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Technological innovation and the Pursuit of Truth: integrating 3D reconstruction and artificial intelligence into criminalistics

Introduction

One of the fundamental tasks of criminalistics is reconstructing past events. In answering its core questions (what happened, where, when, how, who, with whom, and why), crime scene investigation plays a pivotal role. By locating traces and material residues, subsequently analysing them, examining witnesses, and collecting physical evidence, the groundwork for fact-finding can be established.¹ To support this task, crime scene sketches, photographs, and expert interpretations are traditionally employed. At the same time, the technological advancements of the 21st century open new dimensions in evidentiary practice. Digital tools and methods such as photogrammetry, laser scanning, drone imaging, and virtual reality offer previously unforeseen opportunities for accuracy and visualisation.

Beyond technical innovations, the development of digital forensics also impacts the quality of investigations, the evidentiary process, and ultimately public trust in the justice system. Through a three-dimensional model, jurors, experts, and judges can virtually explore the crime scene, thereby gaining more direct knowledge and forming a clearer understanding of past events.²

As part of digital forensics, generative models—continuously developed over the past decade and still evolving—must also be considered. These

¹ Fenyvesi, Cs. – Herke, C. – Tremmel, F. (eds.) (2022): *Kriminalisztika [Criminalistics]*. Ludovika Egyetemi Kiadó, Budapest

² (n.d.): *Forensic animation for legal cases [Forensic Animation for Legal Cases]*. Source: <https://courtroomanimation.com/forensic-animation-legal-cases-guide/> Accessed: 30.08.2025

tools assist in the analysis of crime scene data, enabling the identification of patterns, the establishment of timelines, and even the reconstruction of bullet trajectories.³ At the same time, we must also ask ourselves the following questions: can a model created or interpreted by artificial intelligence be deemed admissible in court? Who bears responsibility if the algorithm errs?

This study presents the potential applications of digital technologies and the legal, evidentiary, and procedural issues associated with them. Following a summary of the possibilities for reconstructing crime scenes, we outline the modern toolkit and then illustrate the technological opportunities, challenges, and questions of AI-based evidence admissibility through brief case studies. Cases from the United States, Canada, and Europe clearly demonstrate that digital reality is not a prospect of the future but an integral part of contemporary justice systems.

Foundations of Crime Scene Reconstructions

One of the oldest and most important acts in criminal procedure is the crime scene investigation. Beyond documenting traces and material residues, its task is to interpret them and connect them to the sequence of past events—criminalistic reconstruction bridges observable traces and the acts in question. In addition to data collection, the interpretive process helps determine the further direction of the investigation and the success of evidentiary proceedings in court.⁴

Formulating different versions is a logical operation that constitutes part of the reconstruction, outlining hypotheses about past events. At the same time, reconstruction is also a spatial and visual interpretation, as the

³ Herke, C.: Hogyan segítheti a mesterséges intelligencia a bűnügyi szakértők munkáját? [How Can Artificial Intelligence Support the Work of Forensic Experts?]. In: Petrétai, D. (ed.): Angyal 60. Ünnepi tanulmányok Angyal Miklós 60. születésnapjára. Jurisconsultus, Budapest–Pécs, 2025. 42–49. o.

⁴ Gárdonyi, G.: A bűnügyi szemle [Criminal Investigation Review]. Ludovika Egyetemi Kiadó. Budapest, 2024.

presumed course of events must be compared with the observed material alterations. If the reconstruction is flawed or incomplete, it may lead to erroneous conclusions.⁵

Distortions of human perception and memory can characterise the limitations of cognitive reconstruction. These include prejudice, fear, or even selective perception, all of which influence the interpretation of events. Cognitive psychology has identified numerous mechanisms that may distort the perception and thus the evaluation of evidence. Among these are the formation of false memories, excessive generalisation, and confirmation bias, all of which jeopardise the objectivity of reconstruction.⁶ In addition, the presence of irrational elements in violent crimes must be emphasised, as these often conflict with the expectations of logical reconstruction. Consequently, classical methods such as crime scene sketches, photography, and written records are not always capable of conveying the actual sequence of events.

