U.P.B. Sci. Bull., Series C, Vol. 87, Iss. 2, 2025 ISSN 2286-3540

EVALUATING SMART BUILDINGS AS FOG LAYER FOR SMART CITIES

Marian-Cosmin DUMITRU [1*], Mihnea-Alexandru MOISESCU[2], Radu Nicolae PIETRARU[3]

The increase in the number of IoT devices inside buildings and cities offers us an extensive degree of information that can be aggregated and used to bring new functionalities to the macro level of the city, thus improving the quality of life of users. Until now, the concepts of Smart Building and Smart City have been treated as two separate entities, with no correlation between the two data sources, a correlation that can add an additional level of granularity that can help us in decision-making. The architecture at the smart building level is a local architecture that generates, processes and aggregates data such as temperature, humidity, air quality or energy consumption inside the building, data that is relevant and can also be used at the smart city level. Starting from this use of data at a macro level, our article aims to demonstrate conceptually that the smart building service level can serve smart city services with the architectural role of fog level. This architecture is to be implemented at a smaller scale that perfectly simulates the smart city concept, within the university campus, where we have several fog nodes represented by campus buildings, achieving analysis of data collected through the open-source platform ThingsBoard, the platform that, through the Edge component, completes the proposed architecture, thus demonstrating the importance and benefits of using buildings as fog nodes within smart cities.

Keywords: Smart Building, Smart Cities, Fog Computing, ThingsBoard

1. Introduction

Being surrounded by IoT devices in everyday life, it is necessary to use them to make our lives easier, thus managing to make our time as efficient as possible. Over 65% of our daily time is spent at home, at work or on the road between the two, so the presence of components to help us make this time more efficient, as well as the aspects related to safety and quality of life are becoming more important. the most necessary. Process automation is particularly important in this context,

* Corresponding author
[1] National University of Science and Technology POLITEHNICA Bucharest, Romania, e-mail marian.dumitru@stud.acs.upb.ro
[2] National University of Science and Technology POLITEHNICA Bucharest, Romania, e-mail mihnea.moisescu@upb.ro
[3] National University of Science and Technology POLITEHNICA Bucharest, Romania, e-mail radu.pietraru@upb.ro

whether we are talking about smart home or smart building integrations or on a larger scale, smart cities. For each of these there are various usage scenarios, temperature regulation and optimization, automatic closing of the external blinds automatically during the day or in case of rain, detection of flooding/gas leaks or voltage drops, as well as within the city through intelligent traffic lights, transport system, increasing the safety of the inhabitants.

Starting from all these specifications, we want to address the problems that may arise due to the huge volume of data generated by all these systems, here the integrations between IoT, Fog, Edge, and Cloud Computing devices and the ThingsBoard platform come into play. Thus, we want to start with the definitions of the concepts that we are going to discuss and arrive at the proposed architecture.

Fog computing definition: "aim of bringing cloud computing capabilities to the edge of the network. Fog computing optimizes cloud environments by processing data at the edge of networks, nearer to the data source", thus being thought of as an additional level that is in proximity to the client where the data is preprocessed before being transmitted to the cloud, the two technologies being complementary.[1]

Edge computing definition: "Edge computing is a paradigm that brings computation and data storage closer to the source of data generation". This eliminates the need to send the data and the need for a continuous connection to the cloud, the data being analyzed directly at the source, in real time, being ideal for critical cases where the decision must be made as quickly as possible. [2]

Smart building definition: "a home learns from its inhabitants, adapts to their life cycle and initiates all decisions itself". Thus, the concept of smart building is differentiated from the initial and increasingly used definition, which refers to the introduction of systems that can be controlled remotely, but with input from the user, from autonomous buildings that are capable of making decisions on their own, based on the user's behavior, following certain scenarios both for daily use and for emergencies, fires, floods, etc. [3]

Smart city definition: "The smart city concept can be understood as a convergence of several key technological features that are related to high-tech urban infrastructure (ranging from sensors to environmentally friendly technologies related to construction, waste management and energy efficiency)". Starting from the interpretation of the information transmitted by the various sensors in the city, decisions can be made that can lead to the improvement of the lifestyle of the inhabitants. We can even go to the next level where the data received from the buildings in the system can be included, thus having a complete view of all stakeholders in the system.[4]

