Fire Security Systems Analysis and Internet of Things Implications

Susana Rodriguez Fuerte, Xinrui Yu, and Jafar Saniie
Embedded Computing and Signal Processing Research Laboratory (http://ecasp.ece.iit.edu/)
Department of Electrical and Computer Engineering
Illinois Institute of Technology, Chicago, IL, U.S.A.

***Abstract*— This paper presents the current use of the Internet of Things (IoT) in fire evacuation and extinction. It examines the different approaches to the problem and technologies like Building Information Modeling (BIM) and mathematical algorithms that can be used to determine the optimal evacuation route. It also evaluates existing fire security solutions such as smoke, flame, motion, and gas sensors, LED lights, buzzers, and SMS modules. Entities that specialize in Residential and Commercial Security Systems and Home Automation are also discussed, along with the services they offer. The main objective of this study is to understand current systems and resources regarding fire evacuation and extinction systems and to analyze different developments in smart buildings to create an efficient system for fire detection and evacuation.**

Keywords—fire, evacuation, extinction, IoT, Building Information Modeling

I. INTRODUCTION

When a fire appears in a house, it often takes a few minutes before everything starts burning, and consequently, evacuation is an optimal and secure option. Each second counts in this type of situation, and to optimize those seconds, the IoT (Internet of Things) is the best option for determining rapid evacuation actions. IoT refers to a collection of physical objects, commonly referred to as "things", that have been equipped with advanced technologies such as sensors and software, which enable them to communicate and exchange data with other devices and intelligent systems through the Internet [1]. In this paper, the options of existing IoT devices related to firefighting and fire prevention systems are analyzed.

There are many different approaches to the problem of how to improve fire evacuation or extinction using the IoTs. Nowadays, 50% of the reported firefighter casualties can be attributed to inadequate or incomplete information relating to the layout of the building and conditions of the fire. This means it is incredibly important to invest more time and money in devices that improve situational awareness. With situational awareness comes technologies such as Building Information Modeling that are being profoundly developed to improve efficiency in securing building structures [2],[3].

Nowadays, there are alternative solutions where a great variety of sensors and gadgets are used to create a more reliable system [4] and [5]. These solutions principally focus on the implementation of the IoTs to improve the efficiency of fire detection and safety and speedy evacuation.

The objective of this paper is to evaluate what is the state-of-the-art regarding fire evacuation and extinction systems using IoT technologies and the advances in smart building design, structure, and materials. Because of the swift fire spread, humans are usually not able to react to it as fast as might be needed, and therefore, tragedies occur. The problem varies depending on the type of buildings, different layouts, and variety of building materials.

Fires inside residential spaces are often big problems because of the increased use of synthetic materials in furniture, carpets, and other items. Synthetic materials are highly combustible, so they can ignite quickly and burn at a much higher temperature than natural materials. Additionally, modern homes are built with tight insulation, making them more vulnerable to fire. The combination of these two factors can create a dangerous situation, where a fire can spread rapidly and generate toxic gases, and become uncontrollable in a short amount of time. Therefore, in this paper, we present and compare different firefighting ideas.

II. TECHNOLOGICAL APPROACH

In this section, all the findings of existing solutions for fire extinction and evacuation are explained. The different ideas mentioned in the introduction are developed in this section.

We present the concept of situational awareness solutions, which is one of the main existing problems and can be easily solved using IoT devices. The capability to acquire real-time information about the events occurring within a burning structure can save both inhabitants' and firefighters' lives. Resources such as Building Information Modelling (BIM) have been utilized in the past few years to gather a vast amount of information pertaining to different phases of a building's existence. Similarly, the real-time status of a building can be obtained through Internet of Things (IoT) systems that are bolstered by a variety of sensors. This information can be combined with BIM to enable real-time analysis and visualization of the fire's development [2].

Another approach to this matter is that although some houses have a simple layout and are easy to exit, other infrastructures have large and intricate architectural spaces. In these cases, routing decisions hold significant importance and must be

supported by automated techniques to enhance both efficiency and precision.