The reliability of the reconstruction is of paramount importance in the context of judicial proof. In the absence of direct perception, the court relies on witness testimonies, expert opinions, and evidence. However, the logical chain built from such evidence may become distorted if the underlying documentation of traces is incomplete or inaccurate. As Gunyecz emphasises, the legality of evidence is a primary concern, since any error may lead to the loss of evidence, thereby constituting a failure of justice.⁷

The application of modern technologies is therefore not optional but necessary. Three-dimensional scanning, photogrammetry, and drone imaging provide reproducible, objective data that can mitigate errors arising from

⁵ Fenyvesi Csaba: A justizmordhoz vezető kriminalisztikai hibák. *Belügyi Szemle*, Issue 2024 /3. 30-59. o.

Source: <https://doi.org/10.38146/bsz-ajia.2014.v62.i3.pp30-59>

⁶ Angyal, M. (ed.): *Kognitív kriminalisztika: Ismeret – elmélet – történet* [Cognitive Criminalistics: Knowledge – Theory – History]. Dialóg Campus Kiadó. Budapest, 2019.

⁷ Gunyecz, Z.: *Bizonyítás a perbíró szemével* [Evidence from the Perspective of the Trial Judge]. *Büntetőjogi Szemle*, Issue 2024/2. 24–33. o.

human subjectivity. With the aid of modern tools, reconstruction thus becomes a measurable and visualizable process, rather than one confined solely to cognitive interpretation.

In summary, crime scene investigation and reconstruction are central elements of criminalistics, and modern technologies may help address their inherent limitations. It is important to emphasise, however, that these technologies do not replace cognitive reconstruction; rather, they support it by reinforcing the guarantees of objectivity. In this way, the interpretation underlying judicial proof can be elevated to a more reliable level, thereby contributing to the fairness of proceedings and strengthening public trust.

Digital Tools in Crime Scene Documentation

Among the classical tools of crime scene documentation mentioned earlier are sketches and photographs. Their use is quick and cost-effective, yet they also have limitations. A crime scene sketch contains subjective elements because the drafter decides which features to emphasise. Photographs provide a more objective record, but their two-dimensional representation may distort spatial relationships.⁸

Digital technologies offer the possibility of overcoming or mitigating these limitations. Photogrammetry, for instance, enables the stitching together of hundreds of photographs to create a three-dimensional model. This can even be accomplished with a simple smartphone, thus providing a rapid and cost-effective reconstruction of the scene. Its quality, however, is influenced by factors such as lighting conditions, sharpness, and angle settings. When combined with other technologies, however, it can yield a comprehensive representation.

Laser scanning provides a similarly precise technology. The device emits millions of laser pulses and calculates the distance of objects based on

⁸ Gárdonyi, G. (ed.): Módszertani útmutató 1: bűnügyi technikusok részére [Methodological Guide 1: For Crime Scene Technicians]. Nemzeti Közzolgálati Egyetem. Budapest, 2014.

the time it takes for the beams to be reflected. The resulting point cloud produces a digital replica that reproduces the original scene conditions with millimetre accuracy. However, the high equipment cost and the extremely time-consuming data processing are among its current limitations.⁹

The emergence of drones has introduced new opportunities for documenting outdoor crime scenes and traffic accidents. Aerial footage enables the mapping of locations that are otherwise difficult to access. When combined with photogrammetry software, drones can also generate three-dimensional models. Their limitations, however, stem partly from weather conditions and partly from regulatory authorisation requirements.¹⁰

Undoubtedly, the use of virtual and augmented reality (VR/AR) technologies ranks among the most advanced. These tools allow crime scenes to be “walked through” while modelling the incident's dynamics and spatial relationships. Their application provides participants in the proceedings with a direct means of obtaining information about the events. Future challenges and tasks, however, lie in addressing data protection issues and the high equipment requirements and resource-intensive nature of these technologies.¹¹

⁹ Ujvári, Zs. – Metzger, M.: A fotogrammetria kriminalisztikai alkalmazása – tudományosan megalapozott módszerek fényképezőgép segítségével történő 3D képrögzítéshez [The Forensic Application of Photogrammetry – Scientifically Grounded Methods for 3D Image Capture Using Cameras]. *Rendőrségi Tanulmányok*, Issue 2024/(különszám). 78–220. o.