An aspect that must be considered when we talk about smart buildings is the efficiency and automation of the processes underlying the building, which should have as insignificant impact on the users as possible. Thus, based on the data collected by the sensors in the building (motion, temperature, sound or CO_2 sensors), a better understanding of the number of occupants can help us to make energy consumption more efficient when there are no more people in the building, without the need for manual interventions on air conditioning systems.[5]

The concepts of smart building and smart city are on the rise, having completed the detailing of the defining concepts for this work (smart city/smart building as well as Fog and edge computing). In the article, the main goal is to present aspects and explanations regarding the need to use a fog level within smart city architectures by integrating smart building services. In section 2 the existing studies conducted on the field will be presented, as well as the detailing of the solutions implemented for both components (smart city and smart building), thus emphasizing an overlap in the data generated and usage scenarios between the two levels. In section 3 we will detail the benefits of using the ThingsBoard technical solution, this being the chosen solution for the implementation of the architecture proposed. Through the ThingsBoard platform, the use of buildings as fire levels at the city/university campus level is validated. Section 4 details the proposed architecture for using buildings as fog nodes for the smart city level, the description of rule chains and the logic of alert creation systems for specific situations such as emergency situations that affect the proper functioning of the building, following that in section 5 we present the conclusions drawn from this implementation as well as the next steps we want to follow.

2. Existing Theories & Previous Work

To understand the usefulness of using smart buildings as fog nodes within cities, various solutions already implemented in specialized articles were analyzed where various scenarios for using Edge computing for smart buildings, decentralized systems, as well as the benefits of these implementations for end users were proposed.

In the article "What is the impact of smart city development? Empirical evidence from a Smart City Impact Index" the authors analyze the impact that the implementation and development of the smart city concept has on the five areas of interest: economic, environmental, social, technological, and governmental. Thus, for each field, the indicators that must be monitored before the start of the implementation as well as during it were defined. Among them we can mention: Local income tax per capita, CO2 emissions or the satisfaction with income. Although there may be certain indicators that over time will be affected for several reasons, not only by the implementation of the smart city concept, but it also generally has a positive impact, the cities where it was implemented having increases for most of the indicators.[6]

If we address the buildings that are to be built, we benefit from greater ease because we can install the systems from the beginning, thus ensuring that all components are compatible and can communicate with each other. But a much wider range of potential targets for the implementation of Edge is represented by the already existing buildings that have/may have a part of the systems already installed, systems that can come from several manufacturers. Starting from this need, Francisco-Javier Ferrández-Pastor et al. propose the implementation of a Fog/Edge solution to ensure integration and interoperability between all systems in the building. To do this, it is necessary to add new actuators to the already installed electrical panel, the fog and edge nodes and, depending on each individual implementation, the addition of new sensors if they are missing.[7]

Regardless of the field of activity to which we address, data security is a very important aspect, even more so when we address a system that must make decisions in real time, for this reason "fog computing has been proposed in smart buildings to administer the massive, security-crucial, and delay-sensitive data, which are produced by IoT devices". If we are talking about individual implementations (for a single building) the impact of a cyber-attack will be smaller, being impacted by a smaller number of users, but if that building acts as a fog node within a larger ecosystem within the smart city these attacks can have a devastating impact. None of these cases should be neglected, the most relevant aspects to be followed to improve security are data storage, data protection, the interconnection and relationship between devices as well as the connection to the cloud. In the case of these attacks, the time needed to recover the system and bring it to its initial state must also be considered.[8]

Starting from the fact that human interaction can introduce certain errors or operational problems within smart buildings, which can affect the planned performance of the implemented system, Andreas Seitz et al. have developed "an architecture designed to establish a location aware environment for conflict negotiation and decision support that is based on fog computing". In the classic model, there can be two approaches to decision-making: based on the rules, in which case certain initially defined rules are followed (for example, the temperature drops below a certain threshold, we turn on the heating) or based on the events when the user is in control. Migrating from a centralized to a decentralized system brings us multiple benefits, such as the fact that the different nodes do not need to know the rules set for the entire building, but only the rules that are relevant to the scenarios that those nodes serve, thus bringing an additional level of security.[9]

