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Original Article

Design of a Modular and Scalable IoT-Based System for Utility Management: A Case Study at 3 Towers Residences

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Abstract - *The utility recording process in residential buildings is often prone to errors due to manual handling, inefficiencies, and delays, which affect billing accuracy and disrupt operational workflow. This paper proposes a conceptual design of a modular and scalable IoT-based utility management system using the Modbus communication protocol, which can connect up to 31 smart meters per node. However, the system supports expansion across extensive residential infrastructure. The proposed design has been validated through expert discussions and stakeholder evaluations, projecting a potential reduction in data transfer time from over five days to just one hour, enabling real-time monitoring, minimizing human error, and ensuring billing is issued on the first day of each month. Although full deployment has not been executed, this paper outlines the conceptual system design, expected benefits, and potential for broader application across similar residential properties in Indonesia and beyond.*

Keywords - *Internet of Things, Modbus communication, Modularity, Scalability, Utility management.*

1. Introduction

Urban residential complexes increasingly face challenges in managing utilities efficiently due to rising occupancy rates and growing service expectations. As a result, Internet of Things (IoT)-enabled utility systems have emerged as a strategic solution to address operational inefficiencies and support data-driven property management practices [1].

In advanced economies such as Germany [2, 3], the United States, and Singapore [4], smart meters integrated with IoT infrastructure have demonstrated the potential for real-time energy monitoring, predictive maintenance, and digital billing. However, implementing fully automated utility billing systems remains limited mainly to pilot projects or premium development.

Contrasting in developing countries such as Indonesia, the deployment of IoT-based utility management systems is still in its infancy. Most apartment buildings rely on manual data collection and spreadsheet-based billing mechanisms, which introduce risks of human error, process delays, and operational inefficiencies. Although some commercial and industrial facilities have adopted smart metering at the building level, sub-metering at the unit level remains underdeveloped, particularly in mid to high-rise residential complexes. This study addresses this gap by proposing a modular and scalable IoT-based design for utility management, with a case study at 3 Towers Residences Apartment in South Jakarta. Despite being premium properties, the utility billing process in these residential buildings is still dominated by traditional methods, which rely heavily on manual meter readings unit by unit, followed by manual compilation and submission to the finance department.

This multi-step process causes significant time delays (averaging over 5 days) and increases the likelihood of data inaccuracies, which ultimately affect billing timeliness and customer satisfaction. To fill this research gap, this research introduces a design approach that integrates smart meters using the Modbus communication protocol to enable one data acquisition node to connect up to 31 meters.

This technical configuration complies with Modbus standards and addresses the spatial and budgetary constraints in retrofitting IoT systems in existing buildings. The proposed system intends to make data collection more efficient, reduce human errors, and quicken the utility billing cycle [5].

The existing utility management process is manual, mainly at 3 Towers Residences Apartment, and contains multiple steps by engineering and finance teams.

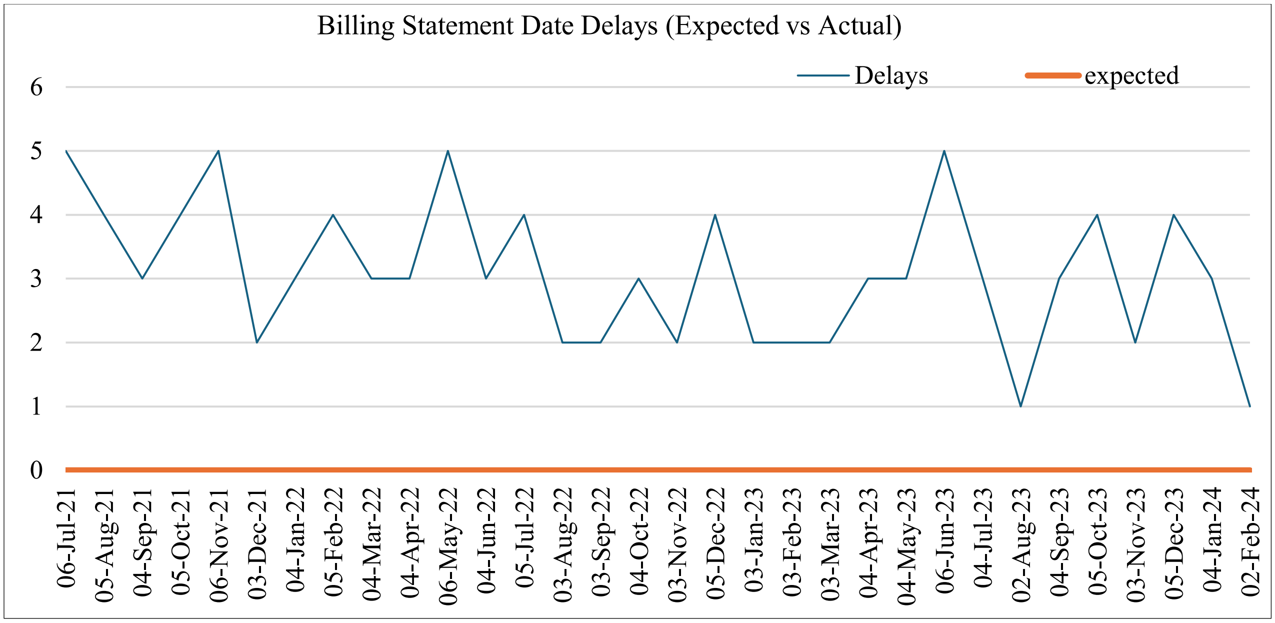


Fig. 1 Illustrates inconsistency in the manual utility management process, highlighting significant time delays

This process is time-consuming and prone to errors and inefficiencies that could delay the delivery of monthly bills to residents [6]. The main task in the current system is as follows:

1. There is a possibility of human errors due to the manual process of reading, noting down, and meter data entry.
2. Prolonged time causes billing cycles to go beyond five working days after the end of the month.
3. A deficiency of Real-time outlook blocks timely analysis and decision-making.
4. Inadequate scalability holds back future upgrades or developments.

To address these challenges, this study answers the following research question:

How can a modular and scalable IoT-based system improve efficiency and accuracy in utility management at the 3 Tower Residences Apartment?

Based on the identified research question above, the goals and benefits of the suggested study are as follows:

1.1. Goals

To design a modular and scalable IoT-based utility recording system that reduces processing time, human error, and operational workload at 3 Towers Residences Apartment.

1.1.1. Benefits

1. Operational Efficiency – Streamlines utility data acquisition from multiple floors and meter units.
2. Billing Accuracy – Minimize data entry errors through automated meter readings.
3. Timely Billing Process – Enables utility bills to be issued by the 1st day of the month.
4. Modular Scalability – Enables future system expansion with minimal reconfiguration.
5. Business Process Oriented Design – Aligns the IoT system design with process improvement goals.
6. Digital Process Transformation Model for Developing Contexts – Demonstrates how IoT-enabled utility recording can drive process efficiency and digital transformation in resource-constrained residential properties.

2. Literature Review

2.1. Business Process Management (BPM)

Improving organizational workflows requires more than a comprehensive management framework. Business Process Management (BPM) is a foundational theory for systematically improving organizational workflows. As Saab [7] highlighted, BPM is a holistic discipline that integrates processes, stakeholders, governance, and technology to align operational outcomes with organizational objectives. The BPM lifecycle modeling, execution, monitoring, and optimization are relevant to utility management in large residential complexes.

2.1.1. Key Considerations

1. Quality Control in BPM: Saab's predictive quality performance framework proposal emphasizes identifying and addressing quality anomalies in real time in line with IoT-enabled solutions that continuously oversee utility processes.
2. Permanent Enhancement: the work context combines predictive data analysis and logical performance tracking, aligning its approach with the core ideologies of Lean and

Six Sigma in directing gradual and sustained improvements [8].

3. Stakeholder Orientation: aligning organizational goals from stakeholder expectations with IoT technology, impacting the Business Process Management (BPM) by ensuring that monthly utility bills are delivered accurately and on time.

By using IoT devices and joining predictive analytics and real-time data processing, improve Business Process Management in terms of detecting, predicting, and mitigating unusual events in utility data to ensure smooth process improvement and stakeholder fulfilment.

2.2. IoT Self-Adaptive Architecture

Modular system design edge and fog computing in Internet of Things technologies contribute to the improvement of real-time data handling in utility management [9]. To improve operational decisions, edge computing enables local data processing at the point of origin, thereby minimizing slow responses and filtering data across distributed nodes.

Fog computing is an intermediary layer that simultaneously enhances the awareness and modularity of the utility system in residential buildings. Self-adaptive architecture can operate without disruption by dynamically adjusting to environment changes, such as device failures or varying data loads [10]. This technology provides a robust framework for scalable and modular IoT solutions in utility management, enabling improved accuracy, reduced operational delays, and real-time analytics.

2.3. Smart Grid Technology

Smart grids are transformative systems that leverage advanced technologies, including IoT, to enhance the traditional power grid infrastructure. Integrating smart grids facilitates bidirectional communication, enabling concurrent monitoring and supervision of energy flow. In the context of apartment buildings, the implementation of smart grids provides a foundation for efficient utility management [11].

The smart grid is evolving to become more complicated and fulfil the needs of more stakeholders. Its evolution exposes various traits, and the innovative grid development features as follows [12]:

1. Difficulty: Coordination challenges across various operational and communication layers
2. Modularity: Support flexible system expansion control mechanisms.
3. Resilience: Ability to maintain operational stability and unpredictable shifts in consumer usage patterns.
4. Versatility: Capacity to adapt to changes in environmental conditions, technology standards, and user behavior over time.
5. Precision: Accuracy and utility measurements are essential for reliable data for operational decisions.
6. Productivity: Operation optimization and managing resources.
7. Safety: safeguarding data privacy, Energy security of utility services

The above features are essential for advancing innovative meter applications.

2.4. RS-485 Basics and Capability

In the context of RS-485 communication, the standard specifies that a single bus segment can support up to 32 unit loads, which traditionally translates to 32 devices. This limitation arises from the electrical characteristics defined in the RS-485 standard, where each device presents a specific load to the network. However, advancements in transceiver technology have introduced devices with reduced unit loads, allowing for a greater number of devices on a single bus segment [13]. As an example, Texas Instrumentsxplains that by utilizing transceivers with a fractional unit load (e.g., 1/8th unit load), it is possible to connect up to 256 devices on an RS-485 bus [13].

Equation (1) is the largest quantity of transceivers that the link can manage.

$$\#\ of\ Nodes\ = \frac{32}{equivalent\ unit\ loading} = \frac{32}{1/8} = 256\, nodes \tag{1}$$

Table 1. Unit-load characteristics

Load	Current at 12V	Resistance	Max nodes on one network
1	1mA	12kΩ	32
1/2	500µA	24kΩ	64
1/4	250µA	48kΩ	128
1/8	125µA	96kΩ	256

Similarly, analogue devices discussed how the input impedance of RS-485 receivers could vary, and by employing receivers with higher input impedance, the number of devices on a bus can be increased beyond the traditional limit [13].

2.5. IoT in Utility Management

The IoT paradigm facilitates seamless connectivity between devices, enabling smart meters to communicate with central monitoring systems through protocols like Modbus RS-485 and Ethernet networks. The integration of several smart meters in an apartment building creates a comprehensive network for data exchange. The capability of real-time data analysis by IoT technology is critical in identifying anomalies, optimizing energy usage, and responding quickly to changes in demand. IoT integration ensures utility monitoring goes beyond data collection to actionable insights [12].

2.5.1. Power Consumption

The unit of electricity is measured as kilowatt-hours or kWh

1 kWh = 1,000 watts for 1 hour.

