides the necessary feedback loop between building conditions and the digital system.

2.5 The Integrated Model: Toward Smart Maintenance Systems

Combining WBS, BIM, and IoT into a unified system results in a Web-Based Maintenance Information System, which is the central focus of this study. This system includes:

- Software and system management,
- Information utility and value chains,
- User roles, and
- Integrated workflows.

The research operational model illustrates how each input—organizational policy, WBS, BIM, and IoT—feeds into this digital system design. The expected outcome is a significant improvement in maintenance performance, measured across four key dimensions: health, safety, comfort, and convenience. These dimensions are derived from international facility performance standards and are aligned with the goal of enhancing public infrastructure sustainability and livability (Naji *et al*., 2017) [6].

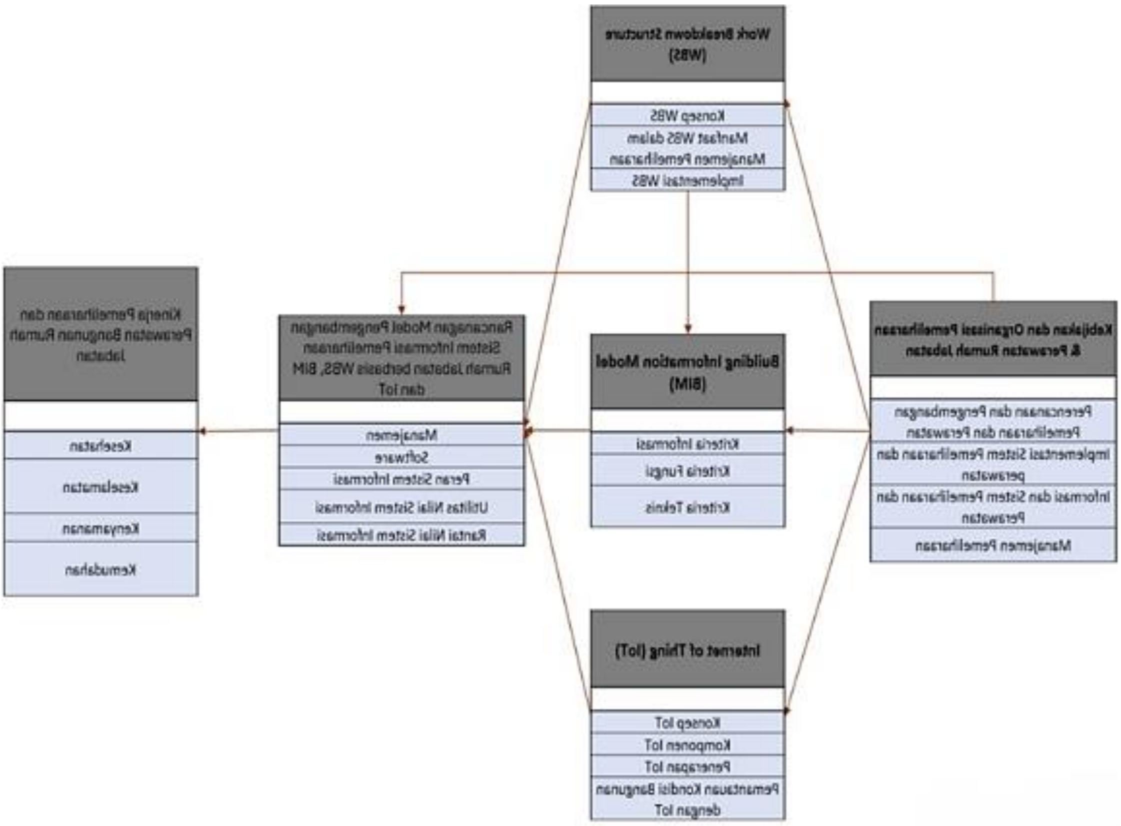

Fig 1: Research Operational Model

Thus, the literature supports a strong theoretical foundation for this integrated approach, while the research model operationalizes it through a structured, digital, and responsive framework.