Based on the BIM platform, optimal evacuation and rescue routes have been derived by some scholars [3] through the use of mathematical algorithms. In this research, the BIM Industry Foundation Classes (IFC)-based model was mapped from 3D to 2D grids for finding the shortest path while using the Fast-Marching Method (FMM). Thanks to this process, rich semantic information is obtained about houses. The results obtained from this work showed that this method of finding paths is more precise than some other conventional algorithms such as the Ant Colony Algorithm (ACA).

Chen and Chu [6] use network analysis combined with BIM to construct a rescue-route pathway. Medial Axis Transforming (MAT), Time-dependent Route Modelling (TDVRP), and MATLAB simulation were integrated by them. This study also takes into account the potential hazards posed by the materials used in construction, as well as the impact of pedestrian traffic on congestion levels. Their approach successfully automated the extraction of indoor building layouts based on BIM semantics and identified the most effective evacuation route using MATLAB [4]. Furthermore, a mobile application has been developed for guiding evacuees through the building interior, as outlined in [4]. Virtual reality is the focus here to achieve a variable immersive game environment (which is also very serious) to show real-time fire evacuation options. This application is capable of identifying the location of evacuees and displaying their position within 3D BIM representations. When individuals install the application and scan physical Quick Response (QR) codes, they can accurately determine their position and identify the nearest available evacuation routes. The system was tested for its robustness and functionality, and the findings demonstrated significant potential to enhance emergency management practices.

As will be seen later, some companies already use this kind of technology to provide their clients with the best service possible.

A. BIM and Sensors

Due to the benefits of BIM, it is used these days for much more than just construction. Thanks to the combination of BIM and sensors, it is easy to get real-time information on fire dynamics, which can be utilized to develop effective evacuation and rescue plans. New sensors can nowadays obtain and analyze real-time information about smoke concentration, temperature, and surrounding environment in a cost-effective way [2]. Furthermore, Chen et al. [3] created a fire rescue system based on the BIM model and the IoT sensor data. Evacuation routes, based on real-time data, can be calculated to help individuals steer clear of dangerous areas, ultimately reducing the risk of injuries and fatalities. Their main objective is to provide firefighters with helpful firefighting information, enabling situational awareness of the scene and create a fast and secure rescue plan. It also helps the inhabitants because when a fire starts, the model will automatically show the fire scene situation and light an escape route with LED pointers according to the on-site scenario. Similarly, Beata et al. [7] presented a BIM-based fire monitoring study that used the movement data of the fire to visualize the fire location in the BIM model. This study can provide coordinate information for fire localization as well. This work is a good example of how modern technologies can be used for controlling and monitoring fire, and sensor-assisted firefighting. A simplified example of how BIM solutions can be is shown in Fig. 1.

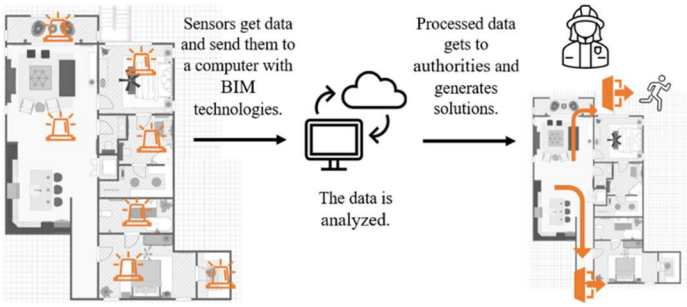

Fig. 1. Overview of BIM solutions against fire

Cheng et al. [8] introduced this idea by presenting a network system that uses BIM and Bluetooth to realize evacuation procedures and fire studying functions. Additionally, it leverages personal location data and a mobile device to design and implement a smart framework for preventing fire disasters. Li et al. [9] incorporated a novel sequence-based algorithm and radio frequency beacons to enable indoor personnel tracking, as the standard sensing structure often fails under extreme conditions like high temperatures and thick smoke. According to test results in emergency response operations, it is proven to be highly effective in facilitating immediate and real-time communication.

Despite the combination of BIM and gathered sensor data that have helped in the field of fire monitoring, the BIM application cannot provide an immersive environment for making rescue-related decisions [1]. Still, if a powerful enough platform was created, the results would be more satisfactory, and the fire evacuation methods would improve.