DOI: 10.53304/RT.2024.ksz.02

Fülöp, P. – Ujvári, Zs. – Petréttei, D. – Kiss, I. – Dudás-Boda, E. – Metzger, M. – Fullár, A.: Az igazságügyi szakértői szemléltetés modern eszközei és lehetőségei [Modern Tools and Possibilities of Forensic Expert Demonstration]. *Ügyészek Lapja*, Issue 2023/5–6. 91–102. o.

¹⁰ Petréttei, D.: A drónok krimináltechnikai és rendészeti felhasználása [The Forensic and Law Enforcement Use of Drones]. *Magyar Bűnüldöző*, Issue 2015/1–3. 70–81. o.

¹¹ (n.d.): Forensic animation for legal cases [Forensic Animation for Legal Cases].

Source: <https://courtroomanimation.com/forensic-animation-legal-cases-guide/>

Accessed: 30.08.2025

Each of these digital tools is thus capable of reducing distortions arising from human subjectivity. They serve a complementary rather than a substitutive role alongside traditional methods, ensuring that reconstructions become more comprehensive.

Case Studies – impacts of digital evidence

The significance of digital technologies can best be understood through concrete cases. In recent years, several proceedings have been influenced by three-dimensional reconstruction or artificial intelligence. Digital evidence is thus no longer an experimental possibility but a living issue of legal practice.

Case of Antonio Jerome Greenlee

In 2009, a court in Georgia authorised jurors to virtually explore the crime scene using a 3D model. The visualisation, created with the Leica and Tru-View system, enabled direct perception of the spatial relationships among the witnesses, the defendant, and the victim. The demonstration significantly contributed to the jury's understanding and to the prosecution's success. The importance of the case lies in showing that digital reconstruction, beyond its illustrative role, can also be utilised as evidence.¹²

McCloud and Cameron – Exoneration of the Innocent

In 1995, two young men were convicted of a shooting that occurred in the hallway of an apartment building. Nearly thirty years later, as part of the Innocence Project and with the involvement of university students, laser scanning was carried out at the scene to reconstruct the events and verify the accuracy of witness statements. The new documentation demonstrated

¹² (n.d.): Leica 3-D laser-scan data provides forensic evidence at murder trial [Leica 3-D Laser-Scan Data Provides Forensic Evidence at Murder Trial].

Source: <https://www.policemag.com/technology/news/15344099/leica-3-d-laser-scan-data-provides-forensic-evidence-at-murder-trial>

Accessed: 10.06.2025

that the version described in the testimonies was physically impossible. Impact marks in the wall, previously concealed with plaster, revealed that the shooting had in fact taken place elsewhere. Thanks to the reconstruction, McCloud and Cameron—who had earlier confessed under coercion—were exonerated.¹³ The case serves as an excellent example of the role of digital forensics in preventing miscarriages of justice.

Archiving of Remains Documentation in Canada

The Royal Canadian Mounted Police initiated the documentation of human remains using 3D scanning. This method made it possible to preserve the original remains while creating digital replicas that will remain suitable for examination for decades. Its advantage lies in the fact that, as new scientific methods become available, the archived material can be re-evaluated without risking damage to the original evidence. In this way, digital recording will serve as a valuable resource for future generations as well.¹⁴

The Case of Michel Serge – Forensic Animations in Court

Michel Serge, a retired investigator, killed his wife. During the trial, a forensic animation was presented that illustrated the trajectory of the bullets, as well as the victim's movements and body positions. This provided the jury with a clearer understanding of the events in question. In the United States, such visualisations are sometimes referred to as “junk science,” sug-

¹³ (n.d.): How an NJIT forensic team helped exonerate two men wrongfully imprisoned for murder [How an NJIT Forensic Team Helped Exonerate Two Men Wrongfully Imprisoned for Murder].

