Integrating AI-Enhanced Industrial IoT Ecosystems with FIWARE for Smart Cities: A Scalable Enterprise Solution

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Abstract. *This study explores how the FIWARE and SAMANAU[1] platforms can be integrated to strengthen IoT ecosystems in smart cities and industrial applications. The proposed architecture leverages open standards, machine learning, and cloud, fog, and edge computing to enable solutions such as smart city dashboards, public infrastructure monitoring, and environmental sensor networks. The key benefits include greater scalability, interoperability, and real-time decision-making capabilities. Comparative analyses demonstrate that open-source approaches offer advantages over proprietary systems by reducing costs and fostering innovation. This work highlights the importance of FIWARE in advancing commercial IoT solutions for more sustainable urban and industrial development.*

1. Introduction

The proliferation of the Internet of Things (IoT) has unleashed a new wave of innovation across sectors including agriculture, urban service automation, urban planning, and property management. By linking devices, sensors, and actuators to the digital realm, IoT

[1]According to this work [Souto 2017], SAMANAU is an innovative platform developed by the Centro de Competência em Soluções Livre at the Instituto Federal de Educação, Ciência e Tecnologia do Rio Grande do Norte (IFRN). It is designed for the collection, processing, and analysis of environmental data, featuring components such as Samanaú.PCD (an energy self-sustaining structure with batteries and a solar panel for low-cost data collection), Samanaú.TX (a low-cost satellite transmitter for use in remote locations), and Samanaú.WEB (a web interface for real-time data visualization, accessible locally or remotely from the internet). For more information, visit `https://ccsl.ifrn.edu.br/produtos/samanau`.

enables continuous, real-time data streams that inform decision-making and optimize operations. However, modern IoT environments introduce significant complexity and scalability challenges. Architectural considerations must account for heterogeneous devices, stringent reliability requirements, and robust security frameworks [Vashi et al. 2017]. At the same time, solution integrators must choose between open platforms—such as Fiware—and proprietary ecosystems that may limit interoperability and increase total cost of ownership (TCO) [Zanella et al. 2014].

SimulateIoT-FIWARE [Barriga et al. 2022] proposes a model-driven approach to design, generate code for, and simulate IoT environments leveraging the FIWARE platform. By developing the domain-specific language SimulateIoT-FIWARE, the research enables abstract modeling of IoT systems, thus increasing the level of abstraction and mitigating the complexity inherent in the integration of heterogeneous technologies. The methodology employs model-to-text transformations to automatically generate source code, configuration files, and deployment scripts, facilitating the orchestration of FIWARE artifacts — such as Context Broker and IoTAgent — in containerized environments managed. Two case studies were implemented to validate the approach: one in a smart building environment and another in an agricultural scenario, demonstrating the versatility and robustness of the method. The results reveal a significant reduction in implementation errors and development time, contributing to greater agility in the delivery of IoT solutions. Thus, the work highlights the potential of the proposed model to improve component reuse and simplify the deployment of complex IoT systems with FIWARE.

Similarly, the work developed by Berbes's group [Berbes Villalón et al. 2022] propose an IoT architecture based on FIWARE, focusing specifically on applications for smart cities. The central objective is to facilitate the implementation of IoT systems by integrating the main components of this technology, thus promoting interoperability between sensors, actuators, and context management systems. To this end, a comparative analysis of existing architectures was carried out, followed by the careful selection of the FIWARE platform based on requirements such as open source, scalability, and semantic interoperability. The methodology involved the implementation of modules for data collection, persistence, and analysis, as well as real-time visualization, using standardized protocols (MQTT and HTTP) and generic enablers such as Context Broker and IoT Agent. The experimental results demonstrated the viability of the model, highlighting its modularity and flexibility to adapt to different contexts and applications. It is concluded that the proposed approach contributes to the consolidation of robust IoT environments, fostering the development of smart and scalable solutions.

Additionally, the article presented by Zyriano's group [Zyrianoff et al. 2021] analyzes the interoperability between IoT platforms, emphasizing the comparison between the Web of Things (WoT) approach and the FIWARE-based solution. The main objective is to evaluate, qualitatively and quantitatively, the characteristics, challenges, and performance of both solutions, in order to identify their advantages and limitations in the context of heterogeneous device integration. The methodology involved a comparative analysis of the architectures, the development of a connector (WoT-FIWARE Adapter) to integrate the WoT interface into the FIWARE ecosystem, and the execution of performance experiments in a real IoT scenario aimed at precision agriculture. The results indicate that, although WoT offers greater flexibility and customization, its implementation demands greater resource consumption and presents message loss under high loads. In contrast, the FIWARE solution demonstrates superior performance in terms of latency and reliability, despite being more specific to the FIWARE ecosystem. It is concluded that the proposed integration enhances the benefits of both approaches, contributing to the advancement of interoperability in IoT systems and promoting the development of intelligent and scalable solutions.

