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Engineering Methods in Forensic Fire Scene Reconstruction

Abstract

During a fire, the design of the building affected by the fire changes. Combustible materials are damaged and destroyed, structures are deformed by heat, surfaces are covered by smoke. The problem is that finding out what has happened on a changed scene can be difficult in a court case. In the present research, the researchers investigated how the tools and methods of traditional fire investigation scene inspection requires engineering solutions to perform a scene reconstruction based on engineering methods, presented credibly and visually in a forensic proceeding. The research analysed the process of fire investigation procedures today. The methodology and tools for conducting a fire investigation scene inspection, the elements and interrelationships of the static and dynamic phases, and the sampling options were examined. They evaluated the scene recording based on engineering methods, the methods of measurement and representation. The researchers analysed the reconstruction possibilities arising from the scene survey methodology, from which reconstruction models were created using conventional 2D as well as 3D representations. The analyses found that by introducing additional dimensions, such as time, new reconstructions that simulate processes can be created. As a result of the research, it was established which engineering data needs to be captured for the forensic application of state-of-the-art computer aided reconstructions in order to show valid results.

Keywords: fire investigation, fire safety, engineering methods, fire scene reconstruction

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Introduction

In forensic evidence proceedings, the exact evidence forms the basis of the proceedings. To this end, the professional recording and collection of decisive evidence is a primary task. In the course of fires, the design of the buildings affected by the fire changes to varying degrees. Combustible materials are damaged and destroyed, structures are deformed by heat and surfaces are covered by smoke. During the fire brigade intervention, combustible materials may be removed or the scene may be altered to varying degrees.

Problems

The problem is that it is difficult to find out what has happened at a scene that has changed in any way. In a court case, an accurate reconstruction is the basis for a complex representation of events. Nowadays, a reconstruction of the scene, reconstructed with engineering precision and presented in a credible and visual way in a forensic proceeding, is of paramount importance.

Objectives

For the above reasons, the researchers, who previously served as professional fire investigators, aim to investigate how the tools and methods of a traditional fire investigation scene inspection require engineering solutions to perform a scene reconstruction based on engineering methods, presented credibly and visually in a forensic proceeding. The aim is to develop an engineering approach and data-driven methodology for fire investigation procedures.

Research methods

In terms of the research methods used, the researchers analysed the process of fire testing procedures today. They examined the methodology and tools for conducting a fire investigation scene inspection, the elements and interrelationships of the static and dynamic phases, and the sampling possibilities. They evaluated the scene recording

based on engineering methods, the methods of measurement and representation. The research analysed the reconstruction possibilities arising from the scene survey methodology, from which reconstruction models were created using conventional CAD-based 2D and 3D representations. A comparative analysis between the traditional methodology and the engineering-based methodology was performed.

Literary overview

A literature search was carried out, reviewing the classic literature and the most recent scientific publications of today. They reviewed key contributors to the scientific literature on domestic fire investigation. The works of László Bérczi, László Fentor, Ferenc Varga, L. Zoltán Nagy provide a comprehensive overview of the classic Hungarian fire investigation procedures, which are basically based on forensic principles. David J. Icove and Gerald Haynes' internationally recognised seminal works *Kirk's Fire Investigation* and *Forensic Fire Scene Reconstruction,* as well as NFPA 921 Fire Investigation Standard describe the methodology of a complex fire investigation. The researchers also reviewed recent publications on fire investigation to keep abreast of current trends. For this purpose, they reviewed, among others, the works on fire investigation published by Flores N. Quiroz and co-authors in the *Fire Safety Journal,* the Interpol fire investigation summaries from 2016 to 2022 published by Michelle Evans and co-authors in *Forensic Science International: Synergy* and searched the publications on databases by Marina Klees and Safa Evirgen, and the articles on BIM and GIS data-based research by Jicao Dao and co-authors. The authors reviewed the most significant literature published in the last 20–25 years and most relevant to their research, from P. Mark L. Sandercock to the recent work on machine learning database construction published by Angelo Aloisio and co-authors.

Hypothesis

Based on the above, the researchers hypothesise that more accurate and visual scene reconstructions can be made from engineering-based data, with valid results compared to forensic methods, from traditional fire investigation scene reconstruction procedures, and that the data can be compared in an exact manner with data used in fire prevention.