Source: <https://news.njit.edu/how-njit-forensic-team-helped-exonerate-two-men-wrongfully-imprisoned-murder>

Accessed: 11.06.2025

¹⁴ (n.d.): 3 court cases that used forensic 3D scan data [3 Court Cases that Used Forensic 3D Scan Data].

Source: <https://datumtechsolutions.com/blogs/public-safety-industry/3-court-cases-that-used-forensic-3d-scan-data>

Accessed: 10.06.2025

gesting that they rest on pseudo-scientific foundations. In practice, however, they can help shorten trial duration and facilitate agreements between the parties.¹⁵

The Case of Christopher Pelkey – An AI-Generated Victim Message

In 2021, at a court in Arizona, the victim's family presented a video created with artificial intelligence in which the murdered man "spoke" through deepfake technology. In the video, delivered in his own voice, the man forgave the perpetrator—a statement the judge treated as an aggravating factor. The video sparked intense debate within the legal community, as it may have influenced the judicial decision and served as a precedent demonstrating the impact of AI on sentencing.¹⁶

The briefly summarised cases clearly illustrate that digital tools shape not only investigations but also judicial decision-making. Alongside the promise of greater objectivity and transparency, they raise new types of evidentiary and ethical questions, thereby charting the path forward for legislators and legal practitioners alike.

The Role of Artificial Intelligence in Reconstruction

The assistance provided by digital tools in reconstruction processes is undeniable; however, the full potential of artificial intelligence in forensic

¹⁵ (n.d.): Forensic animation gets more realistic [Forensic Animation Gets More Realistic].

Source: <https://abcnews.go.com/WNT/story?id=129973&page=1>

Accessed: 30.06.2025;

Source: <https://www.wired.com/2002/05/forensics/>

Accessed: 19.06.2025

¹⁶ (n.d.): From AI avatars to virtual reality crime scenes, courts are grappling with AI in the justice system [From AI Avatars to Virtual Reality Crime Scenes, Courts Are Grappling with AI in the Justice System].

Source: <https://apnews.com/article/ai-virtual-reality-courtrooms-legal-challenges-arizona-f47bfd50bd22469388082169ee77b7f0>

Accessed: 05.06.2025

practice can be realised through its integration. Modern crime scene recording technologies generate vast amounts of data. Processing, organising, and interpreting these data opens possibilities beyond the capacity of human experts. In this domain, artificial intelligence offers solutions by recognising patterns, modelling event sequences, and generating alternative scenarios.¹⁷

In bloodstain pattern analysis, AI can calculate the angle of impact of blood droplets through image processing, thereby providing insights into the victim's body position and the direction of the attack. It also plays a significant role in analysing bullet trajectories. Based on traces found on objects or walls, it can reconstruct the direction of the shots and the shooter's possible position. AI can further assist with identification, capable of recognising footwear impressions and even firearms.¹⁸

An advantage of its application is its ability to recognise patterns that may easily escape the human eye. It can perform analyses on recorded digital models according to various criteria, ensuring that examinations are both reproducible and resource-efficient.

Among the drawbacks, as Nyitrai points out, is that the spread of digitalisation has been accompanied by the emergence of new methods of crime — such as deepfakes and other forms of falsified digital content— which pose serious challenges for law enforcement.¹⁹

¹⁷ Herke, Cs. (2025): i.m. 42–49. o.

¹⁸ Jain, D. – Kher, S. – Liang, L. – Wu, Y. – Zheng, A. – Cai, X. – Plantinga, A. – Upton, E.: Improving and evaluating machine learning methods for forensic shoeprint matching [Improving and Evaluating Machine Learning Methods for Forensic Shoeprint Matching]. arXiv. 2024.