Sample: 10 x 100-watt bulb light used for 1 hour = 1 kWh

2.6. Modular IoT-based Solution

A modular context within IoT ecosystems facilitates the effortless merging of various devices and services through a stratified system structure. This configuration enables autonomous development processes and scalable system growth by disentangling system modules. Such an arrangement improves adaptability and simplifies the integration of diverse device types, advancing interoperability and optimizing resource allocation [14].

The configurable nature of modular IoT components offers bespoke solutions tailored to distinct user needs. This level of customization is vital across applications like residential automation and industrial control systems, where varied operational contexts demand adaptable IoT configurations. Modular structures allow systems to be restructured in response to shifting requirements and technological progress [15].

In the context of intelligent environments, the ability of modular IoT platforms to scale efficiently is essential. Research from a structured review shows that tiered IoT architectures enhance multiplicity and scalability, thereby reforming the coordination of large devices and services. This design paradigm ensures that system expansion does not worsen overall function or interoperability [16].

System robustness becomes a primary concern given the unpredictable conditions in IoT deployments, such as fluctuating bandwidth and inconsistent device behaviors. Modular IoT design combines an adaptive approach to uphold application reliability under these dynamic settings [9]. Moreover, standard technical protocols enable smooth inter-device communication, essential for building scalable and consistent IoT infrastructures [17].

Incorporating edge and fog computing technologies into modular IoT setups significantly improves handling latency and bandwidth constraints. By processing substantial volumes of data closer to the source, this approach shrinks dependence on centralized data centres and allows for more immediate data handling [18].

In industrial environments, modular IoT configurations must be adaptable and expandable. The industrial Internet of Things (IIoT) controls modular architectures to integrate various industrial devices and systems, enhancing operational efficiency and enabling advanced analytics yet supporting industrial applications' diverse and evolving needs [19].

2.7. Automated Billing Systems

The arrangement of smart meters influences the accuracy and transparency of billing processes. Concurrent data from smart meters allows for precise billing calculations based on actual consumption, eliminating estimation errors common in traditional billing systems [20]. According to N. Sushma, the traditional meter record usage data has various drawbacks to this approach, as sometimes the average monthly bills show consumption if the meter is located inside a user's residence. The difference between residential and apartment buildings is that they are not dependent on the user's residence, as the meters are in the service area corridor for an engineer to record power and water consumption. These utility meters are inside the panel with a door lock that residents cannot open or are unauthorized to open. After recording the meter's consumption, the meter must take a snapshot for documentation in case of a future dispute.

Automated billing systems driven by the integration of IoT enhance cost efficiency for both utility providers and consumers. By streamlining the billing process and reducing manual interventions, resources are optimized, contributing to the long-term sustainability of utility management [21].

2.8. IoT Platforms for Utility Management

The right platform is critical for achieving system efficiency, modularity, and scalability. Several open-source platforms, such as Node-Red, ThingsBoard, Kaa IoT, and OpenHAB, offer distinct features tailored to IoT solutions. This section provides an overview and comparison of these platforms to highlight their applicability for utility management in residential properties. Node-Red is a widely used open-source IoT platform developed by IBM that enables the rapid development of IoT uses over a visual programming interface. It allows users to design workflows by connecting various nodes to represent devices, APIs, and services. Node-Red is suitable for:

1. Ease of Use: Its drag-and-drop interface simplifies development, making it accessible for non-technical users.
2. Extensibility: supports a wide range of integrations via its vast library of nodes.
3. Concurrent data processing facilitates concurrent monitoring and processing of IoT data, which is critical for utility management applications.

Limitations such as scalability for managing large-scale systems must be segmented into groups to maintain performance rather than in a centralized runtime environment [22].

2.9. Research Gap and Study Contribution

Previous studies have explored IoT-based innovative metering solutions, particularly in the context of Advanced Metering Infrastructure (AMI) [23], which is commonly applied in the grid to home electricity distribution systems. However, the focus is enhancing communication between utility providers and individual households or consumers by enabling automatic meter readings, demand-side monitoring, and dynamic pricing schemes.

In contrast, utility distribution in apartment buildings is managed internally by building management after electricity reaches the central panel, creating operational complexities that are not addressed in conventional AMI-focused studies. Most existing literature does not consider an intra-building metering system of their integration into internal business processes, such as billing and financial handoffs.

This study addresses that gap by proposing a modular and scalable IoT architecture tailored to the needs of residential property managers, integrating real-time data collection with business process automation to improve efficiency, reduce human error, and support timely billing delivery.

3. Materials and Methods

3.1. Conceptual Structure

This research focuses on developing an IoT-based solution for utility recording at the 3 Towers Residences Apartment, aiming to automate the manual processes involved in capturing utility usage data and generating billing records. The objective is to enable accurate, timely handoffs of utility bills from the engineering team to the finance department, thus optimizing operational efficiency. The following research steps were designed to ensure a systematic approach to achieving this objective.

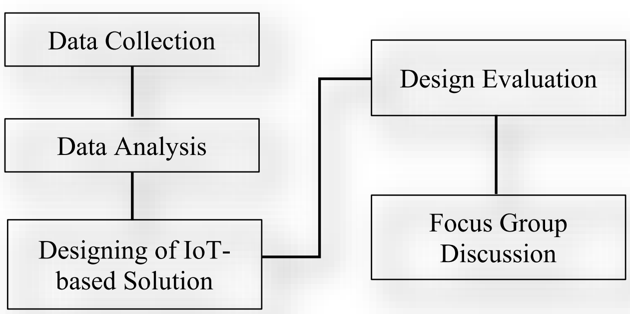


Fig. 2 Research steps

3.1.1. Conceptual Validation

The conceptual validation process was designed to ensure that the proposed modular and scalable IoT-based system aligns with the research objectives and addresses the identified gaps in utility management. This was achieved through:

Simulation of IoT Workflows

Using the Node-RED platform, sample workflows were created to simulate data collection, processing, and transmission from multiple Modbus smart meters. This simulation tests the feasibility of connecting up to 31 devices per Modbus RTU segment.

System Architecture Validation

The proposed architecture is to be reviewed by IoT professionals and property management stakeholders to ensure that the system design is both practical and scalable for real-world application.

Use Case Scenarios

Practical scenarios like electricity consumption data recording will be simulated for test data and verify the system's workflow logic and error handling capabilities.

3.1.2. Small-Scale Pilot Testing Framework

A pilot testing framework is proposed to address the gap in real-world implementation. This framework outlines the steps for future practical testing and is a guideline for implementing the system at 3 Towers Residences Apartment or similar properties.

Scope of the Pilot Test

- Install Node-Red on a local server to manage a small number of IoT devices (e.g., 6-32 Modbus smart meters), where this typical module is named modular.
- Focus on a single Tower building (Tower 3) as the pilot test board to test the end-to-end utility data recording and billing process.

Pilot Test Objectives

- Validate real-time data collection and transmission
- Assess the scalability of the system for incrementally adding additional devices.
- Evaluate the reduction in errors and processing time compared to manual methods.

Key Performance Indicators

- Error Reduction: Measure the percentage decrease in errors during data recording and billing preparation.
- Time Efficiency: Compare the duration of the automated process against the manual workflow.
- System Stability: Monitor the uptime and response time of the Node-Red platform during the pilot test.

Stakeholder Engagement

- Feedback from engineering staff and PPPSRS as representative owners or residents will be gathered through interviews and surveys during the pilot test phase to evaluate the system's usability and effectiveness.

3.1.3. Future Implementation Plans

Although this study is centred on theoretical exploration and system design, it introduces a preliminary testing plan to guide future deployment. The recommended preparatory action includes:

- Collaborating with a trusted local technology provider to facilitate hardware deployment and resolve any technical challenges.

- Conducting iterative testing cycles to identify and correct system malfunctions before broader deployment.
- Exploring the possibility of expanding the pilot program to additional buildings or residential complexes, contingent on favorable initial outcomes.

3.2. Data Collection

This stage involves compiling statistical data and narrative information to thoroughly assess the current methods for monitoring utility consumption and generating billing at 3Towers Residences Apartment.

Combining qualitative and quantitative research techniques offers a stronger evaluation, integrating measurable outcomes with stakeholder perspectives to understand better the implications of adopting an IoT-enabled system. The research utilizes a mixed-method data collection strategy to capture comprehensive insights into the current utility tracking and billing practices at 3 Tower Residences. By integrating empirical performance metrics with stakeholder feedback, the study provides a balanced assessment of the practical and added value of transitioning to digital IoT-based utility management.

3.2.1. Quantitative Data Collection

The objective is to gather quantifiable evidence related to process duration, incidence of human error, and overall productivity of the existing manual procedures for utility monitoring and billing.

Approach

a. Process Time: Measure the duration of each stage in the current manual workflow, encompassing data recording, validation, and preparation prior to submission to the finance department.
b. Error Rates: Review historical records to document the error rates and time delays in preparing utility billing files.
c. Operational Efficiency: Comparison of manual and automated workflows to identify areas of improvement.

Quantitative data that highlights the current process inefficiencies, specifically the time taken for file preparation (currently at least 5 business days), establishing a baseline for comparison with the IoT-based solution process, which aims to reduce time to under one hour.

3.2.2. Qualitative Data Collection

Structured interviews will be used as the primary method for collecting qualitative data. The interviews will be conducted with key stakeholders, including PPPSRS managers and building management staff, as they represent both owners and the operational perspective of utility management.

Objectives of the Interviews

- Understand the gaps or challenges building management faces in the current manual utility management process.
- Explore the expectations and requirements of PPPSRS regarding the implementation of an IoT-based system.
- Gather insights into perceived benefits, concerns, and potential barriers to adopting IoT technology.

3.3. Data Analysis

Evaluate the collected data to detect inefficiencies, errors, and models in the manual recording process.

Methods

- Identify common issues, such as data inaccuracies and time delays, that contribute to inefficiencies in the utility billing process.
- Assess the feasibility of IoT technology in addressing these issues, focusing on the opportunity for improvement of data accuracy, reduced processing time, and cost savings compared to manual methods.
- The qualitative data obtained from the question-and-answer session will be topically analyzed to identify recurring items, patterns, and insights. These findings will inform the design and valuation of the proposed IoT-based utility management system.

3.4. Benchmarking

The justification for selecting Node-Red as the primary tool for developing the proposed modular and scalable IoT-based utility management system is based on thorough benchmarking analysis. Node-Red is a flow-oriented, freely available, open-source development environment, enabling a visual programming tool usually known for its flexibility, accessibility, and capability to integrate IoT devices efficiently. An evaluation of alternative widely used platforms, such as ThingsBoard and KaaIoT, was conducted to assess their compatibility with the operational needs of the 3 Towers Residences Apartment.

Table 2. Comparative analysis: node-red and selected platforms

Features	Node-Red	Things Board	KaaIoT
Ease of Use	Drag-and-drop interface, suitable for rapid prototyping	Moderately intuitive but requires domain knowledge	Moderate, CLI-heavy setup requires expertise
Modularity	Highly modular with custom node development	It supports custom widgets but is less modular than Node-Red	Modular but more focused on device management
Integration	Extensive library of prebuilt nodes for IoT, cloud, and APIs	Pre-integrated support for IoT and dashboards	Focused on device and data management integrations

Scalability	Suitable for small to medium deployments	Scalable for large-scale deployments	Designed for enterprise-scale IoT systems
Customizability	Highly customizable with JavaScript	Customizable but requires coding knowledge	Customizable for enterprise applications
Learning Curve	Low, easy for beginners to grasp	Moderate; requires familiarity with IoT concepts	Steeper, tailored for advanced IoT developers
Community Support	Strong open-source community and active development	Moderate; enterprise focused	Moderate; enterprise focused
Cost	Free and open-source	Free for community edition; enterprise licenses available	Open source with paid professional services

3.4.1. Node-RED Selection Justification

Node-RED was selected for its open source, user-friendly interface, flexible configuration, and modular structure attributes that align with the operational scale and intricacy of the 3Towers Residences Apartment.