B. IoT integration

The main goal of these proposals is to use the benefits of IoT to create a better solution for the problem at hand. IoT enables efficient data sensing, robust transmission, and a centralized and functional fire security system.

Summarizing the main ideas, the IoT consists of a recompilation of data from the environment in real-time and processing all this data to generate a response to achieve a goal, in this case, fire evacuation and extinction. In Fig. 2, an example of this is explained in more detail [10].

The perception layer collects the necessary data and transmits it to the user information transfer module using either WiFi or Controller Area Network (CAN) bus. To guarantee the dependability and security of the data transfer, the transport layer employs double encryption using RSA+AES. The storage layer utilizes a unified storage system as an efficient storage database. This database is utilized to store fire monitoring information from buildings, which is transmitted to the cloud server over the Internet. The cloud server processes this information to provide support for the smart decision and application layers that follow. Within the decision layer, the data is used to trigger fire monitoring alarms and evaluate fire safety.

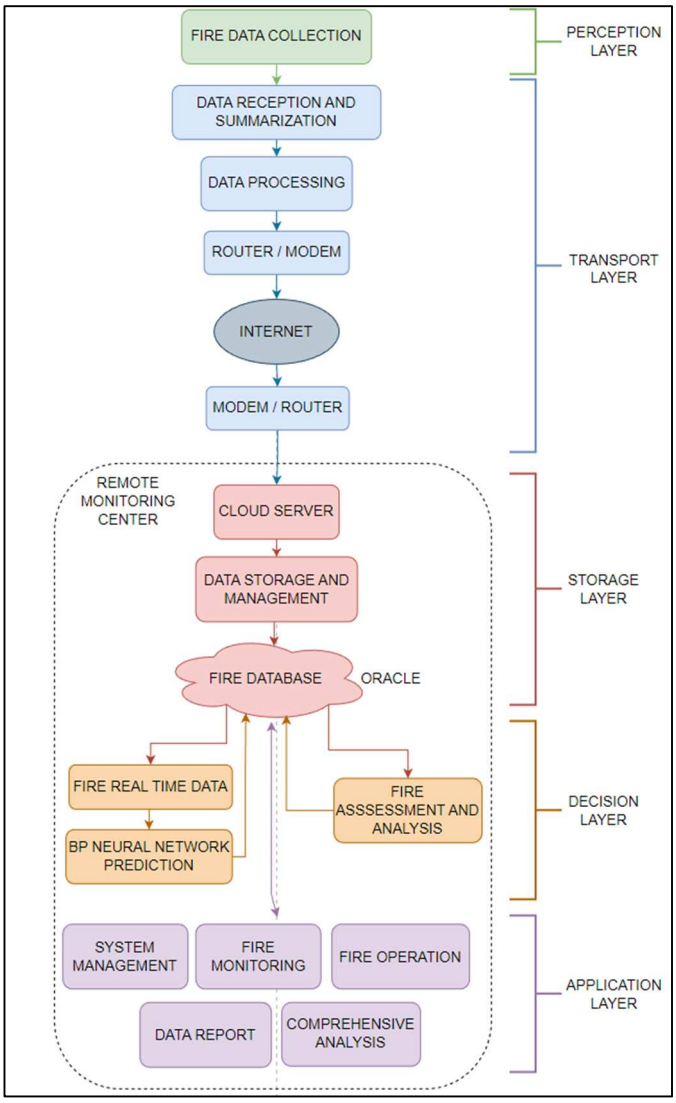

Fig. 2. System Architecture for Fire Monitoring Based on IoT [9]

The application layer, on the other hand, serves as the interface between the monitoring system and the end user. The management team has access to real-time information about the building's location, temperature and humidity readings of the surrounding environment, and sensor readings like pipe flow, pressure, etc. as well as. On top of that, the monitoring system has two additional modules: user management, allowing management personnel to add and delete users, modify user information, and manage user privileges; site management, which manages each monitoring site, including basic information such as additions and deletions. and site management, which facilitates the administration of each monitoring location, including the addition and removal of locations, and maintenance of basic site information.

