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Forensic Aspect of Fire Dynamics Simulation

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Abstract: Forensic aspects of post-fire scene processing can significantly benefit from expert knowledge and the application of tools used for modelling and simulating such events. In order to confirm the application, scenarios were considered based on a fire case in a specific building. The paper presents the results of applying the model and simulating the course of events using the NIST Fire Dynamics Simulator (FDS) as a tool. Verification of the application of simulation models was performed based on an event, a fire at the "Tahirović" furniture factory, located in the village Ivanča, Novi Pazar, which occurred on June 8, 2013. The simulation was conducted to analyse additional information and gain insight into the conditions of fire outbreak and the assessment of resulting consequences. Data used as input for this model were obtained from two sources: the National Centre for Forensic Sciences (NCFS) and material properties retrieved from the FDS database.

The model applied incorporates appropriate approximations of building geometry, material thermal properties, and fire behaviour as input parameters, based on information and photographs from findings and reports of the forensic examination of the fire. According to the forensic examination report, a critical event in this fire was the ignition of stored, easily flammable material in the fire centre zone due to electrical installation malfunctions. In addition to confirming higher reliability statements from the examination report, the simulation results of fire dynamics applied by the model further analysed other elements related to fire occurrence and development from a forensic aspect.

Keywords: Forensics, FDS models, fire dynamics, fire investigation, materials

I. Introduction

The forensic aspect of processing fire scenes can significantly benefit from specialized knowledge and the application of tools that utilize models and conduct simulations of such events. In order to confirm the application of models, scenarios corresponding to fire incidents in buildings were considered. This paper presents the results of applying models and simulating the course of events based on input parameters corresponding to the event investigated from a forensic perspective.

Verification of the simulation model results was conducted concerning the fire incident at the "Tahirović" furniture factory in 2013. The simulation was conducted to analyse additional information and gain insight into the conditions of the fire outbreak, the assessment of the resulting consequences, and the application of protective measures. The data used were extracted from the forensic examination report of the National Centre for Criminal Forensics (NCCF) and material properties obtained from the FDS (NIST Fire Dynamics Simulator) database.

In procedures related to determining the causes of fires, considering the level of destructive impact, models and simulations can be used to support drawing conclusions relevant to the process of determining the causes and uncovering potential deficiencies in the design and maintenance of electrical installations.

In recent years, there has been a trend worldwide that identifying the causes of initial fires due to electrical installation failures. In the Republic of Serbia, out of 24,337 analysed fire cases (2014-2023), according to data from the NCCF, electrical installations were cited as the cause in 6,791 cases. Therefore, electrical installations continue to occupy a significant position as a cause of fires. According to data from the Electric Safety Foundation, the number of fires caused by problems with electrical installations is estimated at 51,000 annually, leading to approximately 500 fatalities, over 1,400 injuries, and over $1.3 trillion in estimated property damage. Consequently, they represent the third leading cause of fires in residential and commercial buildings in the USA. Electrical installation failures account for approximately 55% of the total number of fires [1].

Designing an adequate fire protection system is one of the most important tasks in building design, depending on various factors such as the building's purpose, geographical location, surroundings, occupants, and more. The primary role of any fire protection system is early fire detection to protect and preserve human lives and property. However, even with strict adherence to applicable standards and regulations, situations with unpredictable fire occurrences and developments can arise. Therefore, it is necessary for fire protection systems to be continuously improved [2].

Forensic engineering, as the application of a wide range of scientific disciplines, skills, and methods, significantly contributes to obtaining answers related to establishing facts that may have legal implications. The development of science and technology has made it necessary to apply specialized expertise to successfully investigate certain criminal offences and unwanted events, such as fires. The use of expert knowledge needs to be considered both in terms of responding to unwanted events and in terms of preventive action.

A forensic engineer, as a professional possessing specific skills and expertise, conducts the process of establishing facts and investigating the physical causes of accidents and other unwanted events, such as fires. This is done to prepare engineering reports, forensic examinations, testify in legal proceedings, and provide advisory opinions to assist in resolving disputes affecting life or property. Investigations and reconstructions of fires resulting in loss of life and/or property damage are not always related to legal proceedings but also serve the purpose of preventing the recurrence of such events.