Although the preventive part is particularly important, in some cases, even though the building administrators are cautious, certain events such as fires cannot be predicted or prevented. In these cases, the most important aspect is the reaction time and the time in which the authorities are notified to intervene. Since in emergency cases such as fires, they can quickly spread to the surroundings, it is necessary to integrate smart buildings as component nodes of the smart city. To avoid errors and erroneous notifications to the authorities, several sensors are used, such as temperature, humidity, smoke sensors and only a sequence of certain values will trigger the alarm system. For this scenario, Evangelos Maltezos et al. propose that, in addition to the previously mentioned sensors, a Raspberry Pi 4 should be added to function as an Edge node in this system. [10]

In recent years, the problem of increasing energy consumption has become increasingly important, with various solutions being proposed to reduce the impact of these problems in large cities. We want to optimize the consumption of electricity with as minor impact as possible on the inhabitants of the cities. If we refer to a smaller scale, in the buildings of the city we try to estimate and optimize the electricity consumption as best as possible without impacting the comfort indicators and the lifestyle of the users. The estimate of electricity consumption has a certain deviation depending on the external conditions that may vary during the year depending on the chosen reference area. This is where optimization and automation techniques come in. Comparing existing studies, Abdul Salam Shah et al. concluded that "that genetic algorithms have performed better as compared to the other algorithms", but most studies do not consider all user comfort parameters, parameters. humidity. [11]

From the very beginning, to be able to discuss the efficiency of electricity consumption, we must also discuss the necessary infrastructure, the installation of IoT devices that will receive data about the targeted comfort indicators. To improve the energy efficiency of buildings, we can use a different approach than the one presented previously, and we can include a new layer in our system, the fog computing level, which aims to reduce the time needed to process the collected data. Thus, by introducing new data into the system, information about the user's location, the procedure to switch to energy saving mode inside the building can be automatically triggered, whether we are talking about office buildings or homes. [12]

Depending on the size of the cities and the number of devices that generate data, we can face an unequal distribution of the use of resources over certain time intervals, depending on the areas of interest in the cities, so the use of offloading techniques becomes necessary. In order to optimize the response times we can add new edge nodes distributed in the city, thus being necessary Starting from the fact that "it is hard to fully achieve collaborative services which are often real-time and delay-sensitive", Xiaolong Xu et al. propose creating a model that will make the offloading process more efficient, using edge nodes located on city streets, thus achieving a safe implementation that also has optimal energy consumption. For monitoring, several metrics were followed, including degree of occupancy of the edge nodes in the system, energy consumption, response time, as well as the security of the offloading process. [13]

Whether we are talking about the accelerated increase in the number of devices that are installed inside cities (sensors, video cameras, etc.) or whether we are talking about the accelerated migration of the population to cities, we must consider several factors, all with the goal of improving conditions and the lifestyle of the inhabitants. In order to be able to face these requirements, an important step is a very good definition of the architecture that we want to follow, such an architecture was proposed in the work "Intelligent System Architecture for Smart City and its Applications Based Edge Computing" where starting from IoT devices integrated with Multi-Access Edge Computing nodes and with cloud servers, an improvement in the parameters of interest can be observed: latency, energy consumption and request loss rate. [14]

Making the transition from fixed fog nodes that can be installed inside cities to mobile components, Abdul Majid Farooqi et al. proposed the use of cars inside cities, cars that are equipped with an Internet connection through 5G services, thus realizing Vehicular Ad-hoc networks. Thus, the authors propose the implementation of an algorithm whose goal is to improve the performance of fog nodes by reducing latency and processing time for transport systems. Compared to the general architecture that uses the cloud architecture, the performance obtained by the proposed algorithm reduced latency by 20% and delays by 35%. [15]

In smart cities, which want to adopt and use fog computing, the method of locating fog nodes, their capacity and the distance between nodes are some of the most important parameters that must be considered to benefit from an efficient system. Since "computational complexity of finding the right fog node in the given mesh network is high" it is proposed to transmit the information only to the adjacent fog nodes, thus reducing the time required to establish the most optimal node, which may be very far from the area where it is expected the answer. The implementation of such a Process based on Fog benefits from a better performance in use compared to the use of a Per-Service Request. [16]

3. ThingsBoard Platform - Smart Campus Platform and Fog Level Platform

The purpose of presenting the capabilities and reasons for choosing the ThingsBoard platform is to validate the fog level concept, an intermediate processing level necessary in smart cities.

As validation support, a ThingsBoard implementation of the smart campus/smart building type is presented which is capable of producing useful information at the building level for a higher level of smart cities - for example: temperature variation, thermal comfort index, energy consumption level, this information being aggregated according to the relevance and granularity we need at the room, floor, building or group of buildings level.

