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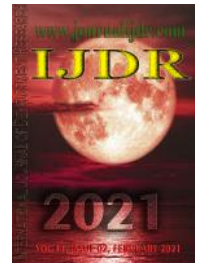
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RESEARCH ARTICLE

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## OVERVIEW OF ENGINEERING FIRE PROTECTION SOLUTIONS IN STRUCTURES

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### ABSTRACT

Fires can cause immeasurable consequences both for material goods and for living beings. So, it is essential to seek ways to prevent their occurrence and impact. In order to achieve this goal, it is necessary to invest in the development of preventive and protective measures. In the event of a claim, active protection systems are of significant importance for damage reduction. Therefore, this article aims at describing the main firefighting systems in structures, highlighting their advantages and disadvantages, and the trends of technological development through the analysis of patents. The results of the study showed that the technologies consolidated in the market, such as fire extinguisher and sprinkler, have a significant percentage of expired patents, indicating that technological knowledge is in the public domain. Technologies such as fire-fighting drone and sonic extinguisher, are emerging, as they have a high number of active patents, and due to their advantages, they reveal the potential for application in the area. Besides that, it was also found that world trends, such as Artificial Intelligence and the development of new materials, are being used to improve the combat and, consequently, mitigate the damages.

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## INTRODUCTION

Fire is an exothermic chemical reaction caused by the combination of three distinct elements which consists of: fuel and oxidizer, usually the oxygen present in the air, and heat, sufficient to cause ignition. The suppression of one of these elements extinguishes the fire. Therefore, combat can take place in three different ways: Isolation, by removing fuel; muffling, which is subtraction of oxygen; and cooling, which consists of reducing heat, which can occur with the introduction of extinguishing agents. It can also generate a chain reaction, which is a sequence of reactions triggered by an element or group of elements that cause new reactions (OLAWOYIN, 2018; QUINTIERE, 2016; BENSON, 2020). Fires can cause immeasurable losses both in material goods and in living beings. Structural fires represent the highest percentage of reported fires, accounting for 37.3% of occurrences (BRUSHLINSKY et al., 2019). Structural fires are those that occur in residential and commercial buildings and historic buildings, for example. In general, the implementation of firefighting systems in structures is primarily aimed at protecting people, seeking to eliminate, or at least mitigate, the number of victims in the event of an accident (CHU; SUN, 2008).

However, even though the protection of lives is the main objective, many objects, works of art, documents, historical buildings, have immeasurable value to society, and their deterioration can compromise important records for culture and society. (ONO, 2004; SÁ; SÁ; LIMA, 2018; VANNUCCI; MAIS; STEFANO; MAFFI-BERTHIER, 2019). In addition, it can cause a substantial impact, both emotional and economic, for the affected community (ANTUNES; GOUVEIA, 2012). Fires can also affect forests (ETHELLES et al., 2020; FREITAS et al., 2020; NIGRO; MOLINARI, 2019; SANNIGRAHI et al., 2020), undergrowth (SCHMIDT; ELOY, 2020; SANSEVERO et al., 2020 ; COLLINS, KM; PRICE, OF; PENMAN, 2018; SYPHARD, AD; KEELEY, JE; ABATZOGLOU, 2017; ROLDAN-NICOLAU, 2020), vehicles (ZHANG et al., 2019; AHRENS, 2013; LI, 2019), among others.

Industrial and manufacturing property fires cause severe losses. In the United States alone, an estimated loss of more than \$ 1 billion annually and in addition to causing injuries and death to civilians (Campbell, 2018). Industrial fires can be caused by different factors, such as: combustible dust, hot work, flammable liquids and gases and electrical hazards (Kay and Mazur, 2020; Aronstein and Lowry, 2011).