The literature indicates that while proprietary solutions often promise optimized performance and more direct system integration, they are limited by a lack of interoperability and reliance on specific vendors, which can restrict the scalability and flexibility of IoT environments. In contrast, the works by Barriga et al. and Berbes Villalón et al. demonstrate how open approaches, particularly those based on the FIWARE platform, offer a robust modular framework that not only facilitates the integration of heterogeneous devices but also the adaptation and reuse of components across different scenarios—from smart buildings to connected cities. Moreover, the study by Zyrianoff et al. reinforces this trend by comparing the Web of Things (WoT) approach with the FIWARE solution, highlighting that although WoT provides greater flexibility and customization, it also entails higher resource consumption and implementation challenges, such as the need for specific adapters to ensure interoperability with FIWARE-based systems. In this way, the literature converges on the idea that adopting open solutions can significantly reduce vendor lock-in, thereby expanding the range of possibilities for developing intelligent and scalable IoT systems—a finding that underscores the contribution of using FIWARE in research projects aiming to leverage the inherent benefits of open platforms.

This paper presents a comparative analysis of two paradigms within a composite scenario that integrates the SAMANAU platform with FIWARE-based solutions and non-FIWARE or proprietary architectures. We incorporate a portfolio of IoT-driven applications—Smart City Dashboard, Urban Data Analytics, Public Infrastructure Monitoring, Dynamic Urban Pricing, specialized Environmental Sensor Network, and a Marketplace—that collectively address urban management intelligence, industrial site oversight, dynamic pricing, and climate data-driven optimization. By demonstrating how Fiware's open, standards-based architecture harmoniously integrates with SAMANAU and these applications, we reveal key benefits in terms of interoperability, scalability, big data processing, and next-generation AI/ML capabilities. The pre-existing SAMANAU platform, prior to the developments presented in this work, comprised components responsible for communication with meteorological stations. These components were capable of acquiring data from various sensors through different communication protocols, and included an environment for the visualization of meteorological information.

The Figure 1 provides a comprehensive overview of the integrated architecture of the IoT ecosystem, illustrating the continuous flow of data from its acquisition in the field and industrial environments to the delivery of results. In this configuration, data collected by sensors and devices are transmitted through various layers to the Fiware environment, where they are normalized, stored, and enriched in a secure and standardized manner. The analysis and storage process takes place, and most of the time, it goes through a machine learning process. The information is then forwarded to other applications, which serve as viewers and integrators of various systems, including Samanaú, the Smart City Dashboard, public infrastructure monitoring, dynamic urban pricing, and the