Although other platforms, for instance, those built for enterprise-level deployments, may offer more extensive scalability, their inherent complexity and greater operational demands were inconsistent with the project's current scope. The ability of Node-RED to interface with Modbus RS-485 smart meters, coupled with the active support from its user community, further strengthens its suitability for the proposed realization.

3.5. Future Considerations

As operational requirements evolve, it may become beneficial to integrate Node-RED with stronger platforms like ThingsBoard or Cloud-based services, such as AWS IoT, Azure IoT Hub, or Odoo IoT. Such a hybrid approach could combine the local data processing strengths of Node-RED with the cloud's capacity for large-scale expansion, offering both elasticity and performance for future system enhancement.

3.6. Design Evaluation

This stage's objective is to conceptually assess the feasibility, reliability, and operational appropriateness of the proposed IoT architecture for automating the recording of utility data.

The focus lies in evaluating the system's ability to consistently capture accurate readings, uphold data integrity, and prepare output formats suitable for integration into financial workflows. The evaluation is conducted at a theoretical level to confirm alignment with the operational environment of 3Towers Residences Apartment.

3.6.1. Evaluation Objectives

Rather than engaging in tangible implementation or prototype testing, this evaluation adopts a conceptual validation strategy. It focuses on verifying that the proposed architecture reflects industry standard approaches and is anticipated to function effectively under a standard utility management context.

3.6.2. Evaluation Methodology

Since the IoT system has not yet been deployed in a live setting, the evaluation is based on analytical and theoretical techniques. These include critical comparisons with similar implementations found in academic literature, adherence to recognized best practices and IoT deployment standards, and reasoned projection from the system's defined specifications. The evaluation focuses on several main performance dimensions critical to IoT-based utility systems, including:

1. Reliability of Data Collection
2. Data Integrity and Address Mapping
3. Network Stability and Efficiency
4. Scalability and Expandability
5. Data/Billing Handoff Compatibility
6. Focus Group Discussion (FGD) Evaluation Indicators

3.6.3. Expected Outcomes

The intended result of this conceptual assessment is to determine whether the proposed IoT system design can theoretically fulfil operational demands related to utility management at 3Towers Residences Apartment. These include the system's ability to Ensure consistent and accurate data capture through smart meter integration, Maintain data integrity via robust address mapping and transmission protocols, operate efficiently under local network constraints, Offer modular scalability for future expansion, Support seamless integration with billing systems; Align with stakeholder expectations as indicated in FGD sessions.

4. Results and Discussion

4.1. Data Analysis

The analysis process integrated qualitative and quantitative data from the 3 Towers Residences Apartment complex to identify issues, potential inefficiencies, and specific requirements for implementing an IoT-based utility recording. This analysis provides a clear rationale for the IoT solution, highlighting expected accuracy, efficiency, and scalability improvements.

4.1.1. Quantitative Data Analysis

Data collected in number form, particularly on building infrastructure, utility demands, and the time required for manual data collection, provided critical insights into the scale and technical requirements of the proposed system.

Scale and Complexity of Utility Monitoring

- A total of 379 units across three towers (Tower-1: 126 units; Tower-2: 103 units; Tower-3: 150 units) and each unit having varying power needs (1BedRoom (1BR) = 4400-watts, 2BR = 5500-watts, 3BR = 7700-watts), the data reveals the complexity and scale of utility monitoring. The IoT-based solution must be capable of handling data from multiple units simultaneously while ensuring accuracy across diverse unit configurations.
- This complexity supports the need for an automated, high-capacity system that can consistently capture and process large volumes of data. The IoT system design will incorporate scalable features to accommodate the varying power requirements and high number of data points.
- The space in the electrical panel box is minimal, and it is impossible to install 1 Modbus 1 smart meter; therefore, the design approach to having multiple smart meter devices for a single node is very appropriate and cost-effective for budget constraints.
- The distance from the server or control room to the longest switch hub panel is Tower-1, which is approximately more than 150 meters. It is recommended that fibre-optic cables between hubs be used to minimize latency.

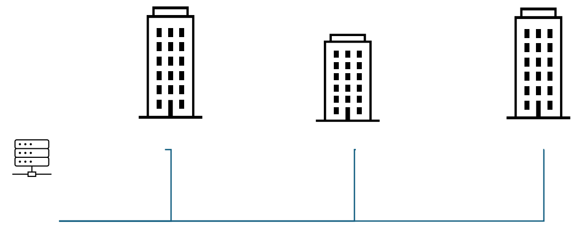


Fig. 3 The cable length from the server room to the switch hub panel is more than 150 meters

Current Process Inefficiencies

- The current manual utility recording process, which requires 5 business days per billing cycle, demonstrated significant inefficiencies in time and labour. An engineer spends extensive hours collecting and compiling data manually, which delays billing and increases operational costs.

- This inefficiency highlights the need for automation. An IoT-based solution can reduce the time required for utility recording from days to hours, enabling more timely billing and reducing labour costs. This finding directly supports the solution's primary objective of operational efficiency.

Table 3. Utility meter manual recording time

No	Department	Roles	Activities	Time (min.)
1	Engineering	Engineer	Waiting for the elevator on each floor	78
2	Engineering	Engineer	Record and snapshot	300
3	Engineering	Engineer	Data entry and uploading pictures	300
4	Engineering	Supervisor	Verification	125
5	Engineering	Chief Engineering	Approving	125
6	Finance	Billing	Data entry into the billing system	150
7	Finance	Supervisor	Approving	125
Total minutes of activity for one Building				1,203
Total minutes for three buildings				3,609

Engineering time consumption	Finance time consumption
2784 minutes	825 minutes
5.8 Business Day	1.72 Business Day
5 Days: 6 Hours: 24 minutes	1 Day: 5 Hours: 45 minutes

Baseline for Accuracy Improvements

- The manual process also poses a high risk of human error in data entry, as engineers need to record data from each unit individually. This increases the likelihood of utility billing inaccuracies, affecting residents and building management.

- Automating data collection with smart meters integrated via Modbus RS-485 protocols will minimize human intervention, reduce the potential for error, and ensure greater data accuracy to align with the building management's goal of providing reliable, error-free utility billing.

4.1.2. Qualitative Data Analysis

The qualitative Insight gathered from stakeholders provides a contextual understanding of the operational and strategic requirements for the proposed IoT solution. Additionally, they highlight potential constraints that must be considered in the system's design and implementation. Key qualitative factors include:

- Stakeholder Requirements for Automation and Real-time Monitoring – identifying the expectations of building management and engineering teams regarding automated utility data collection and real-time system visibility.

- Budget Constraints and Open-Source Solution-Evaluating financial limitations and the feasibility of adopting cost-effective, open-source technologies for system deployment.
- Prototype Validation requirement-Understanding the key performance criteria and stakeholder expectations for a future prototype demonstration before full-scale implementation.

4.1.3. Summary of Data Analysis

The analysis of both qualitative and quantitative data emphasizes the need for an IoT-based utility recording system that:

- Scalable: Capable of handling the complex infrastructure of a large apartment complex with diverse utility needs.
- Efficient: Design to significantly reduce the time and labour required for data collection, addressing current process inefficiencies.
- Accurate: Eliminates manual input processes, ensures accurate data, and consistent utility billing.
- Cost-effective: The Adoption of the proposed open-source software platform and modular device components tends to reduce costs, aligning with the financial constraints of non-profit residential management.
- Prototype test: Small-scale implementation allows for assessing the system's functionality. Build stakeholder confidence before actual implementation.

These insights reinforce the relevance of the proposed IoT-based model and demonstrate its capacity to address utility operational challenges that align with stakeholder expectations.

4.1.4. Error Analysis in Manual Utility Recording

Manual utility recording is error-prone because it relies on handwritten notes and static data between the engineering and finance teams. This compromises the accuracy and consistency of billing, often leading to tenant complaints. Two main categories of errors have been identified based on qualitative observation and feedback from stakeholders:

Typographical Error in Data Recording

Handwriting ambiguities frequently lead to misinterpretation during transcription from paper to spreadsheet. Commonly observed issues:

- Similar shapes often confuse digits such as 4 and 9, 3 and 5, 0 and 8, and 9. Similarly, 1 and 7 may overlap depending on individual handwriting styles.
- For the 379 apartment units, at least two numeric values (electricity and water) must be recorded manually, resulting in 758 entries per billing cycle. Even a conservative typographical error rate of 1% can lead to 7-8 errors per cycle.

Static Data Errors

Discrepancies between the engineering team's static data and the finance team's wattage of each unit are another common issue. These errors occur due to inconsistent data-sharing methods and processes. Approximately 5% of units (around 19 apartment units) experience data mismatches each billing cycle, leading to potential inaccuracies in utility bills.

Tenant Complaints Due to Billing Errors

Errors in utility data frequently lead to tenant complaints to the Tenant Relations team. One recurring issue involves discrepancies where empty units are recorded as having electricity consumption.

These errors often stem from mismatches in data or misinterpretation during manual entry, frustrating residents and undermining trust in the billing process. Such incidents can escalate tenant dissatisfaction, resulting in reputational risks for building management.

4.2. Design of the IoT-Based Solution

The IoT-based utility recording solution design for 3 Towers Residences Apartment builds on the data collection and analysis findings, addressing the key challenges identified in the existing manual process. The proposed design aims to automate utility data collection, enhance data accuracy, reduce manual intervention, and provide real-time monitoring capabilities.

This section outlines the solution's architecture, components, and expected functionality. The IoT framework is organized into multiple layers, each handling a specific part of the data collection, transmission, processing, and handoff workflow. This layered approach ensures a systematic data flow from utility meters to the final billing file handoff.

1st Layer: Data Collection

The existing utility meter remains in place and serves as the power source for the digital smart meter. In this configuration, the existing meter not only provides power but also functions as a redundant backup in case of smart meter failure, and it enables parallel monitoring during the initial three-month period to assess accuracy and measure tolerance gaps between the two meters.

2nd Layer: Data Transmission (Gateway)

The Modbus RS-485 to Ethernet converter is a gateway translating data from smart meters using the RS-485 protocol into Ethernet format. This conversion enables seamless integration with the building's network infrastructure, ensuring compatibility and efficient data transmission. Unlike traditional one-to-one Modbus to smart meter configurations, this study defines a modular IoT system as a single Modbus network capable of integrating up to 30 smart meters. This approach enhances efficiency, minimizes hardware costs, and supports a more scalable IoT infrastructure.