The fire investigation scene visit

Fire investigation is an activity that aims to establish the objective truth of a relevant event in the past. We seek to understand the conditions before the fire, the cause and effect of the fire. In the course of the cognitive activity, facts are established, correlations are discovered and problems are solved. A specific layer of cognitive activity consists of thinking activities (such as logical methods, the application of philosophical theorems, searching, organising, algorithm building). To achieve the objective, the activity must comply with the relevant procedural rules, be planned, conscious and characterised by a unity of intellectual and practical activities.

Stages of fire investigation cognition

- Reconnaissance: Finding out the historical facts, collecting data, processing data and providing the necessary conditions.
- Proof: The data collected during the procedure must be legally relevant and must be accessible and understandable to everyone, therefore, the data must be obtained in an appropriate manner and their veracity must be proved in accordance with the principles and rules of proof (Harding et al. 2022).

General elements of fire investigation

- Methodology: The procedural rules that regulate or systematise the tasks of the fire investigator.
- Tactics: For the on-site inspection, for the hearings. (Parallel is also possible, which increases speed.)
- Technical procedures and their application: Photography, video recording, sampling (Icove et al. 2013).

Basic requirements for fire testing

- respect for the rule of law
- completeness of the evidence

- objectivity
- speed
- data protection, data management (Icove et al. 2017)

Requirements in the description of the scene

- a description of the external environment of the fire
- a description of the fire environment
- description of the area damaged by the fire (building structures, objects, materials)
- findings on the components necessary for combustion
- conditions that facilitate or hinder the spread of fire
- the facts concerning threats to persons, property and the natural environment
- other factors relevant to the fire test (Icove et al. 2017)

Analysis of the acts on the ground

The protocol to the Fire Investigation Rules Act states: "During the fire investigation procedure, the authority shall immediately conduct a fire investigation scene visit" (Decree 44/2011 (XII. 5.) of the Ministry of the Interior; Fentor–Varga 2016).

The fire investigator should document the circumstances of the sampling, if necessary, the description of the objects and remains seized (Harrison 2013). The conduct of the search is a very thorough, meticulous documentation of the facts observed only, which must be recorded by the person conducting the search and for which he is responsible for its accuracy, authenticity and completeness. During the investigation, it is possible to seize physical evidence and take samples of material remains. The investigation consists of a static and a dynamic phase, similar to a criminal inspection (Bánáti 2022).

Static phase

The static phase includes a kind of situational picture, where what is seen is recorded. Things and phenomena at rest are the object of observation. The traces of the fire and the conditions of the scene are visually perceived and recorded. During the static phase

of the investigation, only equipment (camera, video camera, rangefinder) that does not alter the original state of the scene may be used. The main objective of the static phase is to determine the location of the fire (Fentor–Varga 2016).

Dynamic phase

The dynamic phase is the exploratory part of the investigation, where the initial state is changed. This is a very delicate part of the procedure because it is an irreversible process in most cases. During the fire investigation process, only statutory evidence can be considered by the fire investigator, of which the following can be recorded on the spot:

- customer declaration
- hearing of a witness
- document
- inspection report
- material evidence (Servida et al. 2023)

The protocol and physical evidence are only linked to the scene and, due to the nature of the incident, can be used for a limited period of time, as it is obvious that, for example in the case of a residential building, the owner of the damaged property will want to restore the original state as soon as possible, and the guarding of the area may also tie up police resources. The rules for the investigation of fires also set out the requirements for the content and format of the scene investigation report. It should be noted that fire investigators are trained by police personnel in the techniques of evidence recording for use during the on-site investigation in the framework of a specialised training course at the Police Education and Training Centre of the National Police Headquarters in Dunakeszi, which is directly based on the fire investigator training course. This advanced fire investigation training course introduces trainees to the procedures for searching for, recording, packaging and authenticating traces and residues. In addition, the police experts will teach the criminal tactics of forensic photography, forensic sketching and crime scene investigation. The skills taught in the course are essentially basic knowledge of the forensic investigation procedure. A professional description of the crime scene can only be carried out with the necessary professionalism if the knowledge acquired in this course is used (Bérczi–Varga 2016).