Once the general structure of the IoT fire prevention system is clear, some existing ideas of the IoT implementation are explained. In [11], various sensors currently available on the market, such as smoke detectors, thermal detectors, flame detectors, etc., are analyzed as potential new technologies for fire detection. The combination of all these technologies helped in the design of a new architecture for fire security systems. This new system includes smoke, flame, motion and gas detectors, LED lights, buzzers, display panels, GPSs, and SMS modules, all managed by an Arduino microcontroller. This device enhances the effectiveness of fire security systems thanks to the incorporation of the IoT. By utilizing advanced sensors, this fire security system can effectively detect signs of fire, such as rising temperatures and the detection of flames, gases, and/or smoke. In the event of an emergency, the system is capable of immediately alerting building occupants and fire departments via audio and visual alarms, as well as SMS notifications sent by the integrated modules. In this research, it is shown that this system is capable of rapidly responding to critical situations, which is a significant improvement over traditional fire security systems that often require a considerable amount of resources and effort to resolve similar emergencies.

Reference [12] also uses different technologies to detect fire and smoke, such as flame and gas detectors, and send alerts to occupants and fire departments. The real-time fire status is determined by monitoring the readings from these sensors, and the design is created using Proteus software, with the codes written in Arduino IDE. ThingSpeak, which is MATLAB compatible, is then used to analyze the obtained information. The components utilized in this system include Atmega 328P, flame and gas detectors, water pump, and a Wi-Fi module. The proposed system utilizes several software programs, including Proteus, Arduino IDE, and Android Studio, for circuit design and simulation purposes.

The block diagram presented in Fig. 3 illustrates the interconnection of different subsystems required to create a operational system. Although this diagram corresponds to the technology developed in [12], it is sufficiently general to use in other applications.

To avoid the disadvantage of installing many wires when using a new fire prevention system, [13] proposes a simple-to-install system consisting of multiple interconnected nodes that are distributed throughout a house. Each node comprises a microcontroller with embedded devices, such as Wi-Fi, that are connected to flame and smoke detectors, thermometers, hydrometers, and CO_2 sensors. These sensors monitor the environment for fire detection without interruption. The interconnected nodes form a Wi-Fi network. Additionally, a Raspberry Pi with a cellular module is utilized to communicate with a center node that is connected to the other nodes via a bridge node. When a fire is detected, the system immediately sends an SMS message to both the resident and the fire department.

In reference [14], a wireless sensor network (WSN) was developed and built to detect fire in real-time with high accuracy by monitoring the surrounding environment. To do so, a number of detectors and sensors specialized in the early detection of house fires were used. A cellular module was also incorporated

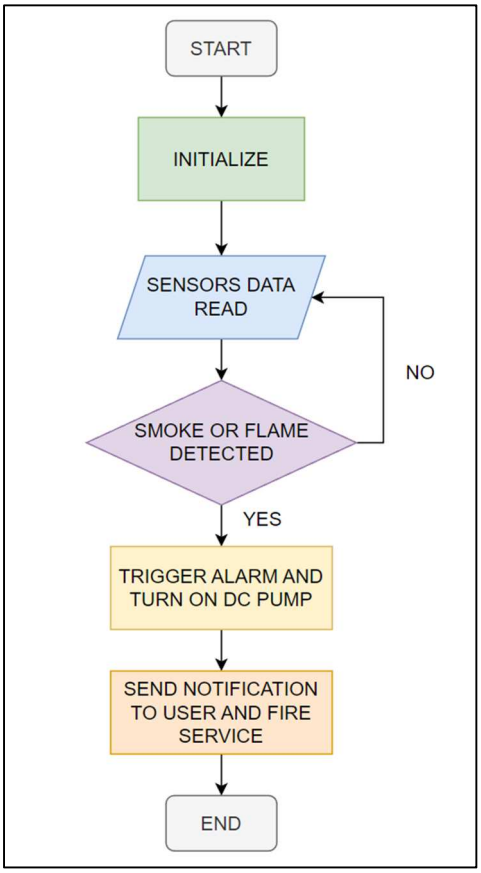

Fig. 3. Safety and Fire Protection Design Flow for Smart Buildings [11]

into the system to send notification messages while avoiding false alarms. The system was able to detect fires at an early stage, even when some of the sensors/detectors were non-operational, with a low power consumption suitable for the task. Similarly, [15] explored the development and implementation of a fire alarm and detection system that uses a microcontroller to read sensor data and a cellular module to send notifications to both users and fire departments in the event of a fire. The proposed method is more cost-effective and has medium coverage versus conventional wireless fire alarms. It is a method that can detect, alert, and control fire and fire-related incidents in a residential setting or industrial environment.