Table 1. Advantages and disadvantages of the analyzed technologies

System	Extinguishing agent	Advantages	Disadvantages
Sprinkler	Water	Most used system in buildings; Fully automatic (due to the bulb).	Water damage after the fire; Need for pipes; Technical water reservoir; Pump station; It may take time to be triggered (bulb rupture).
Fixed System	CO <sub>2</sub> ; Clean agent.	Quick start; Does not cause damage after extinction.	Need for pipes; It depends on detection systems.
Hydrant	Water	Lower cost compared to the sprinkler and fixed system.	It depends on the action of the fire department or a trained operator; Technical water reservoir; Needs structural intervention for installation; Pump station; Water damage after the fire.
Modular system	Agente limpo; Wet chemical; Pó químico.	Does not cause damage after extinction; Modular; Installation flexibility; Fully automatic (due to bulb).	It may take time to be triggered (bulb rupture).
Sonic Fire Extinguisher	Air	Leaves no residue; It does not need to be refilled; It works by sound frequencies.	Under development; There is no usage history; Still applied to small fires.
Firefighting robots	Water; Foam; Wet chemical; CO <sub>2</sub> ; Clean agent; Chemical dust.	Flexibility for extinguishing fires; It does not need a fixed installation; Does not cause damage after extinction.	High value per unit; It depends on detection systems; Combat can take a while to start.
Firefighting drone	Water; Foam; Wet chemical; CO <sub>2</sub> ; Clean agent; Chemical dust.	Flexibility for extinguishing fires; It does not need a fixed installation; Does not cause damage after extinction.	High value per unit; It depends on detection systems; Combat can take a while to start.
Firefighting trailer	Water; Foam; Wet chemical; CO <sub>2</sub> ; Clean agent.	It does not need a fixed installation; Does not cause damage after extinction;	It depends on detection systems; Combat can take a while to start.
Fire extinguisher	Water; Foam; CO <sub>2</sub> ; Wet chemical; Clean agent; Chemical dust.	Simple installation; Low cost.	It depends on human intervention and detection systems; Combat can take a while to start; Indicated for fires in initial phase.

Table 2. Analysis in patent banks of fire extinguishing systems

Types of protection systems	Related patents	Synthesis	Market application
Sprinkler	CA2884358C	The patent refers to a hidden, quick-response sprinkler with a flat plate design that inlays the sprinkler above the ceiling. The design prevents the sprinkler from being visible. The activation occurs with the temperature increase caused by the fire.	Technology available on the market.
	WO2017218538A1	The document presents a sprinkler actuator, which can be of several types of mechanisms, such as, for example, a pyrotechnic or solenoid. With the detection of the fire, a signal is emitted, for the actuator to burst the sprinkler's glass bulb, releasing the passage of water.	Technology available on the market.
	KR20060115511A	The invention proposes a device to open the water passage in the sprinkler when reaching the pre-defined temperature, and to close the water passage with the temperature reduction, due to the extinguishing of the fire. This prevents the entire technical water reservoir from being discharged, spraying the water until the fire is extinguished.	No recent marketing information for this product
	CN104096333B	The patent features a quick-response sprinkler, which uses a fusible traction part with greater sensitivity to temperature compared to the traditional solution, promoting the early start of the system.	Technology available on the market.
Fixed System	CN107929992A	The system has self-adaptive nozzles, which by means of sensors identify the focus of the fire and from controllers, direct the jet of the extinguishing agent at the location of the focus, increasing the effectiveness of the action.	No recent marketing information for this product
	CN110237460A	The patent refers to a fire extinguishing system for buses, which has a fire extinguishing tank connected to the transport system and power supply module, gas release device and sensitive linear detection line connected to the control module.	Technology available on the market.
	JP5323122B2	The present invention features a system composed of a gaseous extinguishing agent and a liquid extinguishing agent. At least one emitter is in fluid communication with the liquid and the gas. The emitter is used to establish a gas stream, atomize and drag the liquid into the gas stream and discharge the resulting liquid gas stream into the fire.	No recent marketing information for this product
	KR101531478B1	The patent addresses fire protection devices, systems and methods by spraying water mist. Using spray heads coupled to a piping system connected to a water supply. In the presence of the fire, the valve is opened by spraying water mist to extinguish the fire.	Technology available on the market.