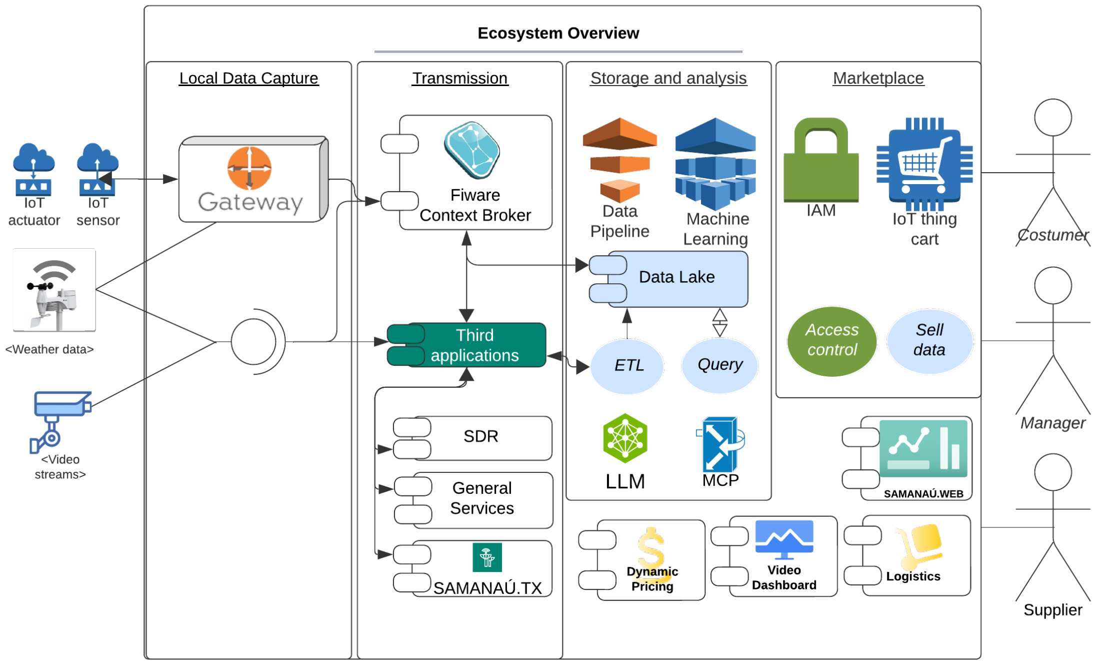

Figure 1. Overview of the IoT ecosystem.

Data Marketplace—thus demonstrating an end-to-end integration capable of supporting both strategic and operational decisions.

This unified approach streamlines decision-making, reduces technological integration complexity, and fosters innovation, resulting in a resilient, scalable ecosystem ready for future expansions.

The Figure 2 illustrates the concept of our system, which uses video analytics agents to automatically detect relevant events from the video stream of security cameras distributed throughout the city of Natal. Intelligent agents communicate with each other to classify events and send the processed data to a Broker, integrated with the Fiware ecosystem. The video stream analysis is performed in near real-time, allowing for a quick and efficient response to urban occurrences. Although this visualization represents a hypothetical analysis for proof of concept purposes, our system is already in operation, monitoring real events and able to contribute to the safety and well-being of the city.

The remainder of this article is organized as follows: Section II outlines architectural and methodological considerations; Section III provides a technical analysis of Fiware integration with SAMANAU; Section IV contrasts this open approach with proprietary systems; Section V presents a real case study; and Section VI offers conclusions and strategic recommendations.

2. Architectural and Methodological Considerations

The development of a robust IoT solution demands careful attention to multiple technological and operational fronts. Key factors include:

Cloud, Fog, and Edge Computing: The architecture must consider where data processing occurs—cloud, fog, or edge. Fiware supports distributed architectures, allow-