The description of the scene should include a description of the external environment of the fire, a description of the surroundings of the fire, a description of the area damaged by the fire (building structures, objects, materials), findings on the components necessary for the combustion, the conditions that facilitated or hindered the spread of the fire, the facts concerning the danger to persons, material goods, the natural environment and other factors relevant to the fire investigation.

One can agree that the on-site inspection is indispensable, urgent and irreplaceable. If the inspection is carried out in an unprofessional or sloppy manner, the procedure may be followed, but there is little chance of legal action being taken after the official procedure, particularly in relation to personal liability for the findings in connection with the fire.

It is therefore the responsibility of the fire investigators to evaluate the fire scene based on the burns, to draw conclusions about the time and place of the fire, the possible sources of ignition and the conditions that may have caused the combustion process (Evans 2023).

Scene reconstruction

Imaging

Imaging is an important task in both the static and dynamic phases of the inspection. The images obtained should be suitable for showing the scene and the damaged area, the conditions and lesions indicating the location and spread of the fire, the factors facilitating and hindering the spread of the fire and the factors relevant to the investigation. The imaging tasks may be carried out using a variety of photographic and video recordings (Érces et al. 2017).

Traditional types of photography

- Environmental photos (showing the scene's surroundings)
- Overview pictures (showing the scene)
- Pictures of the Knot Point (showing part of the scene)
- Detail shots (a type of a photograph that can be taken during both the static and dynamic phases of the inspection, to highlight details of changes, damage or deterioration of objects) (Bérczi–Varga 2016)

Figure 1: *Full panoramic images of a fire inspection*
Source: Picture taken by András Király, fire investigation expert, using a Ricoh Theta Z1 with 2 × 210°.

Traditional photographic methods

- panorama (360° shot)
- meeting (photos taken from two directions)
- crossing (photos taken from 4 directions)
- scale (detail photographed next to a measuring stick)
- specific (e.g. photographing a corpse) (Choi–Yoh 2017; Figure 1)

Examination of the hearing of persons

The hearings and their subsequent usability and interpretability are also critical to the success of the procedure. Witness interviews, as an investigative act, can also be conducted by authorised and trained persons. It is necessary to interview witnesses with primary direct experience of the incident, but also persons in possession of information relevant to the case, if they can provide information that is material and relevant to the fire investigation (Quiroz et al. 2021a).

The discussion of interview tactics is not the subject of this article, but it is an important element of knowledge for the person conducting the procedure. This knowledge includes verbal and non-verbal communication, psychology, the ability to look for logical connections, the ability to understand cues to hidden information and the ability to control the conversation (Quiroz et al. 2021b). Listening to witnesses can, of course, be done at a later stage, but the information relating to the event observed may be distorted, especially in a person who has been through a stressful situation, and the possibility of recalling it decreases over time, and the distorting effect of other information from the environment should not be ignored. It is for this reason that it is mentioned as an equally urgent fire investigation activity to be carried out at the scene, which is an important element of the field data collection. Interviewing tactics can be learned in a communication course by those who are assigned to fire investigation work (NFPA 921 2024).

Testing of samples containing accelerant materials

Combustion residues containing accelerant substances can be captured on scene for a short period of time due to their volatility, and therefore samples taken and transported professionally should be subjected to analytical testing within a short time. The primary task of the experts at the Institute is to support the work of fire investigators with high quality research and well-supported test results (Lentini 2018).

The work of the research institutes is closely linked to fire investigation, as they also carry out analytical tests to determine the presence of accelerants. Materials taken during fire investigation scene visits are analysed using a gas chromatograph coupled to a mass spectrometer to look for the presence of accelerants in the sample (Sandercock 2008). In order to ensure good quality sampling and uniformity of implementation, the research institute (in Hungary) has developed a lockable, verifiable sampling system for fire investigators, called "sampling unit pack", which is controlled by the institute for purity, thus avoiding unwanted contamination that could affect the investigation (Bérczi–Varga 2016).

The sampling unit pack contains 4 sampling units, of which the Test sample bottle is filled with a sample from the location where the presence of an accelerant is suspected, the Control sample bottle is filled with a sample from the same location as the Test sample, and the Blank sample is taken from a location where no accelerant

Figure 2: *Sampling unit package*
Source: Compiled by the authors.

is suspected. The Traveling Blank Sample Bottle is not filled because it is designed to exclude possible storage and transport contamination.