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	US9382696B2	The document features a blocking hydrant, with a locking lid that prevents unauthorized access, but has a mechanism simple enough for authorized access by firefighters. The fire hydrant was also designed to work efficiently in cold weather.	Technology available on the market.
Hydrant systems	US20200054911A1	The present invention provides an apparatus for identifying irregular flow from the hydrant water outlet, in order to prevent unauthorized water fraying.	Technology available on the market.
	EP3245341A1	The patent proposes a hydrant system with adjustable length. It consists of a body made of cast material, a telescopic body, and a fixing flange, to lock the equipment at the desired height.	No recent marketing information for this product
	KR101893898B1	The invention describes a hydrant with embedded sensors that monitors the pressure, temperature, and presence of vehicles parked close to the hydrant. It also has a speaker to emit a voice message, an image unit to create image information with wired and wireless communication.	No recent marketing information for this product
Modular system	US20060131035A1	The document presents a modular fire extinguishing system composed of an extinguishing agent storage tank, a sprinkler coupled to the tank to disperse the extinguishing agent, a valve mechanism for releasing the agent, an inlet for pressurization, and a fire detection system. In the presence of the fire, the sensor sends a signal to the valve mechanism that releases the extinguishing agent to suppress the fire.	Technology available on the market.
	RU2719099C1	The patent describes a modular system consisting of a tank, which contains a pressurized extinguishing agent and a radiator with a sprinkler, coupled to the tank. The device can act from a remote control, by means of an electric start, or automatically activated, by increasing the ambient temperature. The sprinkler with radial outlets increases the spray area and the flow uniformity of the extinguishing agent.	No recent marketing information for this product
	CN203539949U	The invention consists of a modular fire extinguishing system with embedded IoT technology. It comprises a tank with pressurized chemical powder for the suppression of fire, a monitoring and control module, by means of sensors, alarms and a signal processing platform, which performs the performance of the system.	No recent marketing information for this product
Sonic Fire Extinguisher	US10569115B2	The system uses low frequency sound waves, between 20 Hz and 160 Hz, to extinguish the fire. It comprises a transducer configured to receive a signal and emit a longitudinal wave based on the received signal. It also has a wave intensifier attached to the transducer and configured to direct the longitudinal wave.	No recent marketing information for this product
	US10420971B2	The invention exposes an electronic fire suppression method that transmits an electromagnetic wave pattern with frequencies, powers and durations with specific configurations to separate and isolate combustion components, in order to suppress and extinguish the fire.	No recent marketing information for this product
	CN107007961A	The present invention relates to a type of extinguisher with acoustic pressure of adjustable size, including power supply, signal generator, power amplifier and speaker. The signal generator produces a low frequency analog frequency of about 65Hz.	No recent marketing information for this product
	KR101881550B1	The device promotes double fire extinguishing, through sound waves and injection of liquid crystal carbon dioxide capsule. The sound waves generated by the signal generator are transmitted to the fire through the loudspeaker. The expansion and contraction tube is used to remove oxygen, and carbon dioxide is injected to quickly fire the fire.	No recent marketing information for this product
Fire fighting robots	CN109999391A	The invention consists of a type of intelligent fire extinguishing robot, the robot has a mobile platform and machines mounted on the platform, such as an adaptable mechanical arm and a hose that is connected to the tank that stores the extinguishing agent and uses a pump to project the agent into the fire.	No recent marketing information for this product
	CN107193277A	The invention describes firefighting robot and control method, autonomous type, which detects and extinguishes fire without human presence. The system consists of a robot body, mobile chassis, image acquisition module and main controller, which processes the input signals and sends the necessary commands for the extinguishing of the fire.	No recent marketing information for this product
	US8973671B2	The proposed invention is a fire fighting robot for indoor environments, which has the ability to climb stairs and move over different materials. It can withstand very high temperatures of up to 700 ° C for about 60 minutes using the multiple thermal insulation technique.	Technology available on the market.
	CN110102002A	The invention discloses a fire fighting robot based on the Artificial Intelligence system and method, including: central high-speed computing processing platform, fire fighting robot, AI supercomputer processing platform.	No recent marketing information for this product
Fire fightingdrone	CN109464766A	The document shows a method of fire fighting with drones. Developed especially for firefighting in tall buildings, it features a foldable fuselage design and a high magnification camera, to identify the location of the fire, and launch the extinguishing projectile into the focus of the fire.	Technology available on the market.
	KR20170133619A	The invention proposes disposable drones to carry out fire extinguishing. Configured to be able to land on the flame and spray the extinguishing agent over the fire. They are controlled by remote control, they can fly quickly to the fire area, landing in flames like kamikaze.	No recent marketing information for this product