[16] utilized embedded systems like Arduino and Raspberry Pi to develop a system that could effectively detect and alert the affected area in the presence of fire. This approach was successful in achieving the desired outcome. The system senses smoke in the room´s air due to fire and takes real-time images via a camera installed inside the room when there is fire. As soon as the smoke detector is triggered, the system shows a picture of the room via a webapp. The system requires the user to verify and authorize contacting the fire department with text messages. The benefit is that it will reduce the chances of false alarms. As only one photo is captured, the system has low power consumption and requires very little storage capacity.

III. State-of-the-art in Firefighting Resources

Many studies have been commented on in the past sections, but only some of them were implemented in real homes. To see what people, want and need, a good approach is to see what already exists in the market and maybe what can be improved there.

Three main types of businesses are related to the topic of smart homes and fire extinction. The first one is the IoT or the smart building business. This is relatively new and is growing fast. It should incorporate the fire extinction focus to be complete. On the other hand, there are the much older companies that are the ones related to fire extinction and evacuation. These should evolve and introduce the technology in their services to be competitive with the first type. Lastly, there are technology companies that develop multiple technological fronts and some of them are related to fire extinction and evacuation.

Some companies of the first group are studied now to have the main idea of what they do. Climatec [17] is a company that provides building technologies and energy solutions in the USA. It was founded in 1975, and its goal is to create safe, comfortable, and efficient building environments. Although not their priority, they also include fire protection solutions. Another company with the same characteristics is Igor [18], Igor, Inc. was created in 2013 and aimed to start a smart building platform solution. Their main product, Nexos, is an IoT-based smart building platform that utilizes Power over Ethernet (PoE) technology to integrate hardware, software, and cloud analytics components. This integration forms a digital backbone for the building that offers high reliability, bandwidth, and security. Nexos is an innovative IoT-based intelligent building technology that provides comprehensive lighting controls with the capability to integrate with almost any IoT device or smart building application in the market, such as smoke exhaust fans and fire alarm systems.

Unfortunately, these companies that work around the IoT are not as centered on fire detection as they should be. They don´t include any of the innovations that have been studied and only introduce the security regarding fire superficially.

Regarding the second business group, many companies have integrated technology to be up to date with what the market demands. Fire Protection Company [19], for example, was formed in 1918 and is a Chicago-based sprinkler company that has been a pioneer in the industry for a century. With the advancement of technology, materials used in sprinkler systems have become more efficient and lighter. Sprinkler system design has also become a specialized field. Because of it, Fire Protection Company uses BIM Design Engineering Expertise nowadays. This is a clear example of a company that grows with the market. SimpliSafe [21] is another American home security company created in 2006 and uses advanced technology for fire evacuation problems. SimpliSafe manufactures and sells wireless security systems that can be self-installed and linked to a central monitoring center. It uses an interactive monitoring plan with video verification to quickly verify security threats. The SimpliSafe systems consist of a central hub, a keypad, and peripheral wireless accessories and sensors such as video doorbells, smart locks, door sensors, motion detectors, smoke

detectors, glass break sensors, and temperature monitors. In contrast with all the systems seen in the past sections, SimpliSafe frameworks work as a noise-only alarm system, producing an 85-decibel siren.

In between the two groups, companies such as Forest Security are found. It specializes in Residential and Commercial Security Systems and Home Automation and offers wireless or hardwired systems with NVR or Cloud Storage for surveillance. Some of the devices they use for fire detection are smoke detectors and CO sensors. Their product also includes a Remote Wireless keypad that allows controlling the system from another location from the home and a mobile app to receive notifications and control the system anywhere.