In choosing the ThingsBoard platform, several aspects and necessary features were considered, such as: processing campus data, obtaining synthetic data at the building level, the capability to transmit that data to another level, that of smart cities.

To be able to integrate the IoT devices in the system, collect and analyze the data from them, we chose to use the ThingsBoard and ThingsBoard Edge platforms. These are open-source platforms, the benefit of which is that we have access to the source code, and if we need new functionalities for specific scenarios, we can implement them ourselves, or we can discuss them with the community.

The existing libraries are very varied, which gives us the opportunity to use a varied range of sensors and devices in the platform, such as: Arduino, Raspberry Pi, Asus Thinker or Banana Pi. If the existing device is not found in the supported list, we can add it by manually configuring the integration, after testing we can send the details of our integration to the community to publish them.

Configuring a new environment and adding new devices is very easy, it can be done both from the graphical interface and through API calls. Below we will detail all the benefits of this platform:

- Data visualization – Based on the data received from the devices, we can create various dashboards.
- Working with telemetry data – We got multiple configuration options for collecting, storing, and querying our data.
- Rule Engine – Based on the data received from IoT devices, we can set certain rules, critical intervals, which are the basis of alarms.
- Device Attributes – For each device we can set one or more attributes that are stored in key-value form.
- Entities and relations – Within the platform we can set various entities (user, client, devices, tenants) as well as the relations between them.
- Audit Log – The platform administrator can view all changes made by users.
- API & Rate Limits – This function is disabled by default and aims to limit the number of requests that a component entity of the system can make.
- RPC capabilities – Provides the ability to send Remote Procedure Calls.

ThingsBoard Edge is the Edge component of the ThingsBoard platform, a component that can be added to the existing server, thus managing to add a new layer between the already configured platform and the Cloud.

4. Study Case

Analyzing the benefits that the ThingsBoard platform offers us, we decided to continue the implementation using this technical solution to implement the proposed system. The starting point of this research is the information collected by the sensors located in the Faculty of Automatic Control and Computer Science building (later named ED building) within the campus of the National University of Science and Technology Politehnica Bucharest. These data are available by accessing the Digital Twin[1] platform. The Digital Twin platform is a platform that uses ThingsBoard Edge to collect data from sensors located on the university campus, facilitating the aggregation and reporting of key information such as temperature, humidity, and the number of records transmitted over a period. Fig. 1 shows the evolution of the parameters of interest for a laboratory within the ED building (ED312). All this information is transmitted by the IoT devices to the Thingsboard platform.

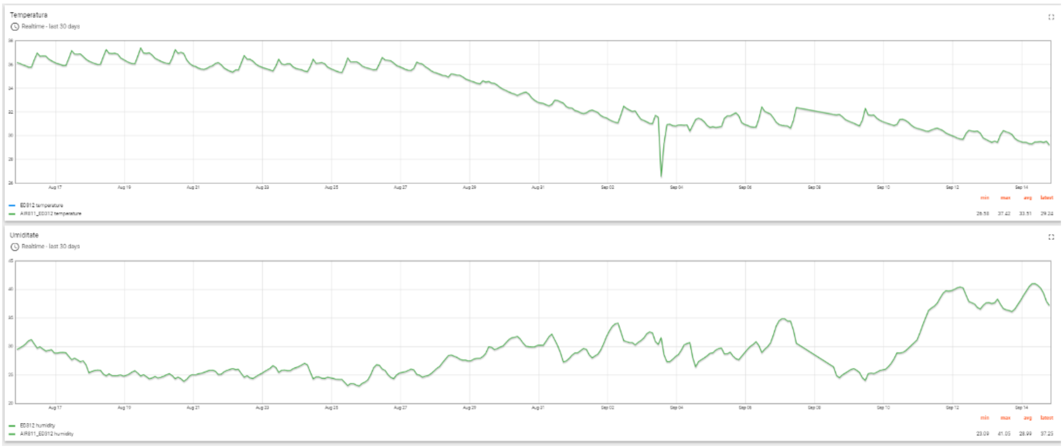

Fig. 1. The evolution of temperature and humidity parameters

Due to the versatility of the chosen platform, we are limited to using the information sent only by the existing devices, new sensors can be integrated very easily, thus managing to add an additional level of information that is relevant at the building level, information such as energy consumption, fire alarms, degree of occupancy of the building etc. In Fig. 2 we have presented the central workflow of the system on which a new node was added, the Fog Computing node, so it is no longer necessary to process the information directly in the Cloud, but this can be done directly in the new node.