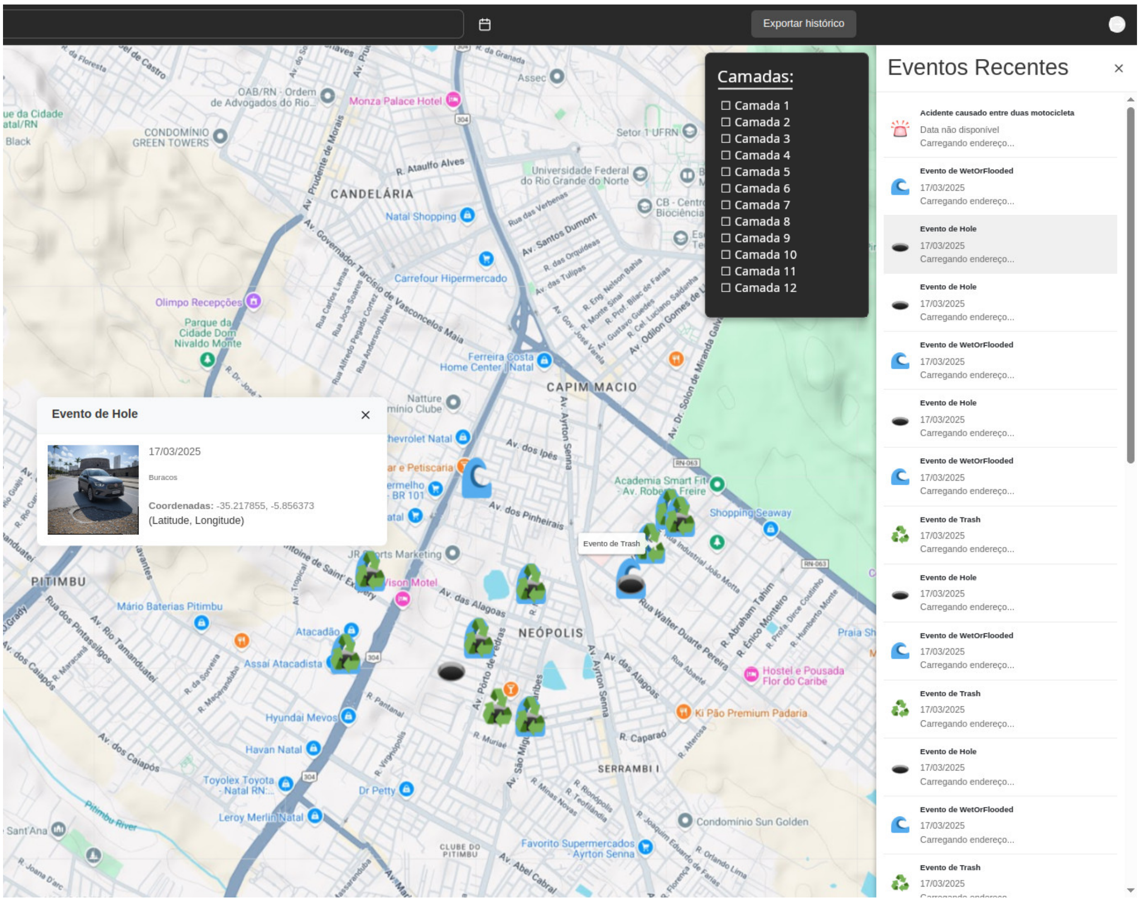

Figure 2. Overview of the event map we're enhancing to improve analysis and decision-making in near real-time.

ing data processing to occur closer to the source, thereby reducing latency and bandwidth consumption [Shwe and Aritsugi 2024]. This design empowers applications like Smart City Dashboard and Urban Data Analytics to leverage real-time analytics for urban management decision support.

AI and Machine Learning Integration: Machine learning models require large, high-quality datasets and suitable environments for training and inference [Carvalho et al. 2019]. Fiware's modular approach and compatibility with AI frameworks streamline integrating ML algorithms that drive predictive maintenance (Public Infrastructure Monitoring), price forecasting (Dynamic Urban Pricing), and resource optimization. Among these capabilities is the system's ability to identify specific events and recognize objects through the visual analysis of camera video streams. Given their sensitivity within the industrial process, the data pipeline and AI-driven analytical procedures are not elaborated upon in detail in this manuscript.

Big Data and Analytics: The large volumes of data generated by IoT challenge traditional storage and analytics tools [Cai et al. 2017]. The Fiware ecosystem facilitates big data integration through components like a connector in charge of persisting context data sources and a Context Broker, providing scalable ingestion, storage, and querying capabilities. This synergy is essential for data-intensive applications like Urban Data

Analytics and the Marketplace. Sources like camera video streams, requiring the identification of events and recognition of objects, highlight the need for such scalable big data processing and storage capabilities to extract valuable insights.

Security, Privacy, and Reliability: IoT environments must ensure end-to-end security, privacy compliance (e.g., GDPR), and reliability. Fiware's built-in authentication, authorization, and context management frameworks, combined with SAMANAU's secure local API and OAuth2 integration, offer robust safeguards [Sousa et al. 2021]. Although proprietary systems often include security features, they may lack transparency in auditing or adaptability to emerging regulatory standards.

Interoperability and Open Standards: Interoperability fosters ecosystem growth and vendor neutrality. Fiware's use of open standards like NGSI ensures seamless integration of diverse sensors, devices, and services. In contrast, proprietary platforms may lock users into vendor-specific data models and protocols, stifling flexibility [Bauer 2022].

In the current landscape of intelligent systems, interoperability among different protocols and standards is essential for the development of efficient and scalable solutions. This section examines the integration between the **Next Generation Service Interfaces (NGSI)**, a specification developed by FIWARE for managing context information, and the **Model Context Protocol (MCP)**, an open standard designed to facilitate communication between large language models (LLMs) and external data sources and tools. The primary characteristics of both protocols, their significance, and the potential benefits arising from their joint adoption are discussed.

2.1. Integration of Protocols for Context Management in Intelligent Systems

The **NGSI** specification, developed by FIWARE, defines a standardized API for context information management. This API enables the creation, updating, and consumption of contextual data within intelligent systems, facilitating interoperability among various components and applications. NGSI employs JSON as its data representation format, significantly simplifying integration across diverse scenarios [FIWARE Foundation 2025].

The importance of NGSI lies in its capability to provide a standardized model for context information management, critical for developing solutions in fields such as smart cities, Industry 4.0, and smart urban governance. By adopting NGSI, organizations can ensure efficient and consistent communication across multiple systems and devices, thereby enhancing interoperability and scalability in implemented solutions [FIWARE Foundation 2025].

Model Context Protocol (MCP) and Benefits of Joint Adoption

The **Model Context Protocol (MCP)** is an open standard aiming to standardize interactions between Artificial Intelligence (AI) applications, particularly those based on large language models (LLMs), and external data sources and tools. MCP provides a unified interface allowing these AI applications to uniformly access multiple data sources, thus eliminating the need for custom integrations tailored for each specific application-data source combination [Anthropic 2025].