The last group is possibly the one that has advanced the most in the technical aspect of fire evacuation. Siemens is one of the companies that are part of this group, and NIST also proposes a project that matches the requirements. Siemens [23] offers customized solutions that provide maximum protection through advanced detection, alarm, evacuation, extinguishing, and fire management systems. Some of the advantages of these solutions include:

- Sinteso detector: Intelligent detectors that continuously assess situation and make decisions based on complicated criteria, minimizing the chances of false alarms triggered by environmental factors. The system will only trigger an alarm when there is genuine evidence of a fire.
- Desigo CC: This is the fire safety management platform that enhances situational awareness of events, enabling a prompt and effective feedback. This platform offers real-time visibility of the status of fire detection devices, generating responses to incidents determined by predefined rules.
- Lifecycle support: future test, inspection, and maintenance.
- Qualified staff.
- Audio alarm and evacuation: Siemens provides advanced audio streaming voice systems that can deliver automated and live messages with exceptional performance throughout multilevel buildings. These systems function as public address systems and offer sophisticated messaging capabilities.

Fig. 4 shows a graph of the Siemens integrated fire system. Another mentioned intelligent fire detection project can be found in NIST [24]. NIST proposes a project whose main idea is to gather global information from the fire ground and response area, analyze all the data, and send the outputs as decision tools to firefighting teams and other incident commands. The research strategy is centered on three primary objectives: advancing smart building technology and robotics, developing advanced firefighter equipment and robotics, and enhancing the functionality of fire department apparatus and equipment through the implementation of smart technology.

Despite most of the time smart homes and fire detection and evacuation are related, some intelligent building companies do not offer fire detection systems. One of those is LittelBird [22]. This company offers services such as control of the house lights, lock, and thermostat, scheduled temperatures, motion sensors, and sensors in doors and windows to know as soon as possible about unauthorized access. Something similar happens with SmartRent [23].

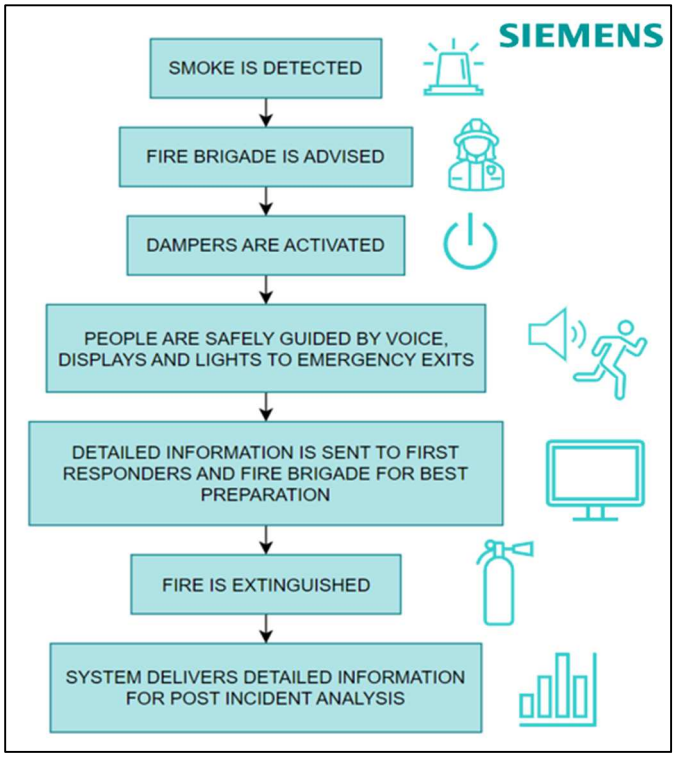

Fig. 4. Siemens integrated fire system graph [23]

IV. Other Ideas

Because of how little some IoT companies take into account the fire problem, it is interesting to study how to make them conscious of it and therefore use their advanced technology for these purposes. Surely, someone that wants to use IoT services in their house, would want to protect themselves and their loved ones against a fire situation also. And surely, it is easier to have all those services from one company only and not from different ones. So, why do IoT companies don't incorporate them?