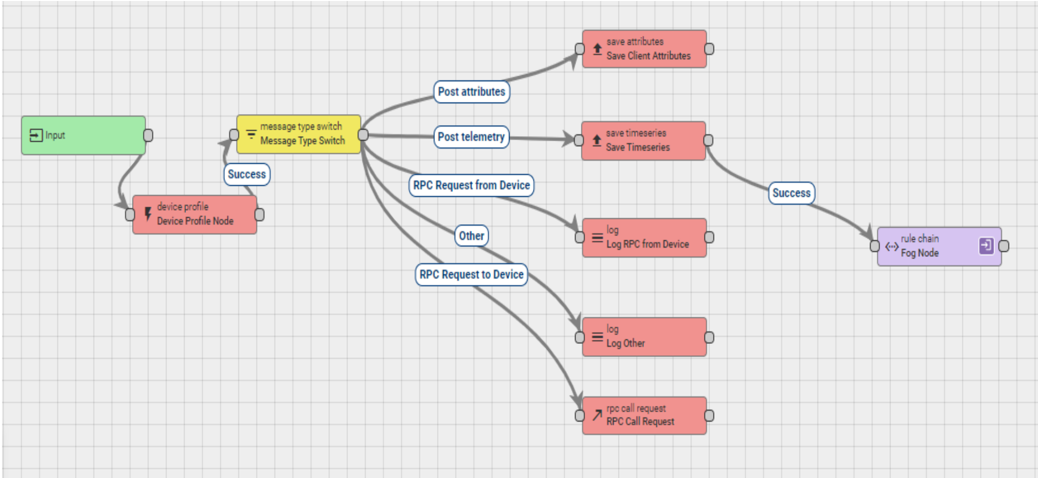

Fig. 2. Root Rule Chain and Fog Node Connection

This implementation through the ThingsBoard platform offers us the functionalities that justify considering the platform as a fog level for smart cities, rule chains that allow automatic data processing, rule chains and alarms that can be sent to a superior smart cities system.

Since we discussed the implementation of the integration between several buildings of a university campus/city, certain information collected such as temperatures from a certain room in the building can become much too specific and irrelevant for the entire system, so this information will only be used at the building level , and will not be taken into account as the defining parameters in the relations between the buildings where we carry out the implementation. Following this scenario, the information regarding the electricity consumption at the building level will be sent to the fog node, based on this a forecast will be made to help us estimate and optimize the consumption as best as possible during the following months, aggregated information about temperatures and humidity inside the building as well as outside, depending on the distance and location of the buildings of interest, as there may be considerable differences, as well as information on air quality, thus managing to reduce the impact of dangerous situations and air contamination.

The proposed architecture for this system is detailed in Fig. 3 and can be divided into three distinct levels, in our case it is applied at the university campus level, being very easily scalable at the city level, following the same structure. Each building of interest on the campus has certain sensors configured on each floor, which may differ depending on the activity conducted on that floor or the specifics of the building. The most common sensors are those for temperature, humidity, and air quality.

The information generated by the sensors is transmitted to the Edge node represented by the Thingsboard Edge Platform using the Message Queuing Telemetry Transport (MQTT) protocol, a protocol that helps us in case of network problems, the generated data being kept in a queue. The Thingsboard Platform represents a crucial step as it gives us the capability to analyze and visualize data very granularly with the possibility to filter and generate specific reports.

Each building within the campus will function as a Fog node within the campus, with data being transmitted further and centralized across the entire campus where the same platform will be used, ThingsBoard, as it offers all the capabilities, we need for this use case.

From the smart city layer, data is transmitted to the cloud provider to be stored and archived, being able to choose any cloud service provider.