Engineering methods in scene reconstruction

Traditional scene reconstruction methods also serve well to support forensic procedures. But why talk about engineering methods? The researchers' aim in researching engineering reconstruction was twofold. On the one hand, they were looking for an engineering-based solution that would provide exact data but also be illustrative. On the other hand, they wanted to strengthen the feedback to the fire prevention field by collecting, recording and implementing engineering data (Aloisio et al. 2024). To this end, engineering methods were integrated into the static and dynamic phases of the scene inspection and applied during the reconstruction (Érces–Bérczi 2018).

Engineering methods used in the static phase

In addition to the traditional scene survey methods, the structural design of the building, the layering and the quantity and quality of the building materials were also recorded during the static phase. In this way, building information with a content similar to that of the building design was created. Once the data had been recorded on scene, the database could be created in batches. In the static phase, a comprehensive record was made of the changes in surface geometry using the imaging techniques mentioned above, which formed the basis for the comparability of the measured data during the reconstruction. 3D field photography and surface scans allow reconstruction measurements approximating real measurements even after imaging (Chowdhury et al. 2024).

Engineering methods used in the dynamic phase

In the dynamic phase, the researchers recorded the extent of changes indicating the location of the fire. In the static phase, they recorded the measured values of changes, deformations, discolourations and material losses on the materials studied, which were assigned to the information of the building material (Stauffer 2020). The difference between the data on the initial building structure before the fire and the data on the damaged structure after the fire showed the exact extent of the damage, from which, in addition to the geometry (location of the fire, direction of fire spread), the intensity of the combustion process and the time of the fire can be deduced from the measured data. An engineering scene inspection based on measurements may, on the basis of the above, complement or challenge the information provided by witness and/or client interviews (De Wolf et al. 2023).

Engineering methods used in scene reconstruction

In the static and dynamic phases, the researchers organised the data collected using engineering methods into a database, and then used the measurements and imaging technology to provide the surveyed scene with the information they had collected about the building (Klees–Evirgen 2022). Building information modelling was used for this process (Steen-Hansen et al. 2021). The method allows the creation of a 3D

Figure 3: *Fire*
Source: Picture taken
by the Budapest Disaster Management Directorate.

building model with exact geometric parameters, which allows the reconstruction of the scene in a very accurate and measurable way. In addition, the model of the reconstructed scene can be presented in a very visual way to non-specialists, i.e. it can serve as evidence in forensic proceedings. The fire in the picture was photographed during the fire brigade intervention at the full-grown stage of the fire. The first photographic images were therefore taken after the fire was fully engulfed in flames and do not allow the place of origin of the fire to be established (Dao et al. 2024; Figure 3).

The post-fire image taken during the on-site inspection of the fire investigation procedure identifies the final stage of damage, but shows a homogeneous picture due to the high loss of material. The authors have integrated the measured and collected data on the burned condition with respect to the fire origin and the direction of fire spread (Xing et al. 2016; Figure 4).

Figure 4: *Post-fire picture*
Source: Picture taken by the
Budapest Disaster Management Directorate and the authors.

For the reconstruction, engineer-precise floor plans and sectional drawings were prepared, which were used to create a 3D model of the part of the building affected by the fire (Figure 5).

The original condition was reconstructed on projection drawings and the data recorded by engineering methods was integrated into the model as building information, in which the fire-damaged structure of the original condition (structural elements in red) was visualised and distinguished from the structural elements that were less affected or removed during the intervention (Zeng et al. 2022; Figure 5).

Compared to a normal 3D model, the model reconstructed in the fire investigation procedure is a BIM model with building information integrated with the collected data, which allows for a comparison with the expected safety level in the fire prevention field (Figure 6).