Adopting both NGSI and MCP provides several notable advantages:

Enhanced Interoperability: Combining NGSI, which already facilitates interoperability among intelligent systems, with MCP, which standardizes connections between AI applications and data sources, results in more efficient and cohesive integration across diverse system components and services.

Dynamic Access to Contextual Data: MCP enables AI applications to dynamically access contextual information provided by NGSI-based systems, enhancing analytical capabilities and improving decision-making within these applications.

Simplified Development: Jointly adopting these standards reduces the need for customized integration efforts, thus saving development time and resources and simplifying the maintenance and enhancing the scalability of implemented solutions.

In summary, the combined adoption of NGSI and MCP has the potential to significantly enhance the efficiency and effectiveness of intelligent systems by leveraging standardized context information management provided by NGSI and the uniform connection capabilities with AI applications offered by MCP. Current research is focusing on related MCP implementations capable of adding value to data. Companies that adopt these standards enjoy a high level of interoperability, promoting several benefits in their solutions.

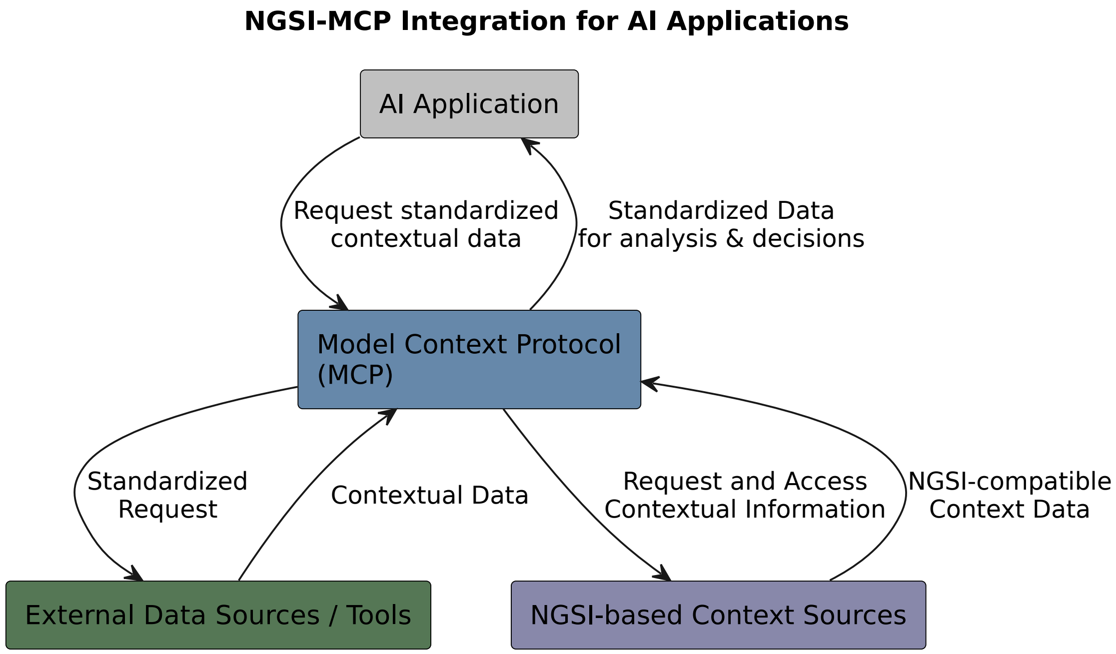

Figure 3. Overview of the standardized interaction model between AI applications, MCP, NGSI-based context sources, and external data sources.

The Figure 3 illustrates how LLM-based AI applications can interact with diverse data sources using the Model Context Protocol (MCP) and NGSI (Next Generation Service Interface). MCP provides a standardized interface that allows AI applications to uniformly access structured databases, IoT sensor data, and context information without requiring custom integrations. This design enhances the scalability, maintainability, and efficiency of AI systems by offering dynamic, real-time access to relevant data across multiple sources.

By combining MCP with NGSI, AI systems gain the ability to manage and utilize contextual data more effectively. NGSI serves as a middleware for organizing and accessing context information, which MCP can then deliver to AI applications. This integration supports improved decision-making, analytics, and overall system interoperability. Together, MCP and NGSI streamline development efforts while enabling smarter, context-aware AI applications.