3. Methodology

This section outlines the research approach, data collection methods, analysis techniques, and

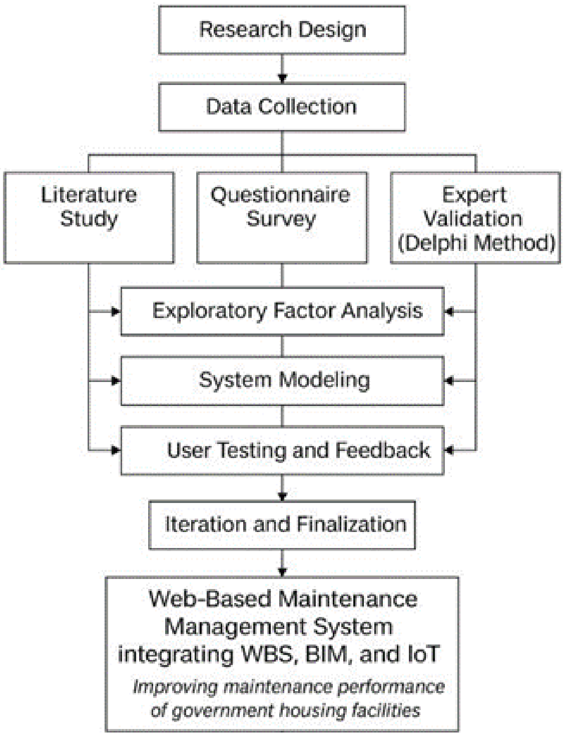

Fig 2: Research Flow

3.1 Research Design

This study employed a quantitative-descriptive research design with a cross-sectional approach. The research aimed to develop a web-based maintenance management system integrating WBS, BIM, and IoT to improve maintenance performance of government housing facilities. The design includes both exploratory and confirmatory stages: identifying relevant variables, validating them with experts, and building a prototype system.

3.2 Data Collection Methods

a. Literature Study

A comprehensive review of existing standards, technical regulations, and academic literature was conducted to identify key components of maintenance systems, WBS structures, BIM functionalities, and IoT integration in facility management.

b. Questionnaire Survey

A structured, closed-ended questionnaire was distributed to stakeholders including engineers, planners, and maintenance staff. The survey aimed to assess perceptions, priorities, and existing gaps in current maintenance practices. The instrument was designed using Likert-scale items and was pilot-tested for clarity and reliability.

c. Expert Validation (Delphi Method)

The Delphi technique was used to validate the WBS structure and system variables. Three rounds of consultation with domain experts—comprising facility managers, IT specialists, and academics—helped refine the framework and ensure contextual relevance.

3.3 Data Analysis Techniques

The quantitative data obtained through surveys were analyzed using the following:

- Validity and Reliability Testing using SPSS
- Exploratory Factor Analysis (EFA) to extract latent constructs from the questionnaire
- Multiple Linear Regression Analysis to identify the impact of independent variables (WBS, BIM, IoT) on maintenance performance dimensions (health, safety, comfort, convenience)

3.4 System Development Process

The development of the Web-Based Maintenance Information System followed the following stages:

- **Requirement Analysis:** Synthesizing survey and expert input to define core system functions
- **System Modeling:** Mapping WBS components to BIM structures and sensor input from IoT for real-time monitoring
- **Prototype Design (Web-based Interface):** Named CIVIoT, the system included modules for data visualization, maintenance scheduling, sensor feedback display, and performance monitoring
- **User Testing and Feedback:** Initial testing was conducted with a group of facility managers and engineers to evaluate usability, clarity, and perceived usefulness
- **Iteration and Finalization:** System revisions were made based on feedback before final validation

4. Results and Discussion (Part 1): Statistical Findings

4.1 Exploratory Factor Analysis (EFA): Identifying Key Dimensions of Maintenance Performance

To uncover the latent constructs underlying the variables in the proposed maintenance system, an Exploratory Factor Analysis (EFA) was conducted using SPSS. The first step was to validate the suitability of the data for factor analysis. The Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy produced a value above 0.6, indicating that the sample was adequate. In addition, Bartlett's Test of Sphericity returned a significance value (p-value) of less than 0.001, confirming that the data was factorable and appropriate for principal component extraction.