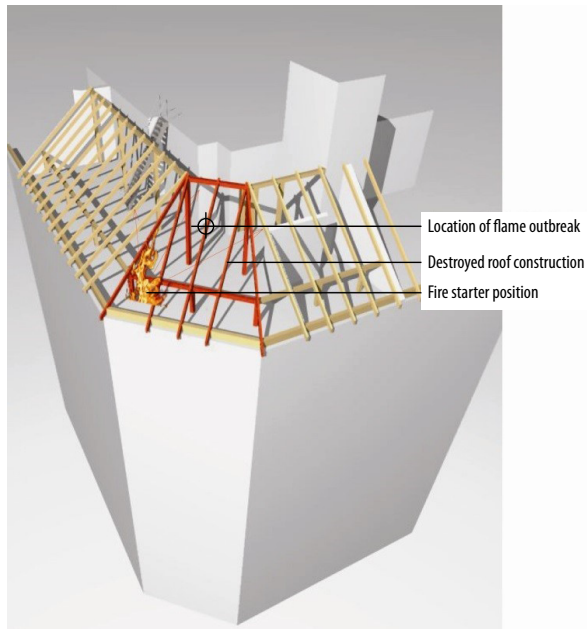

Figure 5: *3D digital reconstruction of a scene using engineering methods*
Source: Compiled by the authors.

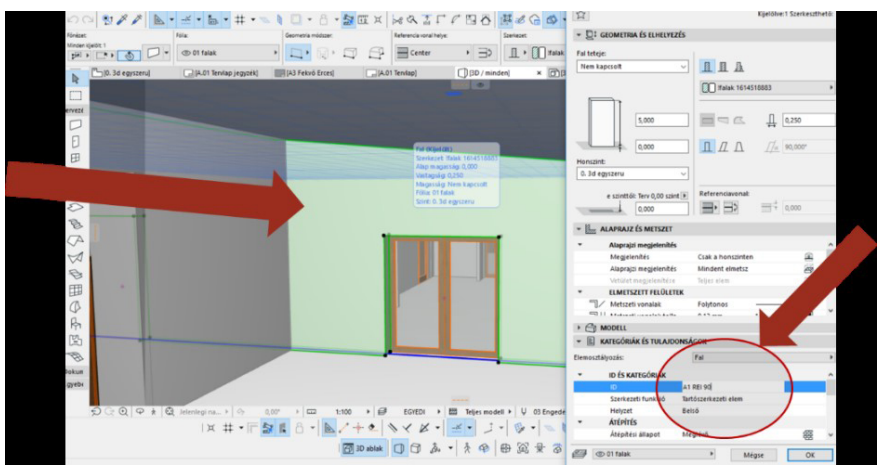

Figure 6: *Integration of data into a Building Information Model (BIM)*
Source: Compiled by the authors.

The reconstruction can be done in a standard way using the above method. The model is a 3D model with building information according to the IFC standard, which has the advantage of being implementable in validated fire simulation software such as the FDS (Fire Dynamics Simulator) simulator (Zheng et al. 2023).

Summary

The researchers analysed and evaluated domestic fire testing procedures with an international perspective. They found that the reconstruction methods used in today's fire investigation procedures are more accurate and visual than scene reconstruction generated from engineering-based data. Measured results of the extent of deterioration, the rate of material loss compared to temperature, and evaluations of the behaviour of building material in a real-scale fire can be well reconstructed using building information models.

During the analyses, the authors found that by introducing additional dimensions, e.g. time dimension, building information dimensions, newer reconstructions simulating complex processes (FDS) can be created. Simulations that represent complete processes are illustrative and the factual data captured by engineering methods are valid. As a result of the research, the researchers found that the forensic application of state-of-the-art computer-aided reconstructions requires the recording of engineering data for the reconstruction, which is partly a field-based and partly a research-intensive task.

Based on the summarised conclusions, the researchers concluded that, compared to traditional fire investigation scene reconstruction procedures, engineering-based data with valid results for forensic procedures can be used to produce more accurate and visual scene reconstructions, the data from which can be compared in an exact manner with data used in fire prevention.

Conclusion

From the above, it can be concluded that data collected by engineering methods can be reconstructed in a modellable way and used as accurate, valid evidence in a forensic proceeding. By applying them, complex processes can be visualised.

Suggestion

By introducing the time dimension, using properly validated simulation software, the further research proposal is to create complex simulations, whereby the data generated by the reconstruction and simulation of real-scale fires can be factually fed back into the field of fire prevention.

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