3. Integrating Fiware with Specialized IoT Applications

Aiming to integrate the FIWARE platform with the SAMANAU environment, along with a suite of specialized IoT applications, to drive smart cities and optimize both urban and industrial operations, this approach leverages FIWARE enablers to ensure interoperability, data management, and advanced analytics. It combines these capabilities with the flexibility and sustainability of SAMANAU, which facilitates the remote monitoring of properties and municipal infrastructure. Certain technical details are deliberately omitted from this work due to their classification as industrial trade secrets.

The **Smart City Dashboard** seeks to contribute to an improved quality of life by making cities safer and more functional. Rapid event detection via near-real-time video monitoring, such as fires and floods, helps prevent accidents, reduce economic losses, and save lives. Moreover, predictive analytics optimizes resource usage, enhances public services, and improves urban planning. In **Urban Data Analytics**, large volumes of information from sources such as commodity prices and logistical parameters are aggregated and processed by machine learning algorithms, transforming raw data into strategic insights for decision-making.

For the construction sector, the **Public Infrastructure Monitoring** application integrates images, vibration sensors, and wearable devices, ensuring continuous and predictive monitoring that reduces risks and improves operational efficiency. In the **Dynamic Urban Pricing** solution, real-time data on supply, demand, and prices feed machine learning-based pricing engines, enabling the identification of optimal transaction opportunities, thereby increasing profitability and reducing inventory losses.

The **Environmental Sensor Network** captures meteorological data with high precision, providing information for predictive models that help mitigate the impacts of climate change on productivity and public services. Finally, the **Marketplace** solution facilitates data exchange and sharing among various ecosystem stakeholders through standardized APIs, encouraging innovation and expanding the potential for new use cases.

Overall, the integrated architecture proposed in this study demonstrates the feasibility of a robust and scalable IoT ecosystem capable of consolidating diverse data sources and offering intelligent solutions for urban and industrial management. This proposal reinforces the advancement of IoT with FIWARE by highlighting its potential to enhance interoperability, improve operational efficiency, and foster continuous innovation in complex environments.

4. Comparing Open vs. Proprietary Approaches

Although proprietary platforms may offer turnkey solutions, they frequently result in vendor lock-in, increased costs, and restricted interoperability. The open-source Fiware approach:

- **Encourages Innovation:** Open standards and a vibrant developer community produce a rich ecosystem of tools and applications.
- **Reduces Costs:** Eliminates licensing fees and simplifies integration, decreasing TCO.
- **Enhances Flexibility:** Facilitates rapid scaling, multi-provider integration, and technology updates.

Despite their advantages, open-source solutions may suffer from a lack of guaranteed ongoing maintenance, formal support, and up-to-date documentation. Additionally, they often rely on forums to resolve issues—factors that can compromise agility and scalability in large-scale projects.

Despite the limitations of open-source, FIWARE offers robustness and scalability for smart cities, supported by a well-structured foundation and an active community of over 200 organizations. Its modular architecture ensures governance, continuous evolution, and flexible integration of new technologies, without vendor lock-in.

By contrast, proprietary systems may limit future growth, increase reliance on a single vendor's roadmap, and impede integration of advanced data analysis tools. The case study below highlights these contrasts.

4.1. Software Integration: Comparison of Scenarios with and without FIWARE NGSI

Interoperability challenges arise when distinct software components from different domains or contexts need to communicate and exchange information. This subsection illustrates how software integration can become simpler and more scalable through the use of FIWARE's Context Broker, which employs the NGSI data model and standardized RESTful API.

4.1.1. Traditional Integration Scenario (without FIWARE/NGSI)

In traditional software integration scenarios, developers are forced to deal explicitly with multiple proprietary APIs and protocols, each with its own data model, endpoints, request structures, and response formats. Such heterogeneity significantly increases complexity, maintenance effort, and cost.

As an illustrative example, consider an application that needs to access data from two independent systems: a temperature sensor (*IoT sensor*) and a Smart Parking solution. Typically, the integration involves distinct API requests:

```
# Proprietary API for temperature sensor:
response = requests.get("http://sensoriot1/api/temperature")
data_temp = response.json()
temp = data_temp['temp_sensor_A34']

```

```
# Proprietary API for smart parking system:
response2 = requests.get("http://smartcity.com/parking_status")
data_parking = response2.json()
status_parking = data_parking['parking_space'][0]['status']
```

Source code 1. Integration without FIWARE (heterogeneous APIs)

In this scenario, the development team must individually handle each specific API, implementing multiple separate queries, parsing diverse data formats, and continuously updating their integration approach each time a new data source or changes in existing data models arise. This lack of standardization often escalates into increasingly complex and difficult-to-maintain codebases as more heterogeneous systems become integrated.