	US10413763B2	The present invention relates to a fire extinguishing system that makes it possible to freely execute the ground and flight movement and can be operated remotely in an unmanned manner, from the connection with a central control system.	No recent marketing information for this product
	CN105667795A	The patent shows a system for launching fire extinguishing pumps for an unmanned aerial vehicle, a drone. The system is controlled by an earth station, which includes a portable machine and the wireless station, in which it processes the data, to position the device and launch the extinguishing pumps.	Technology available on the market.
Fire fighting trailer	US20050126631A1	The patent describes a vehicle that enables use in fire fighting and emergency rescue in remote areas or in other areas normally inaccessible to the fire department. The vehicle comprises front and rear units connected by an articulated joint to improve the mobility and agility of the vehicle. The vehicle has a pump, hose, nozzle, hose storage reel and tank for the extinguishing agent stock.	Technology available on the market.
	US6142238A	The invention addresses a method to fight forest fires, which consists of a coupling set that allows a tank of fluid to be towed by means of a tractor to the fire site, especially with the purpose of spraying and creating a foam for fire suppression .	Technology available on the market.
	CN207371009U	The patent features a simple portable fire trailer that has a trailer chassis, reservoir chamber, three-way valve B, pump chamber, spray water belt, gasoline engine fire pump set, three-way valve A, suction hose.	Technology available on the market.
	WO2012068649A1	The proposed invention describes a discharge system based on CO <sub>2</sub> in a liquid state, at low temperature and under high pressure. The system has a liquid CO <sub>2</sub> tank, power source, feed pumps, vaporizers, high-speed, high-flow hoses, nozzles, diffusers and deflectors for setting CO <sub>2</sub> release and parameter control panel.	Technology available on the market.
Fire Extinguisher	BR102018011520A2	The invention consists of a fire fighting system with automatic or remote activation, loaded with extinguishing agents and explosive charge. When activated, it explodes by spraying the extinguishing agents in the environment. It also allows manual use when launched into the fire, exploding upon contact with flames.	No recent marketing information for this product
	WO2019136327A1	The invention relates to a dynamic fire suppression system, which has a valve that allows manual or remote activation in response to a fire condition emitted by sensors. The system also includes a mechanism for notifying about the status, which can communicate a fault signal to the control panel.	No recent marketing information for this product
	RU2607770C1	The invention proposes the application of nanotechnology to fight fire. The fire-fighting method uses a compacted nanopowder extinguishing agent in a kind of capsule that is launched against the fire by means of a launcher. Upon entering into a contact with the fire, the capsule is destroyed and the nanopowder extinguishes the fire.	No recent marketing information for this product
	KR20190134235A	The invention addresses a fire extinguishing capsule installed in a stick-shaped device. In the presence of fire, the system automatically heats and sprays the extinguishing agent. Quickly extinguishes the most common types of fire with a combination of chemical and physical mechanisms.	Technology available on the market.

And in residences, fires occur mainly due to cooking activities caused an annual average of 550 civilian deaths, 5,020 civilian injuries and \$1.2 billion in property damage (Ahrens, 2019). However, these tragedies can be avoided, or minimized, with adequate means of prevention and protection, with this, the need for more efficient fire-fighting systems is evidenced (OLAWOYIN, 2018). Therefore, it is essential to develop technologies that improve the effectiveness of fire prevention and suppression systems. In addition to the social benefit, the development of new technologies can constitute a substantial competitive advantage for organizations (KIM; LEE, 2017). For this reason, it is essential to understand the state of the art of the field of study in question, and consequently, develop research that contributes to the expansion of the frontier of knowledge. Therefore, the study aims at preventing the main firefighting solutions in structures, both the technologies consolidated in the market, and those under development. Thus, evidencing its advantages, disadvantages, main characteristics and trend of technological development through the analysis of patents and scientific articles.

**FIRE EXTINGUISHING SYSTEMS:** This section presents the main fire extinguishing solutions, some of which are already consolidated in the market and others are still under development.

These systems have advantages and disadvantages, and their choice depends on a cost-benefit analysis, taking into account the interfaces of the place you want to protect. Table 1 shows the advantages and disadvantages of the main firefighting systems: sprinkler, fixed gas system, hydrant, modular system, sonic extinguisher, firefighting robot, firefighting drone, firefighting trailer and extinguisher fire.

#### **PATENT SEARCH FOR FIRE EXTINGUISHING SYSTEMS:**

This section presents a search for priority, through patents on fire extinguishing systems. The oldest patent for a fire extinguisher patent was granted to chemist Ambrose Godfrey in 1723 in England. It is a barrel with an extinguishing agent containing a powder tin chamber, connected to a fuse system, which in the presence of fire, the powder explodes, dissipating the extinguishing agent. This device achieved notoriety due to its efficiency in extinguishing a fire in London (COTE; BUGBEE, 1988; AHMED; MANSOR; ALBAGUL, 2015). From Godfrey's invention to the present, different firefighting systems have been developed and patented. In order to identify trends in the development of engineering solutions, the legal status of each of the combat systems analyzed was mapped using Derwent innovation software, in order to identify the percentage of active and expired patents, this information allows to identify whether the technology is emerging or not. Thus, Figure 1 shows the legal status of the analyzed technologies.