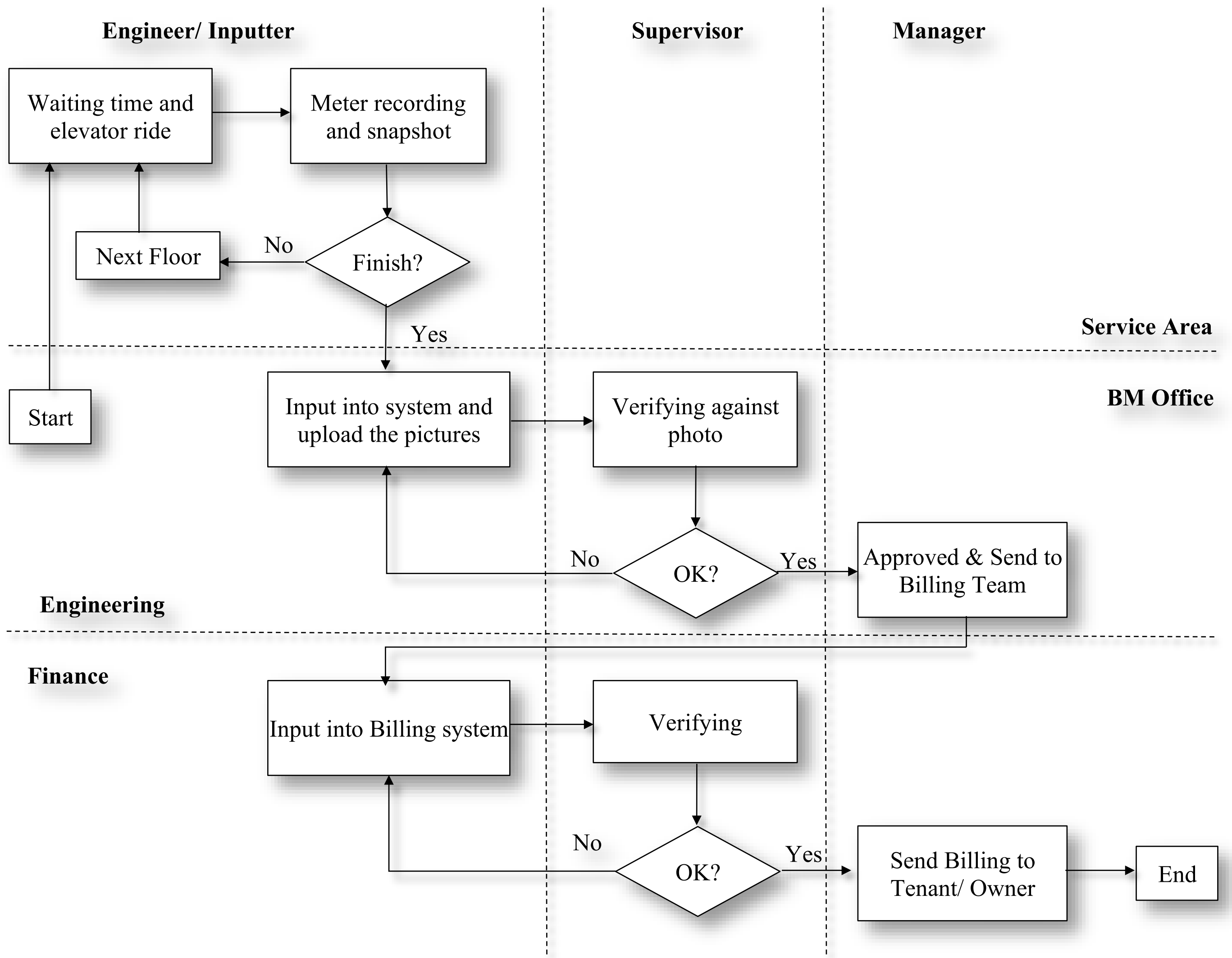


Fig. 4 Current manual workflow utility recording (As-Is)

3rd Layer: Switch Hub Management

The switching hub is a pivotal networking device, linking various Ethernet cables from the Modbus converter to the leading network.

Each tower's smart meter communicates through this switch, allowing organized data flow within the IoT environment.

Network administrators gain better control by employing a managed switch, such as turning off unused ports to eliminate unauthorised access and maintain system integrity.

4th Layer: Transition from LAN to SFP Interface

The system connects the local network to the central server using high-capacity links at this stage. Standard Ethernet cable typically cannot transmit reliably beyond 100 meters. To answer this limitation, SFP modules are an alternative, allowing the network to cover greater distances for without compromising signal quality. This setup helps ensure that faraway devices and server communication remain steady and efficient, even when a large physical gap exists.

5th Layer: SFP to Server

The Small Form-factor Pluggable (SFP) interface establishes the primary data connection to the central server, handling all smart meter data transmissions across the building.

SFP technology is crucial for maintaining consistent, high-speed connectivity, especially the 150+ meter separation between Tower-1 and the server room (situated in Tower-3's basement level).

The fibre optic capability of SFP technology effectively minimizes transmission delays while improving connection stability across extended distances.

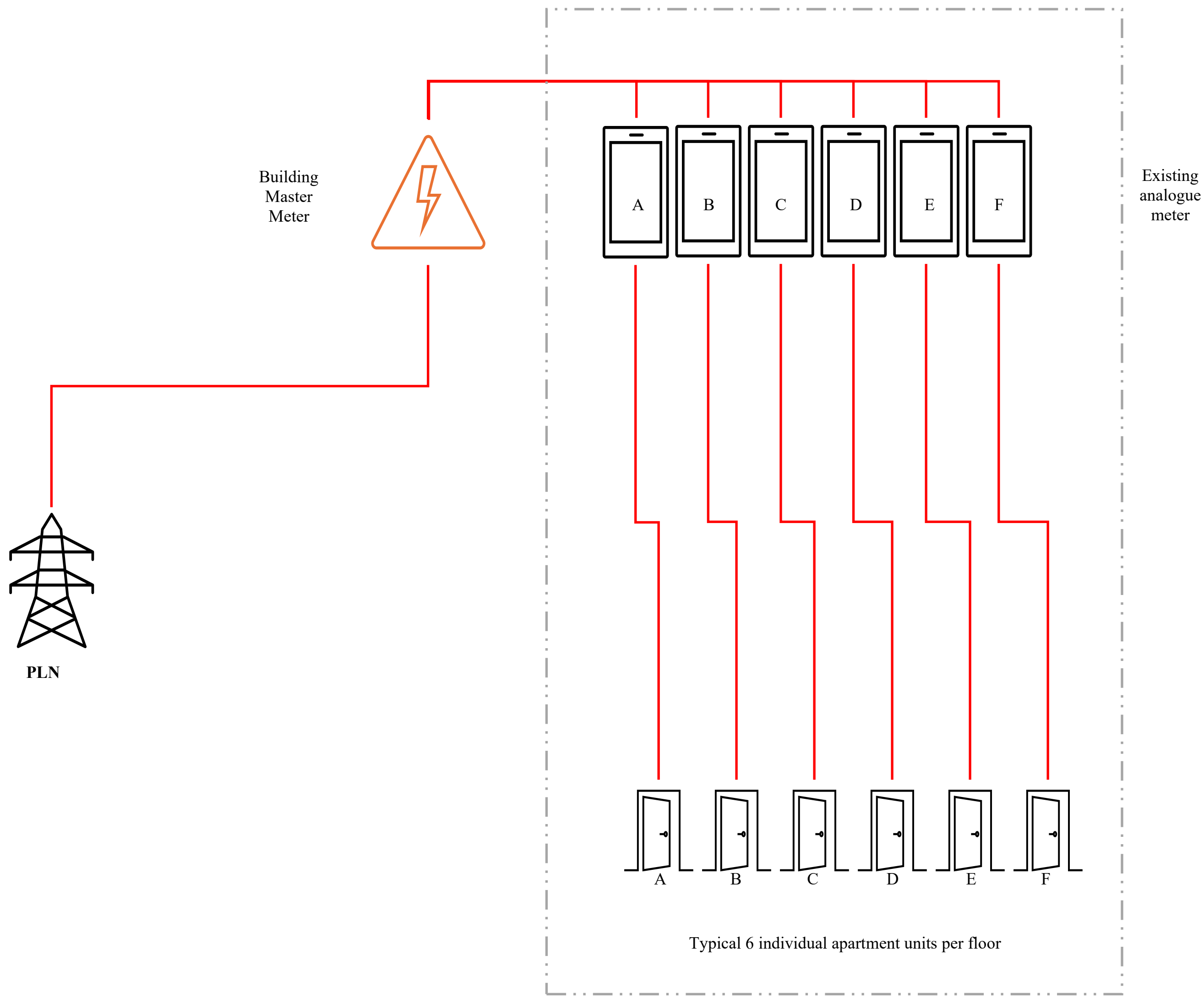


Fig. 5 Existing power grid to individual apartment unit

6th Layer: Data Processing

After being communicated from the smart meters, the incoming data is targeted to the central server, where it gets checked for missing or unusual values. After that, the system totals the usage and performs the necessary calculations to prepare the billing details. Some of the older data is kept, mainly so it can be looked back on later if questions arise. What matters most here is that the information passed on is clean and ready to use when it is time to generate the bills.

7th Layer: Monitoring and Analytics

Node-Red is used by the engineering team to monitor utility readings as they come in. The interface is visual and relatively easy to use, which makes it practical even for staff without a strong technical background. With this tool, they can check whether the data looks accurate before sending it to the finance team. Node-Red also helps them follow consumption trends and notice if something goes wrong, like an unusual spike in usage. An alert can be set up for such cases, depending on what the team wants to track. Since Node-Red is open-source, the building management does not need to pay for licenses, which keeps software costs low without compromising what the system can do.

8th Layer: Data Handoff

Once the data looks correct, the team usually saves it in a file format that works for the finance department, such as Excel (.xls, .xlsx, .csv) or just a text file (txt). There is no fixed format; it depends on what is easiest for them to open and use. The idea is to avoid extra steps so the data can be handed over without having to reformat anything manually.

The primary objective of this layer is to generate a structured, error-free file that the finance team can directly use for billing preparation. By standardizing the data handoff process, this layer enhances accuracy, minimizes manual adjustments, and ensures a smooth transition from data processing to financial operations.