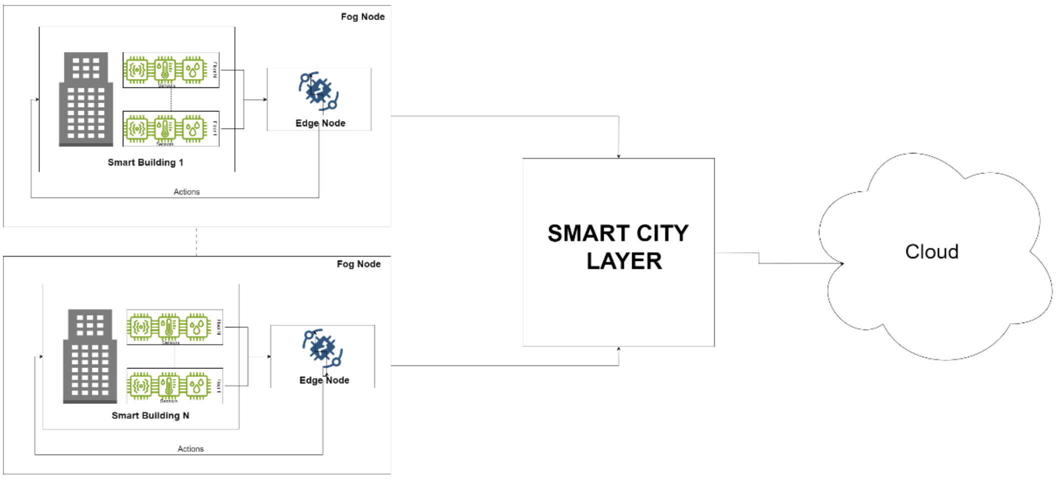

Fig. 3. Proposed architecture, buildings acting as fog layers inside the city

To demonstrate the ease of integration and versatility of the proposed architecture and to present the idea that the necessary modifications to the existing infrastructure are minimal, the architecture presented above was used in the creation of a fire detection system. This can be implemented as granularly as the installed sensors allow, whether we are discussing at the floor level, a group of floors or at the office/room level. Depending on the evolution of the parameters, we can identify these variations within the fog node and based on the defined rules we can create an alarm both at the building level and within the university campus.

Fig. 4 shows the Rule Chain of the Fog node added to the system, a step whose purpose is to alert the stakeholders inside the city regarding the outbreak of a fire, right from the first seconds. Being integrated with the building's but also the city's emergency alert systems, we can obtain a much faster response time, thus reducing the impact as well as possible human and material damage. Having defined some very clear rules, False/Positive cases will be excluded, thus there are only two possible scenarios, the case where Success is returned based on the algorithm, in which case all parameters are optimal, or the case of Failure, in which case it rises the alarm, and the emergency protocol is followed.

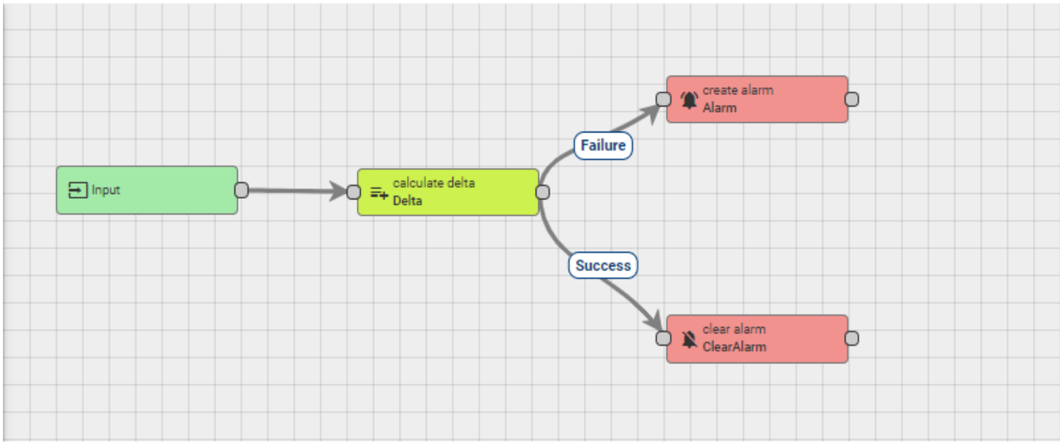

Fig. 4. Fog Node Rule

In Fig. 5 we have the detailed logic of verification and interpretation of the parameters that are the basis of the fire alert system. To reduce and even eliminate errors and false alerts, we do not refer only to the last value sent for the indicator, but we always compare it with the reference values, the values sent previously. Following this scenario, we manage to eliminate the cases in which the sensors can send erroneous values, adjusting and eliminating the spikes.

```
function Details(msg, metadata, msgType) {
var data = {};
if (metadata.prevAlarmDetails != null) {
    data = JSON.parse(metadata.prevAlarmDetails);

    if (temperature >= 75 && humidity <= 25) {
        if (metadata.prevTemperature >= 60 && humidity <=
            35) {
            return alert
        } else {
            //check one more time
        }

    }

    metadata.remove('prevAlarmDetails');
}
return data;
```