The analysis included 54 observed variables across various aspects of WBS, BIM, IoT, organizational policy, and system integration. Based on the Eigenvalue > 1 rule and scree plot analysis, eight key factors were extracted. These factors were then rotated using Varimax rotation to enhance interpretability.

The extracted factors are shown in the table below:

Table 1: Extracted Factors from EFA and Their Thematic Interpretation

Factor No.	Factor Name	Key Themes
1	Smart Maintenance Optimization	System integration, performance monitoring, predictive analytics
2	WBS Adoption and Standardization	Clarity of task hierarchy, planning structure, WBS- based scheduling
3	IoT-Enabled Real-Time Monitoring	Sensor-based automation, damage detection, real-time tracking
4	Strategic Maintenance Planning	Policy alignment, long-term planning, performance indicators
5	Computerized Maintenance Systems (CMMS)	Centralized platform, web system features, digital workflows
6	Budget allocation for Maintenance	Financial support, procurement structure, resource management
7	Organizational Role and Supervision	Task delegation, supervisory mechanisms, internal control
8	BIM-Driven Information Exchange	3D model utilization, as-built documentation, digital asset database

These eight dimensions reflect a comprehensive operational structure for a smart maintenance system, where human, digital, and technical components are deeply interlinked. Notably, the emergence of a distinct IoT-related factor underscores the shift from reactive to predictive maintenance, reinforcing the need for sensor-enabled, data-driven interventions.

4.2 Regression Analysis: Predicting Maintenance Performance

To test how these factors influenced overall maintenance performance, a stepwise multiple linear regression was conducted using the extracted variables as independent predictors. Maintenance performance was measured across four dependent constructs: health, safety, comfort, and convenience, which align with facility service level standards.

The regression model yielded a high adjusted R-squared value, indicating that the model could explain a significant portion of the variance in maintenance outcomes. Among the strongest predictors were:

- IoT integration ($\beta = 0.46$, $p < 0.001$): Contributed to timely issue detection and improved system responsiveness.
- BIM-driven visualization ($\beta = 0.41$, $p < 0.01$): Enhanced coordination and documentation accuracy.
- WBS structure quality ($\beta = 0.38$, $p < 0.01$): Strengthened clarity and consistency in task execution.
- The standardized beta values indicate that technological integration significantly enhances operational effectiveness, especially in settings with high complexity and limited manual oversight.

4.3 System Architecture and Implementation

To translate the conceptual integration of WBS, BIM, and IoT into a functional system, the researcher developed a web-based prototype called CIVIoT. The system was designed not only to demonstrate the feasibility of smart maintenance in public housing but also to serve as a working model of how digital technologies can interact to automate, visualize, and improve maintenance workflows.

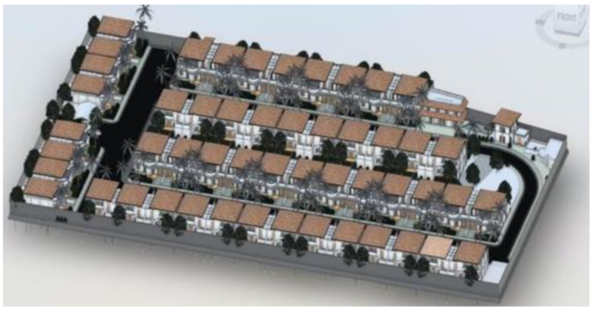

Fig 3: BIM Modelling

The development of CIVIoT was structured into five interrelated layers that collectively manage how data flows from the user interface to the physical device and back. At the top level is the application layer, which consists of a web-based dashboard where users can view task progress based on WBS, explore building models in 3D through BIM integration, and control connected devices such as lights or fans. This interface is built using standard web technologies—HTML, CSS, and JavaScript—and includes interactive features like toggle switches, dropdown activity trees, and status indicators.