Analyzing Figure 1, it is observed that the technologies consolidated in the market, such as fire extinguisher and sprinkler, present a significant percentage of expired patents, represented in red, indicating that the technology has already reached a high level of maturity and technological knowledge is in the public domain. Technologies such as drones and sonic extinguishers have a high percentage of active patents, which indicates that they are emerging technologies and technological knowledge is under protection. Within these solutions, drones have great application potential, having as main advantages: easy access, both in urban and rural environments, being able to operate in adverse scenarios, such as tall buildings or forest fires, for example. The drone manages to act in the focus of the fire, leading to a faster and more efficient extinction, besides guaranteeing the safety of the professionals during the extinction (INNOCENTE; GRASSO, 2019). The extinction system by means of sound waves, even though it is still under development and has no history of application in the market, also has high potential, as it is a type of environmentally correct extinction, which does not generate waste, as it promotes the suppression of fire at from air movement, and can be applied in different environments (PANCHPOR; VAIDYA; PATKAR, 2019). Table 2 stratifies patents for each of the technologies presented and highlights the market application. The analysis of patents allows us to observe the different technologies that are being shipped in products to improve their efficiency.

There is a growing need for the development of fire-fighting technologies, due to their great importance to society. In line with this, there is a worldwide trend towards the use of Artificial Intelligence in the most varied human activities (WIPO, 2019). This line of technological development is strongly adherent to the needs of the fire fighting area. The Global Fire Information System (GWIS) provides a dataset with global fire information that characterizes fire types and regimes around the world, thus enabling the development of products with embedded artificial intelligence, which is able to combat accidents in a increasingly effective (Artès et al., 2019). Another aspect of high adherence to the problem is the development of new materials. Like the application of nanotechnology in fire suppression systems, such as: fire extinguishers and closed circuit extinguishing systems. In order to provide a more universal and effective approach to extinguish fires at all stages. Nanotechnology can also be used to manufacture fire-fighting equipment and clothing. In order to increase the strength and durability of fibers to better resist fire and high thermal energy (Olawayin, 2018). Computing and processing systems can be shipped to assist in decision making for firefighting. The use of multisensors and cameras with thermal image, with the objective of reducing the detection time, using fuzzy logic, Petri Nets, ZigBee network processing, CAN network, Internet of Things, ultra-computational convolutional neural network, for data processing and analysis, providing the machine learning, thereby maximizing assertiveness in decision making (Manjunatha et al., 2015; Sowah et al., 2016; Kanwar and Agilandeewari, 2018; Vijayalakshmi and Muruganand, 2017; Zhang et al., 2020; Cheng et al., 2011; Han and Lee, 2003; Shi et al., 2008; Daryan and Yahyai, 2018). These systems are called smart firefighting, and are primarily aimed at saving lives through the best effectiveness in fire protection and protection, which is achieved through the development of technologies including cyber-physical systems by merging emerging sensor and computing technologies with building control systems, fire fighting equipment and devices (Hamins et al., 2015; Wu et al., 2017). Cyber-physical systems are the future of firefighting due to a variety of approaches such as “collecting data globally, processing information centrally and distributing results locally” (Hamins et al., 2015). This makes it possible to reduce system latency and improve the system’s reaction speed (Wu et al., 2017).

## CONCLUSION

Considering what has been exposed above, it can be inferred that the objectives of the study were met. The description and analysis of the advantages and disadvantages of the main fire-fighting systems, showed that each one has its own peculiarities, and its choice depends

on a holistic assessment of the main interfaces, such as aspects of the place to be protected, cost-benefit of technology, therefore, there is no single or better solution that applies in all environments. The analysis of the patent documents explained that the technologies consolidated in the market, such as fire extinguisher and sprinkler, have a high number of patents with expired status, indicating that the technological knowledge of these systems is in the public domain. However, technologies such as drone and sonic extinguisher, have a significant number of patents with active status, which shows that they are emerging technologies, and according to the advantages highlighted in this article, they can be considered solutions with high potential for application. From the analysis of patents, it was found that global technological trends, such as Artificial Intelligence and the development of new materials, are embedded in fire fighting systems in order to improve their effectiveness, consequently, reduce the damage caused. Finally, for future work, it is suggested to evaluate passive fire protection solutions.

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