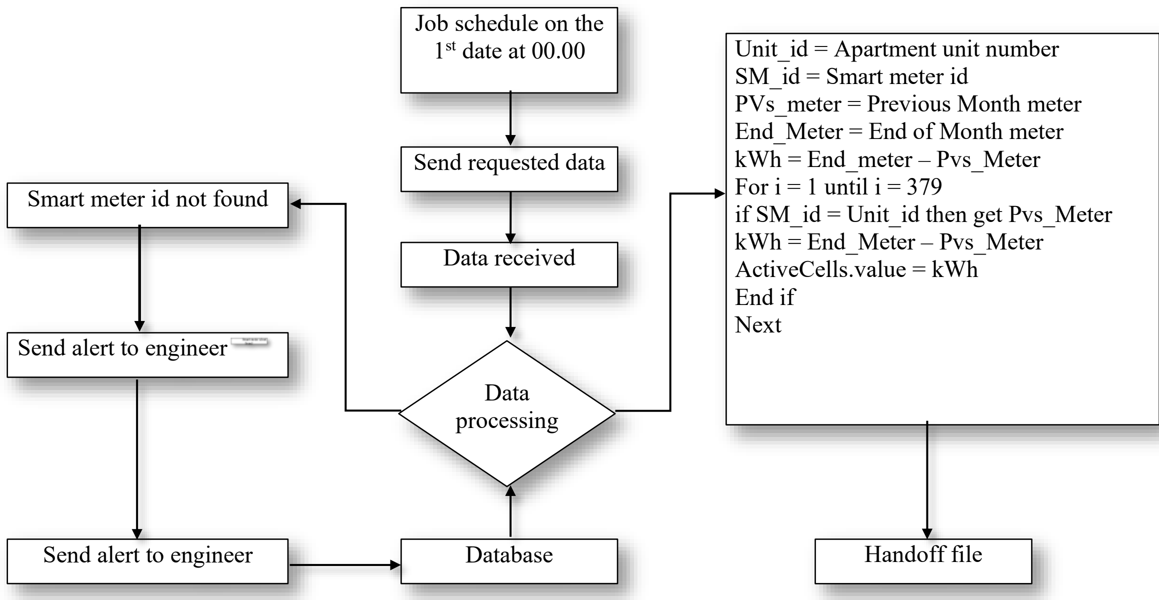


Fig. 6 Handoff file process flow

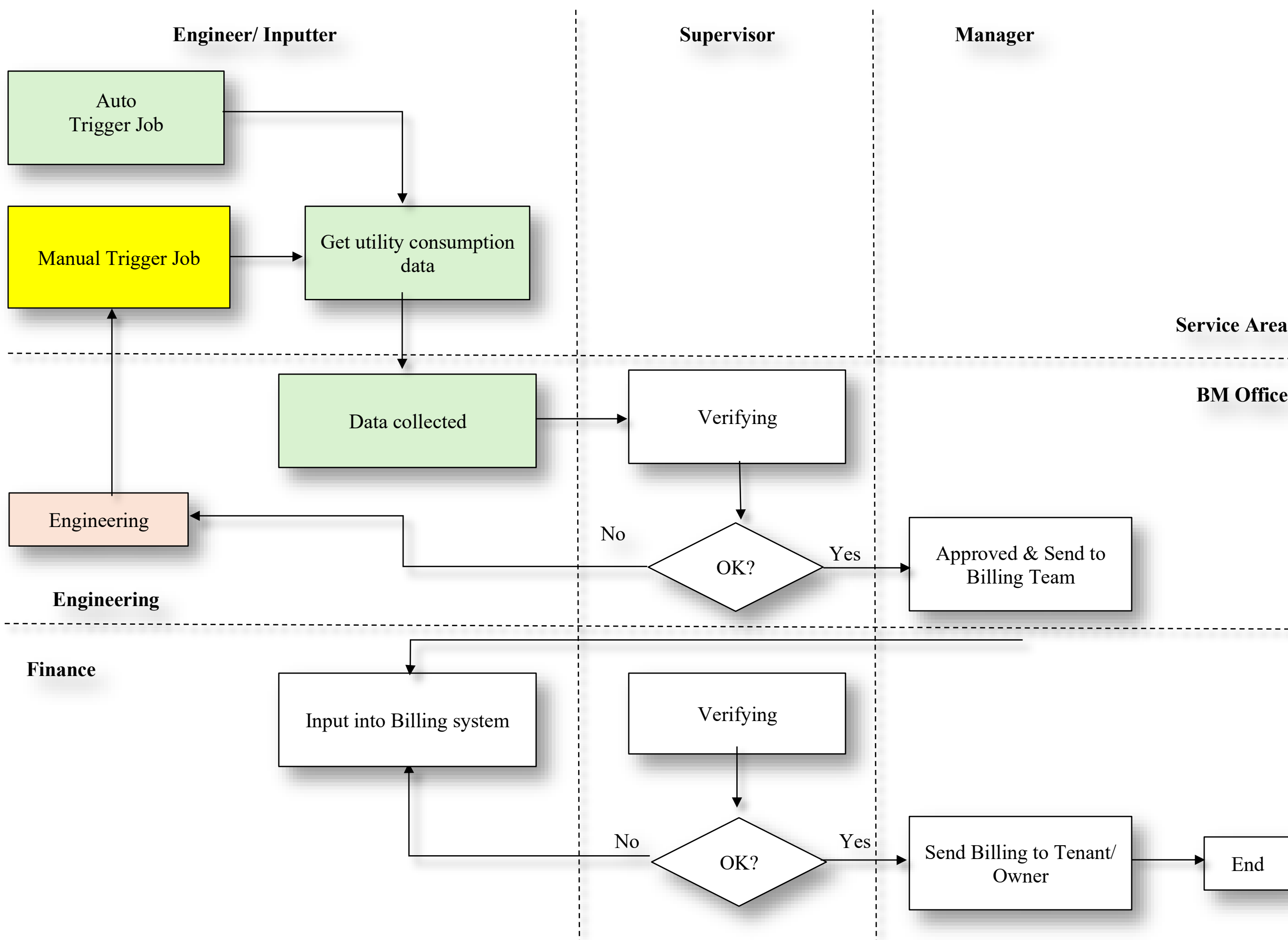


Fig. 7 Proposed IoT-based utility recording workflow (To-Be)

4.2.1. High-Level Architecture

The proposed IoT-based solution consists of several interconnected layers, each critical in capturing, transmitting, processing, and monitoring utility data. This high-level architecture ensures the solution's scalability, reliability, and accuracy.

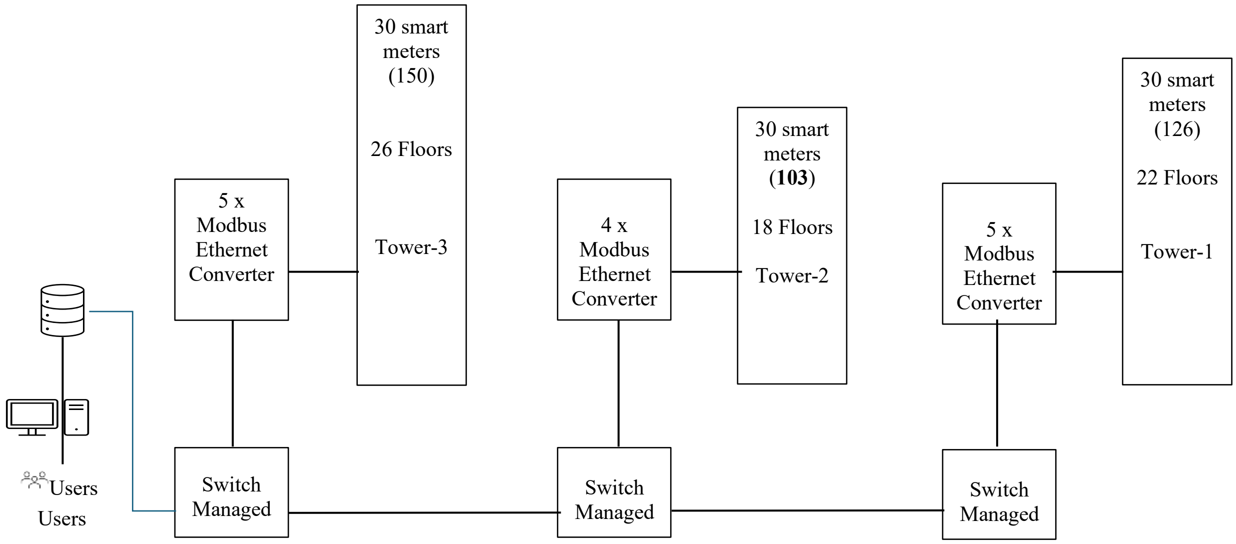


Fig. 8 High level IoT-based architecture

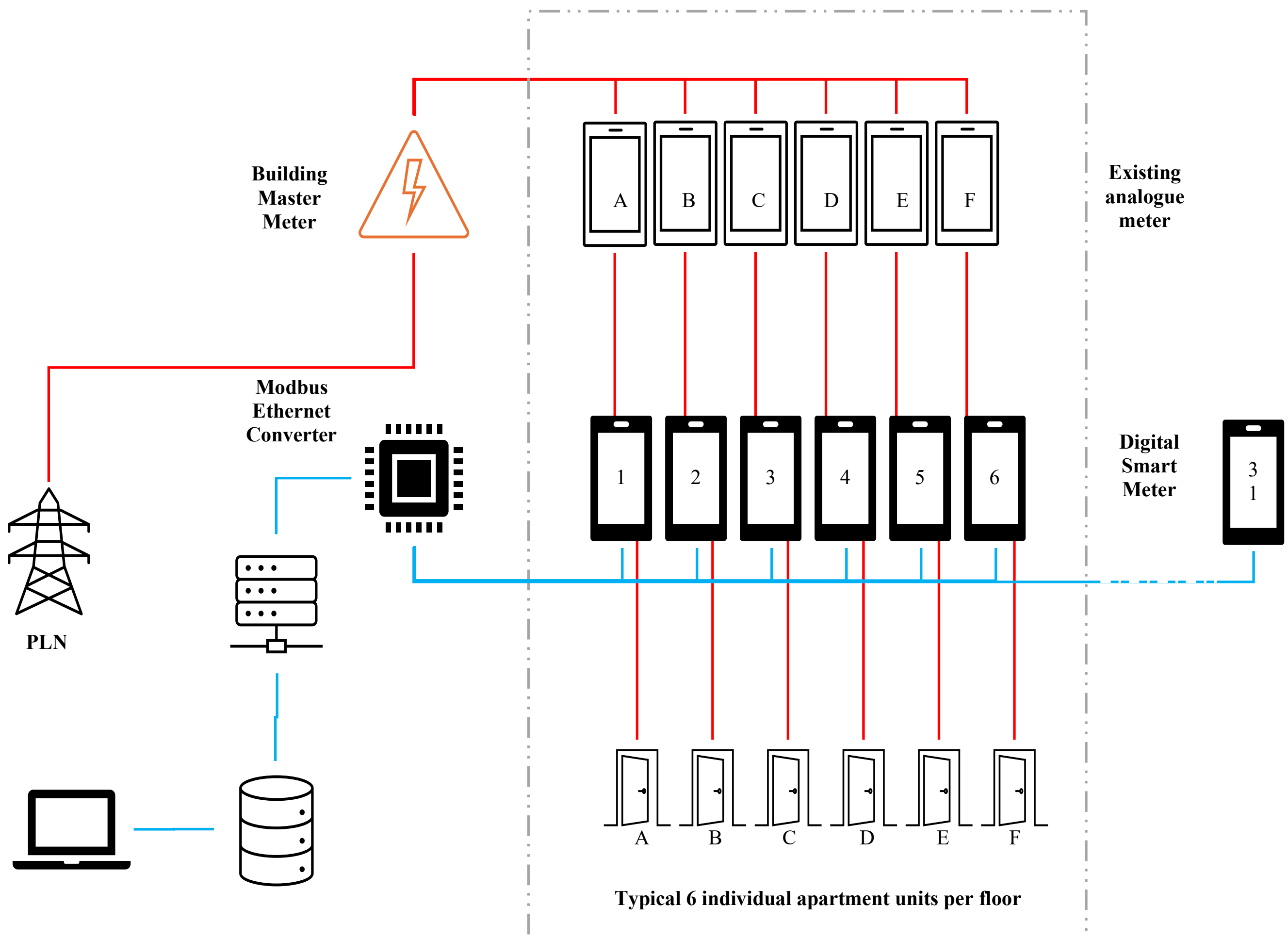


Fig. 9 After IoT-based solution

Data Collection Layer

This layer comprises digital smart meters installed on each floor in the same panel box as the existing analogue meter in the service area to capture real-time utility usage data.

Each existing panel box accommodates up to six smart meters without requiring structural modification or additional enclosures, making the solution space efficient and cost-effective for retrofitting in the existing electrical panel room.

Components

- Smart meters: 31 Thera TEM015XP-DS241 units (for the prototype) with potential scalability to cover all 379 apartment units.

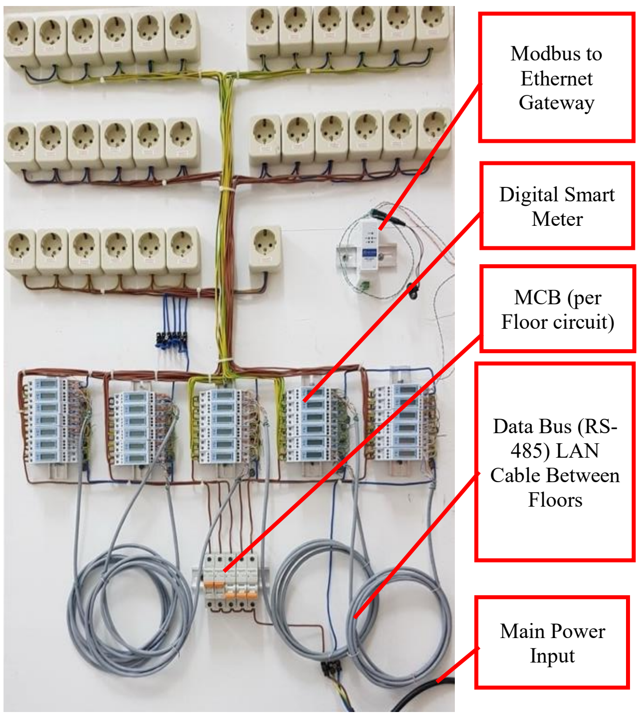


Fig. 10 Physical prototype setup illustrating the modular IoT-based smart meter system architecture using Modbus RS-485 communication for data collection

Naming Convention

- The identity of each smart meter is determined by its tower naming convention and represented by the respective apartment unit number.