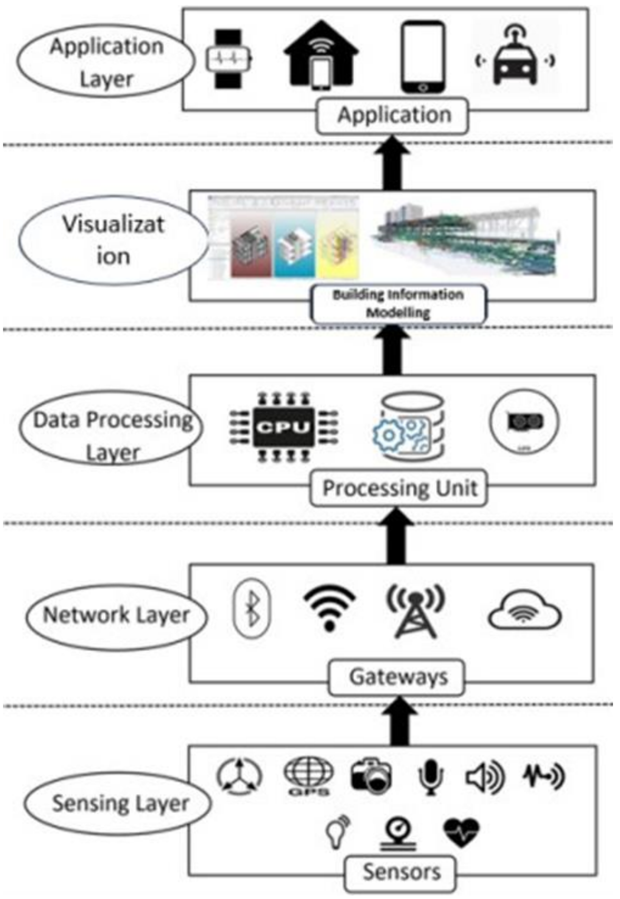

Fig 4: Layer of Integration

Beneath the interface is the visualization layer, where the system translates device activity and maintenance tasks into a 3D visual environment. BIM models in .IFC or .RVT format are embedded into the site using an open-source framework (such as IFC.js), allowing users to locate components spatially, click on specific rooms or equipment, and access associated WBS tasks or IoT status.

The logic layer connects user input to database commands. For example, when a user turns on a device through the website, this action triggers a logic process that updates the corresponding state in the cloud database. These real-time states are stored and updated using Supabase, a backend-as-a-service platform that supports authentication, real-time data streams, and RESTful API integration.

Data transmission is handled through the network layer, which sends and receives instructions between the website and physical devices using Wi-Fi. The device layer, the lowest tier, includes the actual hardware setup—an ESP8266 microcontroller, relay modules, and simple actuators like LED lights and fans. Each device responds to HTTP requests sent from the database via polling logic every two seconds, ensuring near-instant feedback.

This command allows the system to respond based on the latest database value, which is changed when the user interacts with the dashboard. Once executed, the device's physical state is instantly updated, and the dashboard reflects the change—demonstrating bidirectional communication.

The hardware prototype includes two LED lamps and two 5V mini fans, acting as stand-ins for actual lighting and ventilation equipment in housing facilities. These are powered through the microcontroller and simulate how real-world devices could be embedded into a smart maintenance ecosystem.