Source: <https://doi.org/10.48550/arXiv.2405.14878>

Sirisathitkul, C. – Sirisathitkul, Y.: Bloodstain in forensics: from visual inspections to AI-assisted pattern analysis and age estimation [Bloodstain in Forensics: From Visual Inspections to AI-Assisted Pattern Analysis and Age Estimation]. History of Science and Technology, Issue 2025/1. 26–46. o.

Source: <https://doi.org/10.32703/2415-7422--2025-15-1-26-46>

¹⁹ Nyitrai, E.: A digitális adatok és a modern technikai eszközök jelentősége a kriminalisztikában [The Importance of Digital Data and Modern Technical Tools in Criminalistics]. Nemzeti Közszolgálati Egyetem. Budapest, 2025.

Among the risks of applying AI, the most well-known is the “black box” phenomenon. The decisions and conclusions of machine learning algorithms are often not traceable. If an analysis is presented before a court whose methodology neither the expert nor the judge can understand, the question naturally arises: can it be accepted as evidence? Alongside the black-box issue, bias poses another serious problem: if the system is trained on distorted data, its conclusions will be distorted as well. The PredPol system exemplifies this in practice, as the overrepresentation of certain ethnic groups in the training data has led to flawed law enforcement practices²⁰. Thus, this danger may also arise in criminalistics, particularly in the context of crime scene reconstructions.

This is why AI must be used as a supporting tool rather than as an autonomous decision-maker in criminal proceedings. Responsibility must remain with the human expert. AI cannot become an independent source of evidence; it may only be used as supplementary data to complement human evaluation.

In summary, the application of artificial intelligence is dual in nature: it presents both opportunities and risks. It opens new horizons for enhancing objectivity and accelerating evidentiary processes. At the same time, transparency and accountability remain paramount, meaning that AI can only be used within appropriate legal frameworks. The challenge of the future is therefore not merely technological, but primarily legal and ethical: how to integrate AI into criminal proceedings in a way that strengthens, rather than undermines, the legitimacy of justice.

Legal and Regulatory Issues

²⁰ (n.d.): The disparate impact of predictive policing software [The Disparate Impact of Predictive Policing Software].

Source: <https://themarkup.org/newsletter/hello-world/the-disparate-impact-of-predictive-policing-software>

Accessed: 10.06.2025

The tools of digital evidence, 3D reconstruction, and artificial intelligence can only become truly usable in criminal proceedings if they comply with the legal criteria for admissibility. The central question is what qualifies as evidence. A digital model on its own does not possess probative value: it can only be regarded as such if its origin is verified (chain of custody), its methodology is documented, and an expert carries out its interpretation.²¹ A model, therefore, is not an independent source of evidence but rather a demonstrative tool forming part of the expert opinion.

However, the application of artificial intelligence raises further questions. As noted above, the conclusions generated by machine learning are not traceable. They cannot be verified by either the expert or the judge, thereby raising concerns about the admissibility of such evidence.²² In the United States, AI-based evidence is admissible only if the system's operation is properly documented, its developer is subject to audit, it remains under human oversight, and it is free from bias.²³ This also helps to prevent bias, that is, distortions which could otherwise compromise the evidentiary process.

²¹ Nath, S. – Summers, K. – Baek, J. – Ahn, G. J.: Digital evidence chain of custody: navigating new realities of digital forensics [Digital Evidence Chain of Custody: Navigating New Realities of Digital Forensics]. In: Proceedings of the 2024 IEEE 6th International Conference on Trust, Privacy and Security in Intelligent Systems and Applications (TPS-ISA 2024). Institute of Electrical and Electronics Engineers Inc. 2024. 11–20. o. Source: <https://doi.org/10.1109/TPS-ISA62245.2024.00012>

Kreitz, Z.: A chain of custody digitalizálásának lehetőségei [Possibilities for the Digitalization of the Chain of Custody]. *Hadmérnök*, Issue 2025/4. 131–142. o. Source: <https://doi.org/10.32567/hm.2024.4.9>