Fig. 5. Alerting logic

5. Conclusions

In this work, we analyzed the concepts of smart building and smart cities and, starting from certain limitations or aspects that can be improved, we proposed an implementation of an architecture based on the use of Fog and Edge computing. Thus, the use of the ThingsBoard platform was proposed, the platform that offers us the possibility of recording the current sensors already present in our system. The data transmitted by the registered IoT devices were collected and pre-processed by the Fog node introduced in the system, thus improving the response time, as it is no longer necessary to send the data to the Cloud for processing.

Starting from the modeling of the smart building level, which acts as a fog node for smart cities, it is ensured that the need for data processing and transmission to the Cloud (smart cities) platforms is reduced, as well as the increase in reaction speed and the reduction of the time required for alerting in case of detection of a situation emergency.

The main limitation of the proposed solution is given by the possible incompatibilities that may arise when integrating with the open source Thingsboard platform. Although it is a widespread platform, it is not accepted as a single universal solution by all infrastructure providers, hence the risk of incompatibilities.

Through the proposed architecture, the architecture based on the Thignsboard platform, the additional benefits such as alarm raising logic and rule chains give us the versatility necessary to consider the nodes at the building level as a fog node within the university campus.

The Digital Twin platform is a research platform in use, which is undergoing a process of continuous development, the platform through which multiple research directions are developed simultaneously, such as the assessment of the risk of airborne disease transmission [17], the assessment of IoT security inside buildings [18] or the study of the quality of data transmitted through the intelligence of the IoT Digital Twin network.[19]

The use of relevant data generated by buildings in the city represents an important asset of the research, thus we can have much clearer information about energy consumption or other parameters of interest in certain areas of the city. The scenario of generating alerts to city systems and authorities in case of sudden changes in a parameter, or a combination of parameters, was also presented, thus improving the response and evacuation time in critical cases such as fires or events that can affect the daily activities of inside the building. Thus, we can say that the integration of smart buildings as fog nodes inside cities presents itself as a field of interest that can be developed and even implemented on a large scale.

Now, the described platform is not interconnected with a smart city application, but the potential of this idea is presented and evaluated through simulations performed. In future work, we want to improve the current implementation and propose a centralized system in which we can simulate the entire integration of fog nodes inside the cities by implementing the entire infrastructure, by connecting and correlating information from several buildings, thus creating the entire ecosystem.

Another future research direction is represented by the evaluation of the data model, the development of the platform involving the introduction of machine learning elements for studying recorded data and making smart building decisions.

Acknowledgement

This work is supported by NetZeRoCities competence center, funded by European Union – NextGenerationEU and Romanian Government, under National Recovery and Resilience Plan for Romania, contract no. 760007 / 30.12.2022 with Romanian Ministry Of Research, Innovation and Digitalisation, through specific research project P3-Sustanaible Buildings

R E F E R E N C E S

[1] V. Hurbungs, V. Bassoo, and T. P. Fowdur, “Fog and edge computing: Concepts, tools and Focus Areas,” International Journal of Information Technology, vol. **13**, no. 2, pp. 511–522, Jan. 2021. doi:10.1007/s41870-020-00588-5

[2] O. T. Modupe et al., “Reviewing the transformational impact of edge computing on real-time data processing and analytics,” Computer Science & IT Research Journal, vol. 5, no. 3, pp. 693–702, Mar. 2024. doi:10.51594/csitrj.v5i3.929

[3] E. I. Batov, “The distinctive features of ‘smart’ buildings,” Procedia Engineering, vol. **111**, pp. 103–107, 2015. doi:10.1016/j.proeng.2015.07.061

[4] D. Stamopoulos, P. Dimas, G. Siokas, and E. Siokas, “Getting smart or going green? quantifying the Smart City Industry’s economic impact and potential for sustainable growth,” Cities, vol. **144**, p. 104612, Jan. 2024. doi:10.1016/j.cities.2023.104612

[5] G. Cretu, I. Stamatescu, and G. Stamatescu, “Modeling and prediction of occupancy in buildings based on sensor data using Deep Learning Methods,” IEEE Access, vol. **12**, pp. 102994–103003, 2024. doi:10.1109/access.2024.3432584