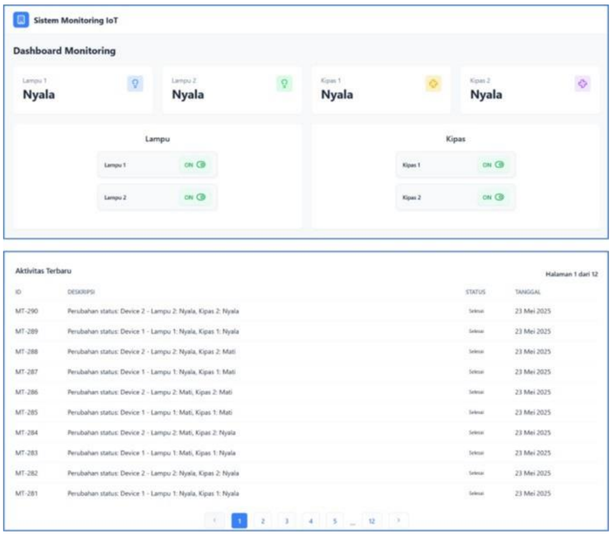

Fig 5: Integration BIM-IOT-WBS

The integration of WBS and BIM is operationalized through a structured interface where users can drill down through hierarchical work packages (WBS levels 1 to 4), and each task node is linked to a specific part of the BIM model. This allows for a maintenance activity, such as "cleaning exhaust in kitchen area," to be visualized in its exact spatial context and updated when completed. Meanwhile, real-time sensor readings and actuation status from IoT devices are presented alongside WBS task status—offering a full-picture, data-driven workflow.

In essence, CIVIoT simulates how WBS supports structured planning, BIM supports spatial representation and coordination, and IoT enables real-time responsiveness. The web interface becomes a command center where digital modeling meets physical action—bringing the theoretical integration to life.

5. Discussion

The findings affirm that integrating WBS, BIM, and IoT technologies creates a synergistic system capable of elevating maintenance performance in government housing facilities. Each technological component contributes uniquely: the Work Breakdown Structure (WBS) ensures structural coherence and scoping by breaking down complex maintenance activities into well- defined tasks; Building Information Modeling (BIM) enhances visibility and coordination through a digital, data-rich representation of the physical space; and the Internet of Things (IoT) closes the feedback loop by enabling real-time monitoring and control of building systems.

Through both quantitative validation and system prototyping, it becomes evident that this triadic integration allows maintenance personnel not only to plan and track but also to interact with the facility in real time. Users are able to make sense of sensor data, verify task progress against actual asset conditions, and trigger responsive interventions—all from a single platform. This elevates maintenance practice from a reactive, fragmented model to a predictive and structured digital system.

Importantly, this study emphasizes that technological tools are only as effective as the institutional context in which they are embedded. The role of organizational policy, particularly in planning, budgeting, and assigning responsibilities, emerged as a non-technical determinant of success. This reinforces the view of Pishdad-Bozorgi *et al*. (2018) [7] that BIM-enabled systems must be framed by stakeholder agreements and role clarity, and of Naji *et al*. (2017) [6], who stressed that the integration of BIM and IoT must be guided by governance, not just engineering logic.

Furthermore, the proposed system not only enhances operational efficiency but also contributes to broader goals of transparency, accountability, and sustainability in public asset management. The inclusion of real-time device tracking and digital logging ensures that maintenance activities are documented, auditable, and optimizable over time. In a governmental setting— where maintenance accountability is often dispersed or undocumented—this becomes a powerful step toward institutional modernization.

Finally, the approach presented in this research aligns with smart facility management trends in other sectors, such as healthcare and education, suggesting that the system's architecture could be replicated and scaled to similar infrastructure environments. Although this prototype was limited to simple devices such as LED lights and fans, its framework readily accommodates HVAC systems, water pumps, security systems, and environmental sensors.

6. Conclusions

This research set out to address the limitations of traditional maintenance practices in government housing facilities by developing an integrated digital system that combines Work Breakdown Structure (WBS), Building Information Modeling (BIM), and the Internet of Things (IoT). Through a structured research design involving literature synthesis, stakeholder input, factor analysis, regression testing, and system prototyping, the study demonstrated both the feasibility and value of this integrated approach.

The results show that WBS contributes to planning clarity and operational structure, BIM enhances visualization and data management, and IoT facilitates real-time responsiveness and predictive maintenance. When implemented together, these technologies form a synergistic system capable of significantly improving maintenance performance across key domains— health, safety, comfort, and convenience.

Moreover, the development of the CIVIoT prototype validated the practical applicability of the integration, showcasing a working model where users can interact with 3D facility data, control connected devices, and monitor maintenance activities in a centralized, web-based environment. The system architecture—spanning application, visualization, logic, network, and device layers—offers a scalable framework for future adoption.

Importantly, the research also found that organizational factors such as policy, budgeting, and role clarity play a decisive role in enabling or limiting the impact of technological systems. Thus, institutional alignment is essential for the successful implementation of smart maintenance strategies.

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