  Format: T+F+U = Tower [1]+Floor [2]+Unit Type [2]
  Sample: Tower: 3; Floor: 23A; Unit Type: F
  Naming convention: 32406 (5 characters)

Table 4. Example of the naming convention in Tower 2

Unit / Floor	A	B	C	D	E	F
GF				20104		
2	20201	20202	20203	20204	20205	20206
3	20301	20302	20303	20304	20305	20306
3A	20401	20402	20403	20404	20405	20406
12A	21301	21302	21303	21304	21305	21306
12B	21401	21402	21403	21404	21405	21406
18	21801	21802	21803	21804	21805	21806

Data Transmission Layer

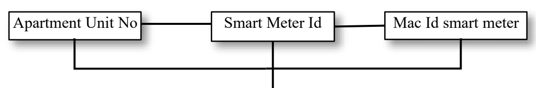
This layer promotes the communication of reliable data from the digital smart meters to the central processing system using Modbus RS-485 communication, which is converted to Ethernet for integration into the LAN network.

Component

- Modbus RS-485 Ethernet converter: USR-DR302 converters facilitate data transmission over the LAN network. This device is designed to be connected to 30 smart meters as a typical configuration for 5 floors (6 apartment units per floor).

Data Processing Layer

This layer consists of a central server that aggregates and processes data received from the smart meters.

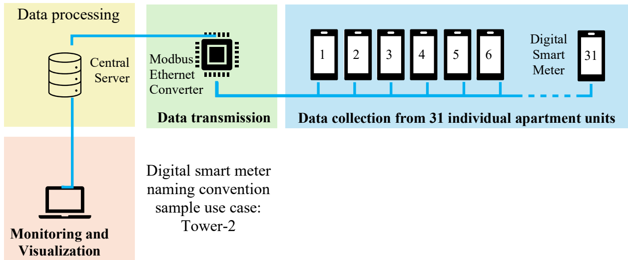


Floor	Unit #	Smart ID	Mac ID	Ampere (A)	Watts
GF	2.GF.D	20104	9C A5 26 95 BB BA	25	5500
2	2.02.D	20204	9C A5 27 95 BB BA	25	5500
3	2.03.D	20304	9C A5 28 95 BB BA	25	5500
3A	2.3A.D	20404	9C A5 29 95 BB BA	25	5500
12A	2.12A.D	21304	9C A5 23 95 BB BA	25	5500
12B	2.12B.D	21404	9C A5 24 95 BB BA	25	5500
18	2.18.D	21804	9C A5 25 95 BB BA	25	5500

Fig. 11 Static data for data processing

4.2.2. System Integration and Process Flow

The integration of the IoT components ensures a seamless flow of utility data from collection to processing and monitoring, enriching the overall productivity and accuracy of the utility recording method.



Unit / Floor	A	B	C	D	E	F
GF				20104		
2	20201	20202	20203	20204	20205	20206
3	20301	20302	20303	20304	20305	20306
3A	20401	20402	20403	20404	20405	20406
12A	21301	21302	21303	21304	21305	21306
12B	21401	21402	21403	21404	21405	21406
18	21801	21802	21803	21804	21805	21806

Fig. 12 System integration process flow

4.2.3. Use Case for IoT-based Utility Recording Solution

Table 5. Use case automated utility data recording and billing

Title: Automated Utility Data Recording and Billing	
Roles	**Description**
Resident	The end user consuming utilities
Smart meter	The device is installed in the same panel as the analogue meter to capture utility data consumption.
Modbus RS-485 to Ethernet converter	Device facilitating data transmission
Central Server	Aggregates and processes data
Engineering staff	Monitor data, detect issues, and manage system operations.
Finance Dept	User processed data for billing.

Table 6. Use case billing data verification

Title: Billing Data Verification	
Roles	**Description**
Smart Meter:	Smart meters capture usage data and transmit it to the central server.
Modbus RS-485 to Ethernet converter	Device Facilitating data transmission
Central Server	Aggregates and processes data
Engineering staff	In case of a dispute, engineering staff use historical data from the Node-Red platform for verification and reconciliation, ensuring billing accuracy and transparency.
Finance Dept	The finance department retrieves processed data for billing.

Table 7. Use case network communication monitoring

Title: Network Communication Monitoring	
Roles	**Description**
Smart Meter:	Smart meters capture usage data and transmit it to the central server.
Modbus RS-485 to Ethernet converter	Device Facilitating data transmission
Central Server	Aggregates and processes data The system continuously monitors data flow from smart meters to the central server.
Node-Red	The Node-Red system alerts the engineering staff if communication fails (e.g., cable disconnection).
Engineering staff	engineering staff to address the network issue.
Finance Dept	

Table 8. Use case: fault detection and alert notification

Title: Fault Detection and Alert Notification	
Roles	**Description**
Smart Meter:	The smart meter detects an anomaly or fault (e.g., sudden spikes in electricity usage or a communication failure).
Modbus RS-485 to Ethernet converter	The data is transmitted to the central server and processed.
Central Server	The system continuously monitors data flow from smart meters to the central server.
Node-Red	An alert is automatically generated on the Node-RED dashboard for engineering staff.
Engineering staff	Engineering staff investigate and resolve the issue, ensuring the system resumes regular operation.
Finance Dept	

Scenario
Normal Flow

- Resident Uses Utility Services: Utility consumption (e.g., electricity) occurs within the apartment unit.
- Smart Meter Captures Data: The smart meter records Real-time utility usage data.

- Data Transmission: The recorded data is transmitted via Modbus/RS-485 communication, converted to Ethernet, and sent to the central server over the LAN network.
- Data Processing: The central server receives and processes the data, storing it in a structured format for further analysis.
- Monitoring and Visualization: The data is displayed on the Node-RED platform, allowing engineering staff to monitor usage and detect anomalies.
- Billing Preparation: The processed data is compiled into a format (e.g., .csv, .xlsx) compatible
- The finance department's billing system streamlines the billing process.
- Bill Issuance: The finance department generates and issues accurate utility bills based on the processed data.

Alternate Flow (Data Transmission Issue)

1. Data Disruption Detected: If a smart meter fails to transmit data, the system generates an alert on the Node-RED dashboard.
2. Engineering Staff Responds: The staff investigates the issue, resolves the disruption (e.g., checking device connections), and resumes standard data transmission.

Expected Outcome

- Improved productivity: By removing manual data recording, the time spent monitoring utilities is reduced from several days to a few hours. Expected to free up resources and reduce operational delays.
- Better Accuracy: Human errors, particularly during manual input and calculations, are expected to decrease as automated data acquisition becomes the new standard.
- Concurrent Oversight: The engineering team will have access to current usage information as it happens and live monitoring capability, allowing them to catch and respond to unusual patterns before they develop into larger issues.

4.2.4. Expected Benefits of the IoT-based Design

The proposed system is intended to answer practical issues revealed during the earlier phases of data analysis and stakeholder input:

1. Automation & Streamlined Workflow: Shifting routine tasks such as meter reading and data logging to an automated system reduces the manual work required and results in a more fluid overall process.
2. Reliable Readings: after the system takes over the data collection, values are expected to be consistent, eliminating discrepancies caused by manual error or oversight.
3. Live Monitoring: With dashboards running on Node-RED, engineers will not have to wait for periodic reports. They can view live data, allowing them to take preventive or corrective action quickly.
4. Modularity: The modular setup means the system is not locked into its prototype or current scale. It can be extended to support all 379 apartment units and other potential integration of additional devices (e.g., digital water meters).
5. Efficient Rollout: One of this design's strengths is that it uses affordable open-source technologies.

4.3. Design Evaluation Result

The assessment of this IoT-based solution relies on a conceptual structure involving a theoretical performance review and insights from stakeholder discussions.

This stage outlines the projected capabilities of the system in resolving utility tracking problems observed at 3Towers Residences Apartment.

4.3.1. Data Collection Reliability

Result: Conceptual evaluation shows that the system can consistently capture utility data from smart meters with minimal communication failure risk. Leveraging the Modbus protocol contributes to this reliability and stable data transmission.

Key Insight: the architecture is considered resilient and able to manage occasional device malfunctions without interrupting the broader data acquisition process, thus supporting stakeholders' expectation of uninterrupted monitoring.

4.3.2. Data Integrity and Address Mapping

Result: the mapping system proposed for linking data to specific units is conceptually comprehensive and ensures accuracy across all apartments.

Key Insight: This approach is consistent with industry and Modbus implementation standards. Stakeholders have expressed confidence in the system's capacity to deliver error-free records for billing and operational use.

4.3.3. Network Stability and Efficiency

Result: the evaluation of network stability and performance is done through theoretical analysis, drawing on known characteristics of Modbus communication combined with ethernet-based data transfer.

Based on the proposed architecture, the system is expected to support steady and continuous data transmission while keeping latency minimal.

Key Insight: The network was found to be capable of managing data from multiple units effectively, aligning with the operational requirements of the building. Stakeholders' feedback also emphasized the need for consistent network reliability to support real-time monitoring and preserve data accuracy.

4.3.4. Scalability and Expandability

Result: The modular structure of the IoT system makes it possible to scale up gradually, allow more devices to be added, and enable future expansion to all 379 residential units. The flexibility designs support the future integration of digital water flow meters and other IoT devices as needed.

Key Insight: Stakeholders highlighted the need for a scalable solution to ensure long-term viability. The proposed design, which can be adjusted with minimal network infrastructure change, aligns with this requirement and supports phased implementation.

4.3.4. Data/ Billing Handoff Compatibility

Result: The data processing and export capabilities of the IoT system, facilitated through Node-Red, enable data export in a standard format (e.g., .csv, .xlsx). This ensures compatibility with the finance department's existing billing processes.

Key Insight: Stakeholders emphasized the importance of streamlining data handoffs for billing. The proposed design fulfils this functional need by offering data outputs that are immediately usable, thereby cutting down the time typically spent on manual data formatting and preparation.

4.4. Focus Group Discussion (FGD) Result

In line with the research methods outlined earlier, a discussion session was organized to bring together individuals directly involved in daily operations, such as engineering staff, building supervisors, and technical professionals. The session focused on open dialogue around how the design might work in practice. The conversation explored not only the feasibility of the concept in the long term. Feedback was gathered based on evaluation points that had been agreed. Highlights from the discussion are outlined below:

4.4.1. Relevance and Strategic Fit

Feedback: The attendees generally agreed that the IoT-based system is a suitable solution for improving how utility data is recorded to enhance operational productivity while eliminating dependence on manual processes.

Result: The proposed model was viewed as appropriately targeted to answer existing issues and aligned with the broader operational goals of the building's management team.

4.4.2. Technical Feasibility and Future Expansion

Feedback: the attendees expressed that the solution could be incorporated into the current network and infrastructure without requiring extensive changes. Furthermore, they believed the system's design offers elasticity for scaling up.

Result: Based on the discussion, the system was considered technically workable and capable of supporting future expansion step-by-step.

4.4.3. Data Accuracy and Reliability

Feedback: Some stakeholders mentioned that the system could likely work with the existing setup in the building and that adding more units in the future would not be too difficult, especially if the expansion was planned in stages. They did raise a few technical concerns but found the design reasonable overall.

Result: The automated data capture approach was positively received to improve data reliability and accuracy.

4.4.4. Cost Effectiveness

Feedback: The use of open-source platforms and cost-efficient hardware was appreciated, though participants recommended a more detailed cost assessment for large-scale rollout.

Result: The solution was viewed as cost-effective if budget planning is managed carefully during implementation.

4.4.5.User Friendliness and Usability

Feedback: Engineering staff found the Node-Red dashboards intuitive and practical, focusing on potential improvements in daily operations.