One idea is that IoT companies are not more centered on fire prevention and evacuation systems because there are many other areas in that IoT can be used to improve safety and security. Fire prevention and evacuation systems are only one of the many ways that IoT can be used to improve safety and security. Additionally, fire prevention and evacuation systems can be expensive and complicated to install and maintain. Therefore, IoT companies may prioritize other areas where the technology can be used to provide more immediate and cost-effective solutions.

To make IoT companies more centered on fire prevention and evacuation systems, they should develop cost-effective and easy-to-install solutions that meet the needs of their customer base. Additionally, they should consider partnering with organizations such as fire departments and insurance companies

to develop and market their solutions. Finally, it is crucial for stakeholders to allocate resources towards research and development to remain current with the latest advancements and emerging trends in fire prevention and evacuation systems.

This means then, that if companies studied further some of the proposed ideas scholars have, such as the ones seen in this project, they might find an economic and perfectly viable solution to their lack of fire evacuation and prevention systems.

Another thing to take into consideration is the fact that even though firefighting companies use IoT technologies, they could use these resources more extensively. Maybe they don´t do so because of the extra cost that means, but with the development of the IoT companies, they will surely be soon left behind in that matter. They should start as soon as possible implementing new solutions to still be the best at what they do.

V. Conclusions

From what was just studied, it can be concluded that there are so many ideas in the market regarding the improvement of fire evacuation systems. Some of the ideas studied are economic and easily implemented while others do not talk about the economic perspective. This could be another approach for further research. The conclusion is also that the IoT can provide a more efficient and accurate way of detecting and responding to fire outbreaks, while also providing more reliable communication between firefighters and building occupants. As it has been seen, a great number of new technologies involve interacting with the user or the person living in the house (via SMS, GSM…) to inform them of the danger they are facing. This is an example of an easy solution to avoid false alarms and fast realization of the fire. Some more complicated solutions could be the use of microcontrollers and nodes all around the house. Although easy to install, it is a complex technology that companies would have to invest in. Sadly, despite all these good ideas, the market has not introduced them completely and there is still a lot of work to do in that field. On the other hand, the companies that were born as firefighting companies do incorporate new technologies and answers to improve their systems. They have many developed ideas and solutions such as mobile applications, remote wireless keypads, BIM studies, etc.

References

[1] R. Eftekharirad, M. Nik-Bakht, and A. Hammad, "Extending IFC for fire emergency real-time management using sensors and Occupant Information," *EasyChair Preprints*, 2018.

[2] H. Chen, L. Hou, G. (K. Zhang, and S. Moon, "Development of BIM, IOT and AR/VR Technologies for Fire Safety and Upskilling," *Automation in Construction*, vol. 125, p. 103631, 2021.

[3] Y.-H. Lin, Y.-S. Liu, G. Gao, X.-G. Han, C.-Y. Lai, and M. Gu, "The IFC-based path planning for 3D Indoor Spaces," *Advanced Engineering Informatics*, vol. 27, no. 2, pp. 189–205, 2013.

[4] X.-S. Chen, C.-C. Liu, and I.-C. Wu, "A BIM-based visualization and warning system for fire rescue," *Advanced Engineering Informatics*, vol. 37, pp. 42–53, 2018.

[5] P. A. Beata, A. E. Jeffers, and V. R. Kamat, "Real-time fire monitoring and visualization for the post-ignition fire state in a building," *Fire Technology*, vol. 54, no. 4, pp. 995–1027, 2018.

[6] B. Wang, H. Li, Y. Rezgui, A. Bradley, and H. N. Ong, "Bim based virtual environment for fire emergency evacuation," *The Scientific World Journal*, 13-Aug-2014. [Online]. Available: https://www.hindawi.com/journals/tswj/2014/589016/. [Accessed: 04-Feb-2023].

[7] M.-Y. Cheng, K.-C. Chiu, Y.-M. Hsieh, I.-T. Yang, J.-S. Chou, and Y.-W. Wu, "BIM integrated smart monitoring technique for building fire prevention and disaster relief," *Automation in Construction*, vol. 84, pp. 14–30, 2017.