4.1.2. Simplified Integration Scenario using FIWARE NGSI

By employing FIWARE's Context Broker and the NGSI data model, developers benefit from a unified, standardized, and simplified integration approach. All heterogeneous data sources—such as IoT devices, parking management systems, traffic management, environmental sensors, among others—can be represented uniformly as NGSI entities with standardized attributes and types.

The following illustrative example demonstrates how the previously complex integration scenario can be significantly simplified using FIWARE Context Broker and NGSI:

```
# Standardized NGSI query for temperature sensor:
resp1 = requests.get("http://broker/v2/entities/SensorA34")
data_sensor = resp1.json()
temp = data_sensor['temperature']['value']

# Standardized NGSI query for smart parking system:
resp2 = requests.get("http://broker/v2/entities/ParkingSpot1")
data_parking = resp2.json()
status_parking = data_parking['status']['value']
```

Source code 2. Integration using FIWARE NGSI (Context Broker)

Using FIWARE NGSI enables all data sources to expose their contextual information through a common, standardized API architecture. This approach allows developers to reduce integration complexity by maintaining a single common pattern across systems, which can lead to improvements in scalability and interoperability. While FIWARE and NGSI implementation initially requires a learning investment, measurements from indicate a reduction in code maintenance effort and integration time for systems with multiple data sources. Table 1 presents a comparative analysis of integration scenarios, highlighting key differences between systems

Consequently, FIWARE's Context Broker and NGSI standard significantly facilitate software integration across heterogeneous contexts, fostering scalability, interoperability, and streamlined information management in multi-domain environments.

Table 1. Comparison between integration scenarios: without FIWARE NGSI and with FIWARE NGSI

Characteristic	Without FIWARE	With FIWARE
Number of different APIs	One API per system/context	One single NGSI API (multiple entities)
Context-specific code	Required; varies by API	Uniform pattern for all contexts
Changes and future updates	Costly and complex	Simple and standardized
Integration and interoperability	Requires 3-5 distinct API implementations (e.g., REST, MQTT, custom adapters)	Single NGSI-LD standard (all integrations use the same API)
Scalability to new systems	Low	High

5. Case Study: Smart Urban Management Deployment

This paper presents as a case study part of a developing ecosystem with a robust and scalable IoT architecture leveraging the FIWARE platform. Although initially adapted for industrial and agribusiness contexts, the architecture demonstrates high adaptability to smart urban environments. This flexibility is evidenced by its ability to integrate heterogeneous devices and provide customized solutions for diverse scenarios, such as urban weather monitoring, smart street lighting, and traffic management, thus expanding the functional scope of IoT applications.

In urban environments, the architecture integrates weather stations strategically positioned throughout cities, enabling real-time monitoring of climate conditions, air quality, and other critical environmental parameters. These data are processed through machine learning and big data techniques, providing valuable insights for urban management and public services.

The network of urban weather stations monitors parameters such as temperature, humidity, atmospheric pressure, precipitation, wind speed, solar radiation, and pollutant concentrations. This data is fundamental for early warnings of extreme weather events, urban flood management, and planning interventions to mitigate urban heat islands.

Furthermore, the architecture can be configured to support smart public lighting systems that adjust brightness based on detected weather conditions or pedestrian presence. It also enables intelligent bus fleet management, optimizing routes based on current weather conditions and minimizing wait times. Additionally, real-time traffic data collection supports the dynamic adjustment of traffic signals, contributing to reduced congestion and improved mobility, especially during adverse weather events.

IoT-based monitoring systems significantly improve urban life quality by enhancing safety, environmental health, and service efficiency. Real-time detection of critical events—such as severe storms, floods, or infrastructure failures—enables rapid response, minimizing risks and economic damage. Predictive analytics based on historical and real-time weather data further support strategic urban planning and smarter allocation of public resources.

The architecture also incorporates emerging technologies such as compact weather stations with embedded metadata generation, software-defined radios (SDR), LoRaWAN, fiber-optic connectivity, and advanced gateways. The integration with different networks provides high-speed, low-latency communication essential for large-scale sensor deployments in urban areas. Concurrently, Edge AI enables on-site execution of AI models close to the data source, reducing dependence on centralized cloud infrastructures and allowing near-instantaneous decision-making during critical weather events.

The integration of FIWARE with AI creates an IoT architecture that emphasizes interoperability, scalability, security, and efficient data handling. This open and modular approach mitigates vendor lock-in and ensures continuous system evolution aligned with emerging technological demands.