Result: High usability with strong support for system adoption among engineering staff.

4.4.6. Integration Compatibility

Feedback: The ability of the system to integrate into existing workflows, including handoff to the finance department, was positively acknowledged.

Result: the design was validated for integration readiness, with no significant concerns raised regarding compatibility.

4.4.7. Live Monitoring and Proactive Supervision

Feedback: Stakeholders emphasized the value of live observing and the potential for proactive issue management and anomaly detection.

Result: Positive endorsement of the system's real-time data monitoring capabilities, aligning with operational goals.

4.4.8. Potential for Reducing Process Time

Feedback: Participants noted that the proposed system's projected reduced utility recording time would lead to significant operational efficiencies.

Result: Confirmation that the design would achieve substantial time savings, aligning with the study goals.

Feedback obtained during the FGD reflected a consensus that the IoT-based approach is both feasible in its design and well-suited to the operational context in which it would be applied. Stakeholders widely acknowledged the system's potential to improve operational efficiency, data accuracy, and real-time monitoring capabilities.

Recommendations for minor refinements were noted for future consideration, particularly regarding cost management and phased implementation strategies to ensure a smooth transition.

4.5. Discussion

4.5.1. Cost Reduction Analysis

The design of the IoT-based utility management system achieves a significant cost reduction, primarily by minimizing the manhours required for utility data collection. Engineering staff dedicate approximately 40 manhours per month to collect and verify utility data from 379 apartment units manually. With the proposed IoT-based system, this task is expected to require only 1 hour per month, resulting in a 97.5% reduction in manhours and significantly improving operational efficiency.

The percentage reduction in manhours is calculated as follows:

Equation (2) Manhours savings calculation,

$$\text{Manhours reduction\%} = \left(\frac{Current - proposed\ time}{current\ time}\right) x\ 100\% \quad (2)$$

Conversions= 5 days = 5 x 8 manhours = 40 hours

Expected manhours of the proposed system = 1 hour

$$= \left(\frac{40-1}{40}\right) x\ 100\% = \left(\frac{39}{40}\right) x\ 100\% = 97.5\%$$

4.5.2. Financial Impact

Assuming an hourly wage of Rp. 28,797. The estimated monthly savings in manhours reduction of direct labour costs can be quantified as follows:

Monthly Savings = (39 hours saved) x Rp. 28,797. = Rp. 1,123,083.

On an annual basis, the total savings would be:

Annual savings = 39 hours/month x Rp. 28,797 x 12 months

The annual savings would be equal to Rp. 13,476,996.

These savings demonstrate the financial viability and operational benefits of automating the utility recording process using an IoT-based system.

4.5.3. Additional Efficiency Gains

Beyond the direct labour cost reduction, the system provides further benefits:

- Reduction in Administrative Errors: automation minimizes manual entry errors, reducing the need for rework, complaint handling, and error correction.
- Reallocation of Resources: Saved time can be reallocated to higher-value activities such as maintenance, predictive analytics, or resident support, increasing overall operational productivity.

This cost reduction analysis highlights the financial viability and efficiency improvements brought by the IoT-based system, making it a strategic investment for 3 Towers Residences and similar residential properties.

4.5.4. IoT-based Success Metrics

Table 9. IoT-based success metrics

Metric	Current	Target	Method	Impact
Error Rate Reduction	5% errors per billing cycle	< 0.5% errors	Compare error rates before and after IoT implementation	Reduces billing disputes, improves trust, and enhances accuracy in utility billing.
Time Efficiency	5 Days for data processing	< 1 hour	Time tracking for manual workflows vs automated IoT processes	Accelerates bill generation, improving cash flow and service delivery timelines
Resident Satisfaction	Low due to manual inaccuracies	90% satisfaction rating	Conduct surveys and interviews	Enhances confidence in the billing process, fostering better relationships with residents
System uptime	No automated monitoring	99.95% uptime	Monitor system performance logs for downtime and service interruptions	Ensures consistent and reliable services, minimizing resident disruptions
Cost Efficiency	High labour and operational costs	Reduce costs by 30%	Compare the before and after implementation budgets	Frees up resources for other operational improvements, benefits all parties
Data Accuracy	Manual data is prone to inconsistencies and errors	100% data integrity	Audit IoT data flow for accuracy, completeness, and alignment with billing requirements	It improves confidence in billing, reduces manual errors, and enhances transparency for residents.

Energy Efficiency	No monitoring of system power usage	< 3% Increase in energy usage	Measure the IoT infrastructure's energy consumption after deployment	Ensures the system remains cost-effective and environmentally sustainable
Scalability	Manual system, limited capacity for expansion	Seamless integration of future devices	Conduct simulations with increased device load to evaluate system performance under expanded scenarios	Support property expansion and scalability while maintaining service quality
Process automation	Manual intervention in all steps	90% process automation	Measure reduction in manual tasks and reliance on the engineering team	Reduces workload on staff, allowing for focus on higher-value activities
Typographical errors	~ 1% per digit (7-8 errors)	< 0.1%	Compare manual vs IoT-based data	Eliminates manual entry errors, enhancing data integrity and trust
Data sync errors	~ 5% of units (19 units)	0%	Cross-check finance against engineering	Resolves mismatches in data, improving inter-departmental

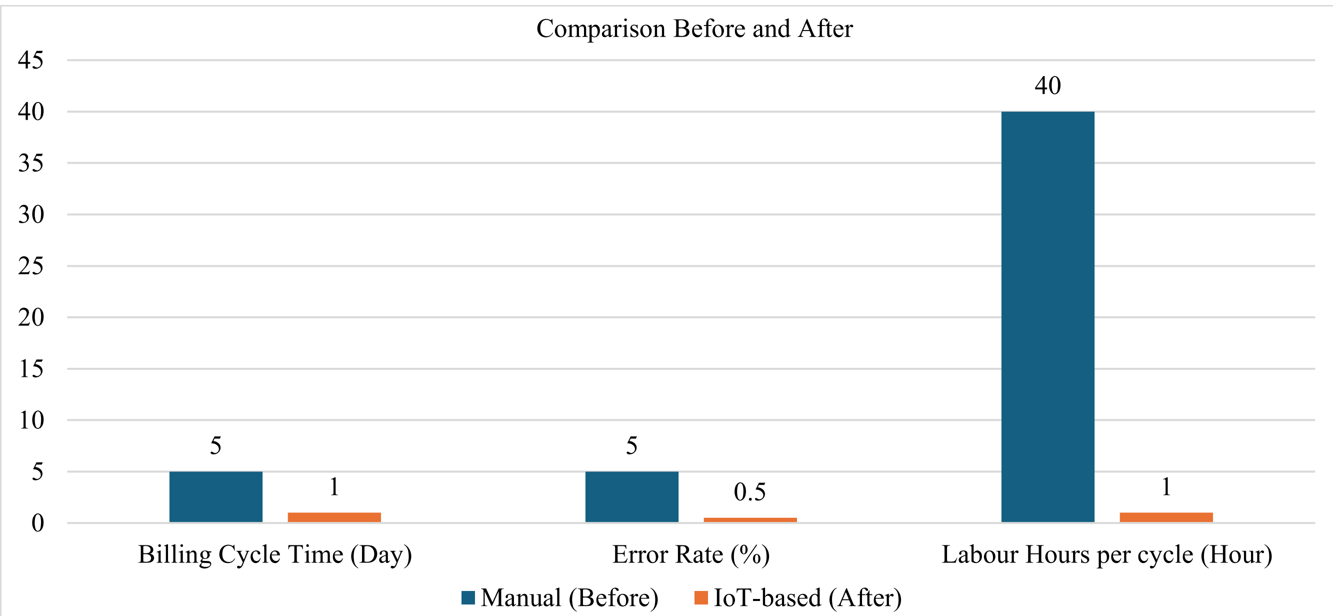


Fig. 13 Comparison chart before (As-Is) and after (To-Be) IoT-based utility system design

Table 10. IoT-based process transformation mapped to BPM objectives

BPM Objective	Manual Process (As-Is)	IoT-based Solution (To-Be)	Process Improvement
Reduce Process Time	Manual meter reading takes 5 more days to complete	Automated data captured within 1 hour with smart meters	Time savings of over 90% enable on-time billing
Improve data accuracy	Prone to human error during recording and transcription	Real-time digital measurement reduces transcription errors.	Accuracy significantly improved, reducing billing disputes
Enhance transparency and accountability	There is no audit trail, and handwritten logs can be manipulated or lost	Logged automatically with timestamps and user access traceability.	Enables auditability and stronger governance
Enable integration across departments.	Manual handoff to finance delays billing	Direct API/export to the finance system for faster invoicing	Shorter handoff time improves customer experience
Reduce operational cost	Requires multiple staff and repeated site visits	Remote capture reduces labor and travel costs	Cost-efficient and sustainable for long-term use
Enable scalability and future readiness	Limited by staff availability, not scalable	Single Modbus line supports 32 smart meters on one interface	Supports expansion with minimal infrastructure cost

4.5.5. Comparative Evaluation against Existing Literature

Numerous studies on IoT-based smart metering have focused on residential or industrial applications using Advanced Metering Infrastructure (AMI), which is typically configured for grid-to-home deployment and depends heavily on wireless infrastructure. This study proposes a building-level architecture using Modbus/ RS-485 capable of connecting up to 31 smart meters per node in a shared communication bus to reduce device-to-gateway costs.

Wireless AMI system requires multiple routers to transmit data across units or floors. In multi-storey apartments, this increases hardware costs, signal interference risks, and higher maintenance overheads. By adopting a wired topology with Modbus to Ethernet conversion, this study achieves greater connection stability, reduced latency, and simplified infrastructure, particularly in high vertical buildings such as 3 Towers Residences Apartment. From a business process perspective, existing literature largely overlooks the integration of utility data into organizational workflows.

Most smart metering systems focus on sensor deployment and dashboard visualization without addressing the billing preparation process, handoff between departments, or workflow automation. This study distinguishes itself by embedding IoT-based data acquisition directly into a BPM-aligned model that enables real-time tracking, automatic report generation, and timely delivery of billing files from the engineering to the finance team.

Table 11. Summary of comparison against the previous study

Feature	Prior Studies	This Study
Target Infrastructure	Standalone houses or industrial units	High-rise apartment complex
Communication Protocol	WiFi, LoRa, Zigbee	Modbus (RS-485)
Architecture Type	Individual unit connections	Shared node per 31-unit meters
Deployment Model	Grid to home	Panel to unit, building internal
Business Process Integration	Not included	Embedded in BPM handoff flow
Hardware Cost	High (routers, multiple gateways)	Low (shared Modbus line)
Space Efficiency	It needs a new panel or enclosure	Uses existing MCB panel space
Result Orientation	Monitoring and Visualization	Process optimization and billing automation

5. Conclusion

This study presents the conceptual design of a modular and scalable IoT-based utility management system for 3 Towers Residences Apartment. Positioned within the Business Process Management (BPM) domain, the research emphasizes the systematic improvement of utility workflows through digital transformation. The proposed architecture integrates smart meters, Modbus/RS-485 communication, and constrained spaces. The system allows up to six smart meters to be installed in existing MCB panel boxes, eliminating the need for additional enclosures. A prototype comprising 31 smart meters has been installed in the engineering room, demonstrating the feasibility of the hardware layout and cabling topology. However, full system integration and real-time data testing have not yet been completed, primarily due to limited internal engineer capacity and the absence of a formal engagement with an implementation vendor. As such, the project is currently on hold pending the appointment of a qualified partner.