The integration of multidisciplinary knowledge and technical solutions forms the basis of forensic engineering, aiming to discover the causes and assess the consequences of the event, which materialize through elements necessary for law enforcement procedures. Forensic risk assessment refers to the ability to calculate the probability of unwanted events occurring to timely identify the need for preventive action or assess responses taken in the event of unwanted events. The results can be directed towards preventive action, identifying individuals or circumstances that may lead to unwanted events such as fires, or discovering the causes of unwanted events and the activities undertaken to mitigate the consequences or apply strategies to reduce harmful effects on individuals, property, and the environment. It can also contribute to planning and providing the necessary minimum resources for the efficient and effective protection of the work and living environment. Forensic risk assessment is one of the basic elements of modern forensic practice in many fields, drawing attention from the scientific community and research.

The forensic approach, in addition to identifying the elements and circumstances that led to the outbreak of fires, can lead to conclusions regarding designed systems and compliance with protection measures, especially regarding electrical installation failures.

The presence of fire risk exists in all human activities and systems. Risk is an inevitable part of business, especially considering the volume of data provided and processed in business processes.

In procedures related to determining the causes of fires, considering the degree of destructive impact, models and simulations can be used and applied to reach conclusions relevant to the analysed event.

II. Results of the forensic approach to event analysis

Results of the forensic approach to event analysis, in this case, fire, provide significant support to insights into the dynamics and considering causes of such events. The use of forensic principles and tools, including models and simulations, enables the analysis of fires and their consequences. In this work is analysed and presented the main findings obtained through the forensic analysis of the fire at the "Tahirović" furniture factory in 2013:

1. Verification of simulation models: simulation results, based on input parameters corresponding to the actual fire event, were compared with findings from the forensic report. Validation of these simulation models confirms their effectiveness in accurately reconstructing fire scenarios.

2. Support to identification of fire sources and causes: analysis of the simulated event sequence allows for the precise location of fire sources and causes. In the case of the "Tahirović" factory fire, electrical installation faults were identified as the primary cause, corroborating findings from the forensic investigation.

3. Assessment of fire spread and consequences: simulations provide valuable insights into fire spread and behaviour, allowing for a comprehensive assessment of consequences. This includes understanding how the fire spread within the building, its impact on surrounding structures, and resulting damages.

4. Evaluation of fire protection measures: analysis of simulated scenarios enables the assessment of the effectiveness of existing fire protection measures. In cases where deficiencies are identified, recommendations for improving fire safety practices can be made to prevent similar incidents in the future.

5. Forensic risk assessment: the forensic approach allows for a thorough risk assessment, taking into account the probability of fire occurrence, potential consequences, and preventive measures. This holistic evaluation enables stakeholders to make informed decisions about fire protection strategies and resource allocation.

Overall, forensic fire analysis using simulation tools has proven instrumental in uncovering key details about fire dynamics, sources, causes, and consequences. By integrating expert knowledge with advanced technology, forensic engineers can provide valuable insights that contribute to improving fire safety practices and reducing risks associated with fire incidents. The paper presents analysis of possible sequence of events by applying models and simulation tools in order to contribute discovering the circumstances of the fire outbreak and its consequences at the "Tahirović" furniture factory, located in the village of Ivanča, Novi Pazar. The fire occurred on June 8, 2013, around 3:50 PM.

According to the factory layout concept, the manufacturing and warehouse premises consist of three halls, approximately 51x18x7 meters, structured as G + R (ground floor and roof). They are arranged in parallel, with a distance of about 6 meters between them. The positions of the factory halls, enclosed in a fenced area, approximately 150 meters from the asphalt road, are shown in Figures 1 and 2. The hall closest to the access road (hereinafter referred to as Hall 1) and the middle hall (hereinafter referred to as Hall 2) are constructed with aerated concrete blocks, bordered by concrete sills (Figure 3). Hall 3 is constructed with blocks made of clay bricks. The slab between the ground floor and the first floor is made of steel beams and concrete slabs. Other materials and installation methods correspond to those used in the first two halls.

All buildings are connected to the water and electricity supply networks and are equipped with a fire detection system as well as a hydrant network.

In the process of determining the cause of the fire, evidence found at the scene, data obtained from police officers of the Novi Pazar Police Department who took statements from eyewitnesses of the fire, and firefighters who extinguished the fire were considered.