As the number of IoT devices and concurrent applications increases, the microservices-based design of FIWARE facilitates elastic scaling and modular integration. Container orchestration tools can manage the deployment, scaling, and availability of services across distributed infrastructure. While increased scale may introduce latency due to inter-container communication, these effects can be mitigated through optimal cluster configuration, edge processing, caching strategies, and service affinity.

This ensures that even under high demand, system responsiveness and reliability remain within operational thresholds. The adherence to open APIs and standardized protocols ensures long-term scalability and adaptability, supporting sustainable growth and innovation. To illustrate the practical implications of these architectural choices, the following subsection presents two contrasting implementation scenarios for urban weather monitoring: one based on a proprietary approach and the other leveraging the open and modular FIWARE + SAMANAU ecosystem.

5.1. Scenario

Two strategic options are evaluated:

- **Option A (Proprietary):** A closed IoT platform requiring custom middleware for data integration, incurring licensing fees and prolonged development cycles.
- **Option B (Fiware + SAMANAU):** An open, modular ecosystem combining Fiware's Context Broker and IoT Agents with SAMANAU's solar-powered stations, integrated with the Smart City Dashboard, Urban Data Analytics, Dynamic Urban Pricing and the Environmental Sensor Network.

The **scenario in option A** provides vendor-supported initial integration but depends on proprietary middleware, mandatory licensing and extended timelines. Such systems—e.g., video management on non-standard protocols without third-party interoperability—often require costly license upgrades for basic scalability, imposing artificial barriers, vendor lock-in and long-term dependencies that hinder adaptability and increase maintenance complexity.

The **scenario in option B** enables MVP deployment in months rather than years. Its open APIs and flexible data models support agile iterations and seamless integration of advanced ML for yield forecasting, dynamic pricing and resource optimization. Over time, it eliminates licensing fees and vendor lock-in, reducing costs while scaling through additional sensors and marketplace services.

5.2. Major Impact

By anchoring urban management in FIWARE's open and modular architecture, cities shield themselves from market volatility and rapid technological shifts. As new paradigms of AI and heterogeneous communication protocols emerge, this platform integrates them seamlessly, avoiding costly re-engineering efforts and preserving agility. In contrast, proprietary solutions—characterized by rigid architectures and an escalating total cost of ownership, stifle innovation, deepen vendor lock-in, and hinder sustainable growth.

6. Final considerations

By integrating the SAMANAU platform and advanced IoT applications with Fiware, organizations can achieve an agile, cost-effective, and scalable ecosystem. This synergy addresses the complex demands of architectural considerations, AI/ML integration, big data processing, secure communication, and compliance. The comparative analysis reveals that open standards-based solutions not only streamline deployment but also enable continuous innovation and long-term strategic alignment.

To ensure an effective and resilient integration of intelligent solutions, the following set of best practices may guide the process of design and implementation:

1. **Adopt Open Standards Early:** Embrace Fiware and NGSI during initial project phases to avoid vendor lock-in and simplify integration.
2. **Invest in Training and Community Engagement:** While the FIWARE ecosystem provides important standardization benefits, organizations should be aware of the potential learning curve and initial implementation efforts, which may involve a considerable amount of developer training. Nonetheless, the use of its open-source and standardized components can contribute to streamlining the development of smart solutions. The availability of documentation, tutorials, and community support can facilitate adoption and promote efficient knowledge transfer.
3. **Implement Data Spaces and Marketplaces:** Encourage data sharing and collaboration among stakeholders to amplify value creation and innovation.
4. **Utilize Agile Methodologies for Iterative Development:** Develop MVPs and refine solutions iteratively, reducing time and ensuring alignment with evolving goals.

In an increasingly connected world, the choice between proprietary and open-source IoT platforms profoundly impacts cost, scalability, and strategic adaptability. By integrating Fiware with solutions like SAMANAU, Smart City Dashboard, Urban Data Analytics, Public Infrastructure Monitoring, Dynamic Urban Pricing, Environmental Sensor Network, and the Marketplace, organizations position themselves at the forefront of IoT innovation, fostering sustainable growth and unlocking transformative insights.

Acknowledgments

The authors express their gratitude to the Embrapii Unit of the Instituto Metrópole Digital (IMD) for the financial and technical support that enabled the realization of this work. The authors would like to express their gratitude to FINEP and CNPq for the financial support provided for the development of this research. This work was partially funded by FINEP under grant number 03.22.0044.00 and by CNPq. Their support was essential to the success of this project. This article was revised for language and clarity using ChatGPT, an AI language model developed by OpenAI.

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