[8] N. Li, B. Becerik-Gerber, B. Krishnamachari, and L. Soibelman, "A BIM centered indoor localization algorithm to support building fire emergency response operations," *Automation in Construction*, vol. 42, pp. 78–89, 2014.

[9] Y. Li, J. Yi, X. Zhu, Z. Wang, and F. Xu, "Developing a fire monitoring and control system based on IOT," *Developing A Fire Monitoring and Control System Based on IoT | Atlantis Press*, 01-Nov-2016. [Online]. Available: https://www.atlantis-press.com/proceedings/aiie-16/25866342. [Accessed: 04-Feb-2023].

[10] F. S. Perilla, G. R. Villanueva, N. M. Cacanindin, and T. D. Palaoag, "Fire safety and alert system using Arduino sensors with IOT integration," *Proceedings of the 2018 7th International Conference on Software and Computer Applications*, 2018.

[11] K. E. Jack, A. S. Adigun, F. A. Adewale, and A. B. Inyang, "Improved Fire Safety and protection model for smart buildings with internet of things," *The 5th International Conference on Future Networks & Distributed Systems*, 2021.

[12] A. Mahgoub, N. Tarrad, R. Elsherif, A. I. Al-Ali, and L. Smail, "IoT-Based Fire Alarm System," *in Third World Conference on Smart Trends in Systems Security and Sustainablity (WorldS4)*, pp. 162–166, 2019.

[13] F. Saeed, A. Paul, A. Rehman, W. H. Hong, and H. Seo, "IoT-Based intelligent modeling of smart home environment for fire prevention and safety," *J. Sens. Actuator Networks*, vol. 7, no. 11, pp. 1–16, 2018.

[14] A. A. Izang, S. W. Ajayi, C. B. Onyenwenu, F. Adeniyi, and A. Adepoju, "An SMS Based Fire Alarm and Detection System," *Int. J. Comput. Trends Technol.*, vol. 58, no. 1, pp. 58–61, 2018.

[15] M. S. B. Bahrudin and R. A. Kassim, "Development of Fire Alarm System using Raspberry Pi and Arduino Uno," *in 2013 International Conference on Electrical, Electronics and System Engineering (ICEESE*), pp. 37–42, 2013.

[16] "About Climatec," *Climatec*. [Online]. Available: https://www.climatec.com/company. [Accessed: 04-Feb-2023].

[17] Igor, "DC Power & Igor Solutions: Innovative smart building technology," *DC Power & Igor Solutions: Innovative Smart Building Technology*, 28-May-2020. [Online]. Available: https://www.igor-tech.com/news-and-insights/articles/how-dc-power-and-iot-technology-will-revolutionize-your-next-building. [Accessed: 04-Feb-2023].

[18] "About us - fire protection company ," *Fire Protection Company*. [Online]. Available: http://www.fireprotectioncompany.com/about-us/. [Accessed: 04-Feb-2023].

[19] SimpliSafe, "Smart Alarm Systems & Home Security: SimpliSafe," *SimpliSafe Home Security Systems*. [Online]. Available: https://simplisafe.com/security?pcrid=634258387565. [Accessed: 04-Feb-2023].

[20] *Smart home technology for multifamily properties*. [Online]. Available: https://www.golittlebird.com/products/smart-home. [Accessed: 04-Feb-2023].

[21] "SmartRent products and solutions offerings," *SmartRent*. [Online]. Available: https://smartrent.com/products/. [Accessed: 04-Feb-2023].

[22] "What is the internet of things (IOT)?," *What Is the Internet of Things (IoT)?* [Online]. Available: https://www.oracle.com/internet-of-things/what-is-iot/. [Accessed: 04-Feb-2023].

[23] "Smart Fire Safety Solutions - Advanced Protection for people, assets and services ," *siemens.co.uk*. [Online]. Available: https://new.siemens.com/uk/en/products/buildingtechnologies/smart-fire-safety-solutions.html. [Accessed: 09-Feb-2023].

[24] "Smart fire fighting," *NIST*, 12-May-2021. [Online]. Available: https://www.nist.gov/programs-projects/smart-fire-fighting. [Accessed: 09-Feb-2023].