Fig. 1 Factory Halls Layout

The farthest from the access road is Hall 3, which is constructed with clay brick blocks.

Fig. 2 Main Entrance Appearance to Hall 2 After the Fire

According to the findings, all three halls of the furniture factory were affected by the fire. Visual inspection from the outside revealed that Hall 1 and Hall 2 were fully engulfed in flames, while damage occurred on Hall 3 due to the effects of hot gases on PVC joinery and the penetration of hot gases into the upper area of the hall. Inside, alongside the vertical concrete sills, there are load-bearing steel columns.

On Hall 1 and Hall 2, the metal roof structure collapsed. On Hall 2, the wall on the upper floor, closer to the first hall, collapsed, and numerous cracks were observed on the walls on all sides of the building (Figure 3).

Fig. 3 Damage to the Wall of Hall 2

Fig. 4 Interior View of Hall 2

Based on information obtained from authorized representatives of the company regarding the type, quantity, and distribution of stored materials and machinery, it was found that there was not a significant difference in the fire load between Hall 1 and Hall 2 [11].

The total fire load of a building or part of a building represents the thermal energy released during complete combustion in a fire. During the calculation, all combustible materials are taken into account according to the standard (SRPS U.J1.020), which are part of the building, installations, equipment, and materials located in the building. The fire load of Hall 2 is 3.08 GJ/m² [11]. According to standards, this fire load can be classified as a high fire load.

However, based on the information received, it could be concluded that the second hall sustained greater damage due to the prolonged duration of the fire, indicating that the centre of the fire was in Hall 2.

Upon inspection of the interior of Hall 2, complete thermal destruction of the structure was observed, along with the materials inside it. Combustible materials were completely burned, while metal parts of the structure, and equipment were extensively deformed due to the fire (Figure 4).

Forensic analysis led to the conclusion that the fire was initiated, most likely, by the ignition of stored flammable materials in the centre of the fire zone due to a malfunction in parts of the electrical installation or electrical equipment used for lighting (fluorescent lamps). The mechanism of failure in lighting using fluorescent tubes is such that sparks (heated or glowing objects) occur, and in some cases, even open flames.

III. Results of Fire Modeling and Simulation

In order to analyse and potentially obtain further information, a model was applied, and a fire simulation was conducted to consider the findings and implementation of fire protection measures. This approach applied regarding forensic conclusion that the analysed event likely originated from a malfunction in the electrical installations.

To illustrate possibility of include the dynamics of the fire, a computational fluid dynamics model using large eddy simulation techniques was employed [3-5]. The object was modelled following the principle of dividing the building of interest into small three-dimensional rectangular control volumes or computational cells to which a numerical model is applied. This model calculated the density, velocity, temperature, pressure, and gas concentration in each cell. Based on the conservation laws of mass, momentum, species, and energy, the model tracks the generation and movement of fire gases.

IV. Simulation of structure and content

The dynamics of the fire were analysed and presented based on the findings and reports of the fire investigation at the "Tahirović" factory. A computer simulation of the fire was conducted using the FDS tool and Smokeview for visualization, to provide insight into the fire development and thermal conditions that may have existed during the fire. The code snippet written for the simulation purposes, representing a file with a .fds extension that defines the parameters necessary for simulating the ignition and development of the fire. For the purpose of modelling some generalisation and abstraction were conducted. Simulations were performed with different parameters, which were defined according to the findings of NCFS, especially related to time, material, ventilation, etc.

Based on the input material properties, the fire growth and spread were shown (Figures 5-7).

For the purpose of analysis, a fire scenario was developed for the fire with input elements of the model that approximately represent the actual geometry of the building, as well as the thermal properties of materials and elements related to fire development, based on available information from the scene and photographs from the findings and expert reports.

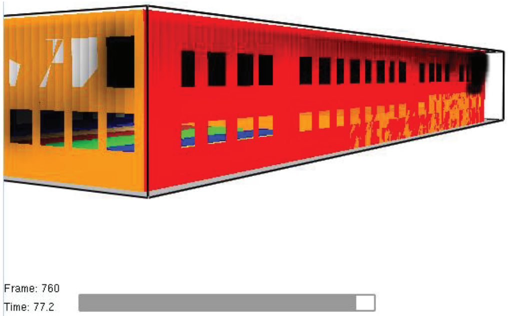

Fig. 5 Simulation of the fire ignition

The fire source is approximated as a rectangular object representing the ignited material with a certain rate of heat release [3-5]. It was assumed that the rate of heat release in the fire would rapidly increase, reaching a maximum of approximately 800 kW within 7 minutes. In real conditions, it might have taken longer for the fire to develop; the actual ignition time is not known. The simulation started with flame ignition corresponding to real-time (Figure 6) [6].