²² (n.d.): Ensuring chain of custody and verifiability for AI-generated content [Ensuring Chain of Custody and Verifiability for AI-Generated Content]. Source: <https://sealstorage.io/resources/blog/ensuring-chain-of-custody-and-verifiability-for-ai-generated-content>
Accessed: 30.06.2025

²³ (n.d.): AI-generated evidence: a guide for judges [AI-Generated Evidence: A Guide for Judges]. Source: <https://www.ncsc.org/resources-courts/ai-generated-evidence-guide-judges>
Accessed: 30.06.2025

The question of responsibility is likewise a crucial one: who bears it—the developer, the police officer, or the expert? Since AI can only appear as a supporting tool, responsibility must rest with the human expert. This ensures that decisions are grounded in human judgment, which necessarily entails criminal liability as well.²⁴

The European Union's AI Act, adopted in 2024, has elevated the use of AI in the justice system to a new level. The regulation classifies all such systems as “high-risk AI” and imposes strict requirements: CE marking, audited and documented operation, and continuous human oversight are mandatory.²⁵ The regulation makes it clear that AI cannot serve as an independent source of evidence and may be used only if transparency and verifiability are guaranteed.

In addition to legal concerns, attention must also be given to the principle of procedural fairness. The acceptance of digital evidence can only be legitimised in society's eyes if its application occurs within a fair, respectful, and transparent process.²⁶

Overall, it can be concluded that 3D reconstructions and AI tools can only become part of evidentiary practice under strict legal and ethical conditions. The challenge of the future does not lie in what these technologies are capable of, but in how legislation and legal practice can frame their application so that they strengthen, rather than weaken, the legitimacy of justice.

²⁴ (n.d.): Who's liable when AI makes legal mistakes? [Who's Liable When AI Makes Legal Mistakes?].

Source: <https://aicompetence.org/whos-liable-when-ai-makes-legal-mistakes/>
Accessed: 20.06.2025

²⁵ (n.d.): EU AI Act [EU AI Act].

Source: <https://artificialintelligenceact.eu/>
Accessed: 20.06.2025

²⁶ Vári, V.: Az eljárási (procedurális) igazság jelentősége a rendőri munkában [The Importance of Procedural Justice in Police Work]. In: Barabás, A. T. – Christián, L. (eds.): *Ünnepi tanulmányok a 75 éves Németh Zsolt tiszteletére. Navigare necesse est*. Ludovika Egyetemi Kiadó. Budapest, 2021. 509–518. o.

Summary

Digital technologies — such as photogrammetry, laser scanning, drone imaging, and VR/AR — have revolutionised the practice of forensic reconstruction. These tools have introduced more precise and detailed methods of documentation while also offering new possibilities for visualisation, thereby opening new dimensions in judicial decision-making. Artificial intelligence supports the processing of the resulting datasets, the recognition of patterns, and the reconstruction of sequences of events, thus enhancing the objectivity and efficiency of the evidentiary process.

Alongside the opportunities inherent in these technologies, their application also entails risks. Algorithms may be opaque, distorted data can produce bias, and questions of responsibility may confront practitioners with ethical dilemmas. If transparency and expert oversight cannot be ensured in the use of such tools, both the fairness of proceedings and public trust may be undermined. The EU AI Act stipulates that all systems intended for judicial purposes fall into the high-risk category and may therefore be used only under strict safeguards.

The study concludes that digital tools, and thus digital reality, are not the future but already an integral part of contemporary justice. They complement rather than replace human expertise, thereby strengthening the objectivity of evidentiary processes.

The challenge of the future is twofold: on the one hand, to ensure the integration of technological innovations into the processes of investigation and evidence; on the other, to establish the safeguards under which society can accept such evidence with confidence. The pursuit of truth remains a human responsibility - and digital tools can only fulfil their true role if they reinforce, rather than replace, that responsibility.