Despite limitations, the design remains valid as a design science output and has been positively evaluated through stakeholder discussions. Process analysis revealed inefficiencies in the manual utility recording workflow, particularly in billing delays, error-prone data entry, and limited transparency or coordination between engineering and finance teams. Its modularity also allows for replication across other residential properties with similar challenges. This research gives insight into the field of BPM by demonstrating how IoT technologies can be embedded within operational processes to enhance efficiency, accountability, and service quality in property management. Moving forward, successful implementation will depend on phased deployment, vendor coordination, and change management strategies to ensure long-term adaptation and impact.

Authors' Contribution

First Author (Corresponding Author): Gunarto Wibisono

- Conducted a comprehensive investigation into the existing utility usage recording processes at 3 Towers Residences Apartment.
- Designed a modular and scalable IoT-based system for automated utility data recording, ensuring timely data acquisition at the beginning of each month.
- Analyzed the impact of the proposed IoT automation system on operational efficiency and evaluated potential improvements in the utility management workflow.
- Drafted and refined the manuscript to align with academic and publication standards.

Second Author: Ahmad Nurul Fajar

- Provided academic supervision and strategic guidance throughout the research process.
- Offered constructive feedback on system design, research methodology, and data interpretation.

- Reviewed the manuscript and provided critical insights to enhance the final paper's clarity, coherence, and scholarly quality.
- Provide input on the selection of an appropriate title.

Data Repository

Mendeley Repository Open Datasets https://data.mendeley.com/datasets/298hjrz9cm/1 DOI: https://doi.org/10.17632/298hjrz9cm.1

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Appendix

(a) Additional Data

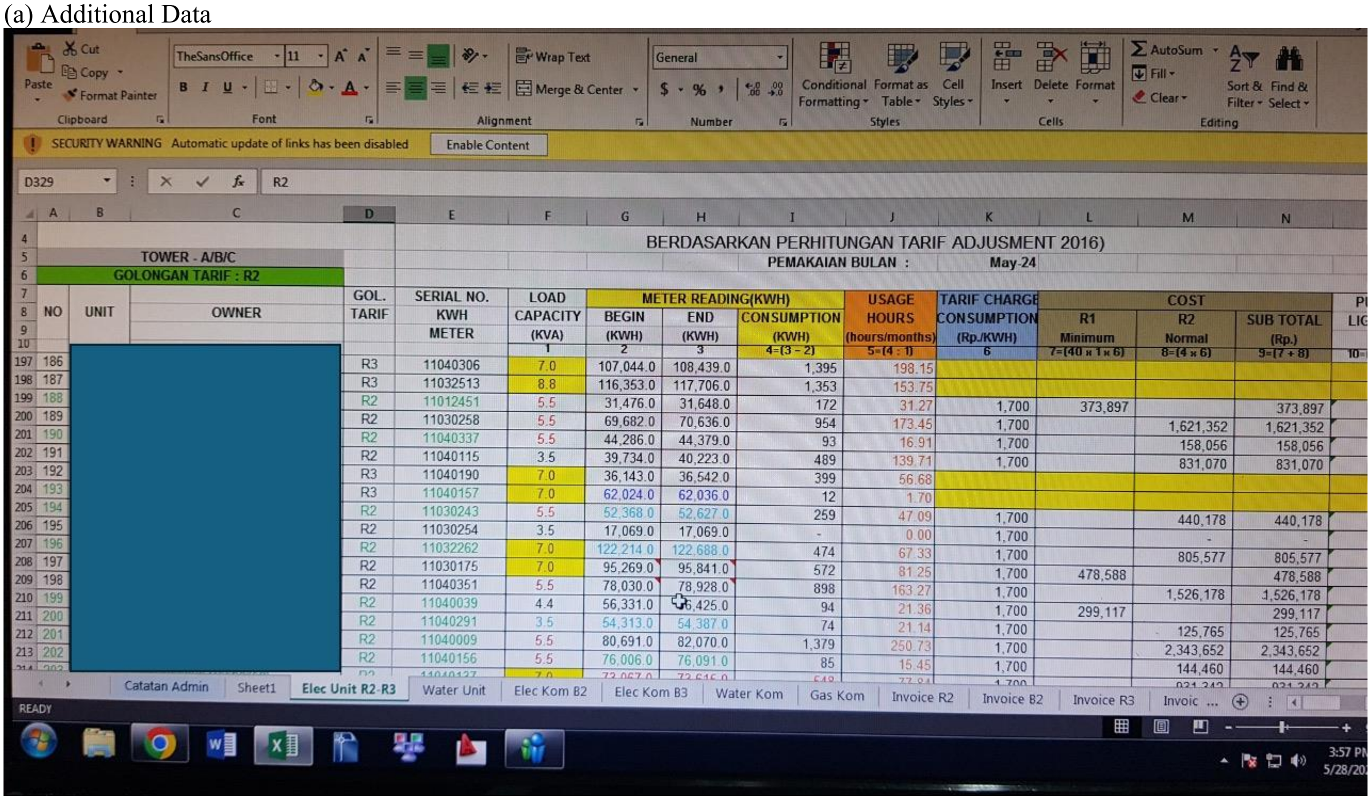

Fig. 14 A snapshot of a spreadsheet for utility consumption each month

Fig. 15 Monthly distribution of billing emails from the building management office to tenants

Sender	Date Received	Subject	Expected Received date
dept.****@gmail.com	4-Jun-2024	Informasi Tagihan Periode / Information Monthly Invoice JUNI 2024	1-Jun-2024
dept.****@gmail.com	3-May-2024	Informasi Tagihan Periode / Information Monthly Invoice MEI 2024	1-May-2024
dept.****@gmail.com	4-Apr-2024	Informasi Tagihan Periode / Information Monthly Invoice APRIL 2024	1-Apr-2024
dept.****@gmail.com	4-Mar-2024	Informasi Tagihan Periode / Information Monthly Invoice MARET 2024	1-Mar-2024
dept.****@gmail.com	2-Feb-2024	Informasi Tagihan Periode / Information Monthly Invoice FEBRUARI 2024	1-Feb-2024
dept.****@gmail.com	4-Jan-2024	Informasi Tagihan Periode / Information Monthly Invoice JANUARI 2024	1-Jan-2024
dept.****@gmail.com	5-Dec-2023	Informasi Tagihan Periode / Information Monthly Invoice DESEMBER 2023	1-Dec-2023
dept.****@gmail.com	3-Nov-2023	Informasi Tagihan Periode / Information Monthly Invoice NOVEMBER 2023	1-Nov-2023
dept.****@gmail.com	5-Oct-2023	Informasi Tagihan Periode / Information Monthly Invoice OKTOBER 2023	1-Oct-2023
dept.****@gmail.com	4-Sep-2023	Informasi Tagihan Periode / Information Monthly Invoice SEPTEMBER 2023	1-Sep-2023
dept.****@gmail.com	2-Aug-2023	Informasi Tagihan Periode / Information Monthly Invoice AGUSTUS 2023	1-Aug-2023
dept.****@gmail.com	4-Jul-2023	Informasi Tagihan Periode / Information Monthly Invoice JULI 2023	1-Jul-2023
dept.****@gmail.com	6-Jun-2023	Informasi Tagihan Periode / Information Monthly Invoice JUNI 2023	1-Jun-2023
dept.****@gmail.com	4-May-2023	Informasi Tagihan Periode / Information Monthly Invoice MEI 2023	1-May-2023
dept.****@gmail.com	5-Apr-2023	Informasi Tagihan Periode / Information Monthly Invoice APRIL 2023	1-Apr-2023
dept.****@gmail.com	7-Mar-2023	Informasi Tagihan Periode / Information Monthly Invoice MARET 2023	1-Mar-2023
dept.****@gmail.com	3-Mar-2023	Informasi Tagihan Periode / Information Monthly Invoice FEBRUARI 2023	1-Mar-2023
dept.****@gmail.com	3-Jan-2023	Informasi Tagihan Periode / Information Monthly Invoice JANUARI 2023	1-Jan-2023
dept.****@gmail.com	5-Dec-2022	Informasi Tagihan Periode / Information Monthly Invoice DESEMBER 2022	1-Dec-2022
dept.****@gmail.com	3-Nov-2022	Informasi Tagihan Periode / Information Monthly Invoice NOVEMBER 2022	1-Nov-2022
dept.****@gmail.com	4-Oct-2022	Informasi Tagihan Periode / Information Monthly Invoice OKTOBER 2022	1-Oct-2022
dept.****@gmail.com	3-Sep-2022	Informasi Tagihan Periode / Information Monthly Invoice SEPTEMBER 2022	1-Sep-2022
dept.****@gmail.com	3-Aug-2022	Informasi Tagihan Periode / Information Monthly Invoice AGUSTUS 2022	1-Aug-2022
dept.****@gmail.com	5-Jul-2022	Informasi Tagihan Periode / Information Monthly Invoice JULI 2022	1-Jul-2022
dept.****@gmail.com	4-Jun-2022	Informasi Tagihan Periode / Information Monthly Invoice JUNI 2022	1-Jun-2022
dept.****@gmail.com	5-Aug-2021	Informasi Tagihan Periode / Information Monthly Invoice JULI 2021	1-Aug-2021
dept.****@gmail.com	2-Aug-2021	Informasi Tagihan Periode / Information Monthly Invoice AGUSTUS 2021	1-Aug-2021
dept.****@gmail.com	4-Jun-2021	Informasi Tagihan Periode / Information Monthly Invoice JUNI 2021	1-Jun-2021
dept.****@gmail.com	6-May-2021	Informasi Tagihan Periode / Information Monthly Invoice MEI 2021	1-May-2021
dept.****@gmail.com	6-Apr-2021	Informasi Tagihan Periode / Information Monthly Invoice APRIL 2021	1-Apr-2021
dept.****@gmail.com	4-Mar-2021	Informasi Tagihan Periode / Information Monthly Invoice MARET 2021	1-Mar-2021
dept.****@gmail.com	4-Feb-2021	Informasi Tagihan Periode / Information Monthly Invoice FEBRUARI 2021	1-Feb-2021
dept.****@gmail.com	6-Jan-2021	Informasi Tagihan Periode / Information Monthly Invoice JANUARI 2021	1-Jan-2021
dept.****@gmail.com	4-Dec-2020	Informasi Tagihan Periode / Information Monthly Invoice DESEMBER 2020	1-Dec-2020
dept.****@gmail.com	4-Nov-2020	Informasi Tagihan Periode / Information Monthly Invoice NOVEMBER 2020	1-Nov-2020
dept.****@gmail.com	6-Oct-2020	Informasi Tagihan Periode / Information Monthly Invoice OKTOBER 2020	1-Oct-2020
dept.****@gmail.com	3-Sep-2020	Informasi Tagihan Periode / Information Monthly Invoice SEPTEMBER 2020	1-Sep-2020
dept.****@gmail.com	6-Aug-2020	Informasi Tagihan Periode / Information Monthly Invoice AGUSTUS 2020	1-Aug-2020
dept.****@gmail.com	4-Jul-2020	Informasi Tagihan Periode / Information Monthly Invoice JULI 2020	1-Jul-2020
dept.****@gmail.com	8-Jun-2020	Informasi Tagihan Periode / Information Monthly Invoice JUNI 2020	1-Jun-2020
dept.****@gmail.com	6-May-2020	Informasi Tagihan Periode / Information Monthly Invoice MEI 2020	1-May-2020
dept.****@gmail.com	4-Apr-2020	Informasi Tagihan Periode / Information Monthly Invoice APRIL 2020	1-Apr-2020
dept.****@gmail.com	5-Mar-2020	Informasi Tagihan Periode / Information Monthly Invoice MARET 2020	1-Mar-2020
dept.****@gmail.com	5-Feb-2020	Informasi Tagihan Periode / Information Monthly Invoice FEBRUARI 2020	1-Feb-2020
dept.****@gmail.com	7-Jan-2020	Informasi Tagihan Periode / Information Monthly Invoice JANUARI 2020	1-Jan-2020