[6] Y. Lim, J. Edelenbos, and A. Gianoli, “What is the impact of Smart City Development? empirical evidence from a smart city impact index,” Urban Governance, vol. **4**, no. 1, pp. 47–55, Mar. 2024. doi:10.1016/j.ugj.2023.11.003

[7] F.-J. Ferrández-Pastor, H. Mora, A. Jimeno-Morenilla, and B. Volckaert, “Deployment of IOT edge and fog computing technologies to develop Smart Building Services,” Sustainability, vol. **10**, no. 11, p. 3832, Oct. 2018. doi:10.3390/su10113832

[8] I. Martín Toral, I. Calvo, E. Villar, J. M. Gil-García, and O. Barambones, “Introducing security mechanisms in OpenFog-compliant smart buildings,” Electronics, vol. **13**, no. 15, p. 2900, Jul. 2024. doi:10.3390/electronics13152900

[9] A. Seitz et al., “A fog architecture for decentralized decision making in smart buildings,” Proceedings of the 2nd International Workshop on Science of Smart City Operations and Platforms Engineering, Apr. 2017. doi:10.1145/3063386.3063768

[10] E. Maltezos et al., “A smart building fire and gas leakage alert system with edge computing and NG112 emergency call capabilities,” Information, vol. **13**, no. 4, p. 164, Mar. 2022. doi:10.3390/info13040164

[11] A. S. Shah, H. Nasir, M. Fayaz, A. Lajis, and A. Shah, “A review on energy consumption optimization techniques in IOT based Smart Building Environments,” Information, vol. **10**, no. 3, p. 108, Mar. 2019. doi:10.3390/info10030108

[12] A. Maatoug, G. Belalem, and S. Mahmoudi, “Fog computing framework for location-based energy management in Smart Buildings,” Multiagent and Grid Systems, vol. **15**, no. 1, pp. 39–56, Mar. 2019. doi:10.3233/mgs-190301

[13] X. Xu et al., “Intelligent offloading for Collaborative Smart City Services in edge computing,” IEEE Internet of Things Journal, vol. **7**, no. 9, pp. 7919–7927, Sep. 2020. doi:10.1109/jiot.2020.3000871

[14] M. Al-gaashani, M. S. Ali Muthanna, K. Abdukodir, A. Muthanna, and R. Kirichek, “Intelligent System Architecture for Smart City and its applications based Edge Computing,” 2020 12th International Congress on Ultra Modern Telecommunications and Control Systems and Workshops (ICUMT), pp. 269–274, Oct. 2020. doi:10.1109/icumt51630.2020.9222460

[15] A. M. Farooqi, M. A. Alam, S. I. Hassan, and S. M. Idrees, “A fog computing model for VANET to reduce latency and delay using 5G network in Smart City Transportation,” Applied Sciences, vol. **12**, no. 4, p. 2083, Feb. 2022. doi:10.3390/app12042083

[16] J. Choi and S. Ahn, "Scalable Service Placement in the Fog Computing Environment for the IoT-Based Smart City," Journal of Information Processing Systems, vol. 15, no. 2, pp. 440-448, 2019. doi: 10.3745/JIPS.03.0113.

[17] T. Bidilă, R. N. Pietraru, A. D. Ioniţă and A. Olteanu, "Monitor Indoor Air Quality to Assess the Risk of COVID-19 Transmission," 2021 23rd International Conference on Control Systems and Computer Science (CSCS), Bucharest, Romania, 2021, pp. 356-361, doi: 10.1109/CSCS52396.2021.00065.

[18] R. -A. Craciun, R. N. Pietraru and M. A. Moisescu, "Secure IoT Gateway: The First Layer of Cybersecurity for Secure Infrastructure in Smart Cities," 2023 IEEE International Smart Cities Conference (ISC2), Bucharest, Romania, 2023, pp. 1-5, doi: 10.1109/ISC257844.2023.10293352.

[19] R. N. Pietraru, A. Olteanu, A. Ş. Velicu and R. -A. Craciun, "Healing IoT Data for Indoor Air Quality Using Artificial Intelligence," 2024 E-Health and Bioengineering Conference (EHB), IASI, Romania, 2024, pp. 1-4, doi: 10.1109/EHB64556.2024.10805630.