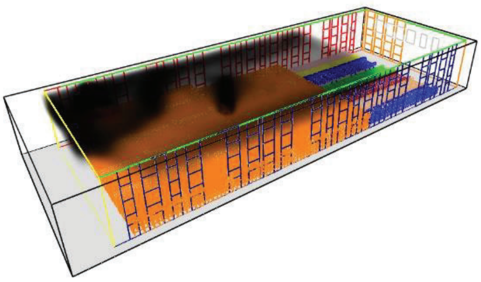

Fig. 6 Display of fire and smoke

The depiction of fire flare-up and the amount of released smoke are shown in Figure 7. Approximately after 7 minutes from the start of the fire, the temperatures of the upper or hot gas layer are more than 800°C.

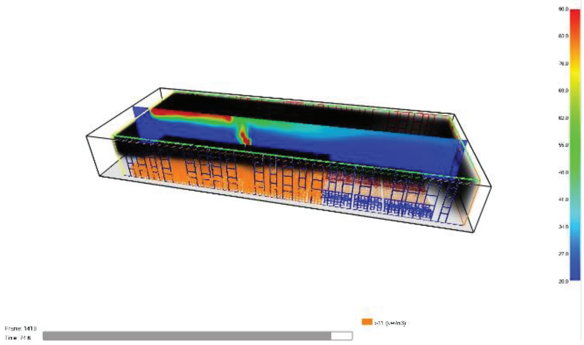

Fig. 7 Reasing of temperature during fire ignition

By conducting the simulation, approximations of flame propagation through the structure of the building were obtained (Figure 8). The simulation provided three-dimensional approximations of flame surfaces where fuel, heat, and oxygen are present, allowing the flame to exist. The flame can be seen spreading throughout the entire space of hall 2 in approximately 2-13 seconds. The flame front expanded to the roof of hall 2. The amount of smoke released at the beginning of the fire and when the window glass shattered due to high temperatures is presented in kg/m2. The simulation considered the rate of fire growth and the rate at which it spread throughout the entire hall.

Models and simulations can further analyse the hazards of short circuits, conductor overloads, large transient resistances, electro thermal devices, the use of sparking appliances and devices, arc welding, static electricity, atmospheric electricity, depending on the type of object being analysed [7-10].

This primarily confirms the validity of the designed fire protection systems and checks the implementation of measures in cases of fire occurrence, but also improves fire protection measures based on the findings of the conducted forensic analysis, especially for measures related to electrical facilities, electrical installations, and electrical devices.

V. Conclusion

As in other studies, our research confirmed that forensic risk assessment is one of the basic elements of modern forensic practice and represents an area of interest for the contemporary scientific community. The forensic approach can contribute not only to the identification of elements and circumstances that led to the outbreak of fires but also to conclusions that may relate to measures for protecting against electrical installation failures. By using computer simulation, the prediction of fire occurrence and spread conditions and events correlating with information from findings and opinions from expert reports might be analysed. The simulation model is based on parameters determined according a fire that broke out by igniting a sponge stored in Hall 2 of the "Tahirović" factory. The combustible materials that completely burned out on this occasion, as well as the cracks in the concrete floor of Hall 2, indicate that extremely high temperatures developed in the fire. The entire space was quickly filled with smoke and hot gases, and all flammable parts across the surface area were burned. By burning through the ceiling from the bottom side, hot gases escaped through openings created as a result of the fire, onto the building's roof. Smoke halos above the ground-level openings confirm that the fire originated on the ground floor.

The applied model correlate to the findings of the NCFS and give opportunities to analyse other elements related to the occurrence and development of fires from a forensic perspective. Furthermore findings might be used to assess the compliance of electrical installation protection measures, as well as to analyse any necessary improvements in protection measures in this area and the development of technical norms for the application of fire protection measures.

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