Reconstruction and Demonstration in Three Dimensions

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Abstract

The continuous technological advancement in forensic science creates new opportunities for recording, analyzing, and demonstrating crime scenes in court. Three-dimensional (3D) modeling and reconstruction have become one of the most advanced tools in crime scene investigation and forensic evidence presentation, surpassing traditional documentation methods by providing more detailed and interactive visualizations. The application of 3D models enables the spatial and temporal reconstruction of events, contributing to a more precise interpretation of evidence and enhancing the efficiency of investigations.

This study explores the forensic applications of 3D reconstruction, focusing on crime scene examinations, forensic demonstrations, and courtroom evidence presentation. The research highlights that 3D technologies not only facilitate the digital documentation of crime scenes but also allow for testing alternative investigative hypotheses and verifying witness statements. Integrating 3D modeling into forensic investigations enhances objectivity in criminal inquiries and aids in informed decision-making within the justice system.

Furthermore, 3D printing and photogrammetry technologies expand the toolkit of forensic analysis by enabling injury reconstruction, the comparison of crime scene evidence and objects, and the creation of models suitable for courtroom demonstrations. The study emphasizes that while 3D technologies offer significant advantages, their application must consider data protection, procedural legal challenges, and admissibility issues.

In conclusion, the research finds that 3D modeling and reconstruction have become essential tools in forensic evidence analysis and courtroom proceedings, with the potential to play an even greater role in supporting criminal investigations and legal processes in the future.

Keywords: *3D reconstruction, 3D modeling, modern forensic tools, courtroom demonstration*

I. Introduction

The continuous evolution of forensic methods is essential for the accurate investigation of criminal cases and the effective support of the justice system. Over the past decades, technological advancements have introduced new tools and methodologies in crime scene investigation and evidence presentation, among which 3D modeling and

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reconstruction play a particularly significant role. Three-dimensional modeling not only adds a new dimension to crime scene documentation but also brings revolutionary changes to forensic science and the judicial process.

The application of 3D technologies allows for the realistic recording and detailed analysis of crime scenes. Instead of traditional two-dimensional photographs and sketches, prosecutors, defense attorneys, and forensic experts can now examine evidence using interactive three-dimensional models. These models enable the precise determination of shooting angles, the analysis of injuries, and even the reconstruction of an offender's movements, aiding in the development of various investigative hypotheses. Moreover, 3D scanning of crime scenes ensures that a given situation can be reexamined later, eliminating the risk of evidence distortion or destruction.

Beyond crime investigation, one of the most critical applications of 3D modeling is courtroom demonstration. Complex crime scenes and events are often challenging to present clearly to judges or juries. However, with the aid of 3D models, crime environments can be simulated in court, allowing forensic experts to accurately demonstrate how a particular event may have occurred. Realistic reconstructions enhance the transparency of judicial proceedings and contribute to well-founded legal decisions.

The aim of this study is to explore the forensic applications of 3D modeling, highlighting its role in crime scene investigation, evidence analysis, and courtroom presentations.

II. Crime Scene Reconstruction

The first recorded written references to crime scene investigations date back to the 22nd century BCE[1], while an official crime scene report from the reign of Pharaoh Ramses IX (circa 1100 BCE) documents the investigation of a tomb robbery.[2] However, it was not until the late 19th century that forensic science began to establish crime scene examination on a scientific foundation. This shift incorporated the systematic analysis of crime scene evidence, traces, and environmental conditions, significantly contributing to the advancement of objective forensic investigations. As natural sciences and technological procedures evolved, so did crime scene examination methods, becoming increasingly precise. The introduction of procedural safeguards, such as ensuring impartial witness testimonies and adhering to written documentation, further reinforced the objectivity of forensic investigations.[3]

The primary goal of crime scene investigation is to reconstruct and understand the circumstances of a crime while collecting evidence that can answer key investigative questions. This process is particularly complex, as crime scenes typically present only the aftermath of events, leaving room for multiple interpretations. Investigators must identify and analyze both apparent and latent traces, determining their origin and significance. However, crime scene evidence alone is often insufficient for reconstructing

[1] P. Déri, A. Budai, *Korszerű bűnüldözés [Modern Law Enforcement],* Budapest, ORFK, 1991, p. 102.

[2] G. Kovács, *A helyszíni szemle normatív szabályozásának igénye éslehetőségei a büntetőeljárásban [The need for and possibilities of the normative regulation of crime scene investigation in criminal procedure]*, in K. Szoboszlai Kiss, G. Deli (eds.), Tanulmányok a70 éves Bihari Mihály tiszteletére *[Studies in honour of the 70-year-old Mihály Bihari]*, Győr, Universitas-Győr Nonprofit Kft., 2013b, p. 292.

[3] G. Gárdonyi, *A bűnügyi szemle [The Crime Scene Investigation]*, Budapest, Ludovika Egyetemi Kiadó, 2024. p. 19.

the full sequence of events. Additional sources such as police reports, witness statements, and forensic expert analyses are essential in forming a comprehensive understanding.

Crime scene reconstruction can be approached through both conceptual and technological methods. Conceptual reconstruction plays a crucial role in crime scene analysis, allowing investigators to infer the sequence of events and the possible behavior of perpetrators. This method has deep historical roots, as its importance in criminal investigations has long been recognized. A fundamental aspect of this approach is a thorough understanding of the crime scene and the modus operandi of the offense. Over time, conceptual reconstruction has evolved, with different scholars emphasizing various aspects, further enriching the methodological framework.

The dynamic phase of crime scene investigation often reveals evidence suggesting alternative methods of commission or different perpetrator behaviors. It is particularly important for reconstruction efforts to consider potentially irrational actions by offenders, as crimes frequently occur under emotional, psychological, or situational influences. Investigators must adopt the perpetrator's perspective to avoid cognitive biases and erroneous conclusions.

One of the main limitations of conceptual reconstruction is its potential reliance on a single, potentially flawed hypothesis. If investigators focus exclusively on one scenario, they risk overlooking alternative possibilities, ultimately leading to misleading conclusions. Therefore, a comprehensive and flexible approach is required for effective crime scene analysis. While conceptual reconstruction is an essential investigative tool, it should not be the sole method employed. A frequently overlooked aspect in the literature is that this method alone does not always provide sufficiently reliable results, necessitating the integration of alternative techniques such as technology-based reconstructions.

The inclusion of 3D modeling and digital reconstruction addresses many of the limitations associated with conceptual methods. The use of advanced forensic technologies allows for the precise documentation of crime scenes and the visualization of multiple hypotheses. This is particularly valuable in cases where an offender's irrational behavior, the crime's dynamic nature, and subjective human factors introduce uncertainties. A single misinterpretation or inaccurately constructed scenario can hinder the discovery of the truth and the consideration of alternative possibilities. By combining conceptual analysis with technological advancements, forensic investigators can enhance the accuracy and reliability of crime scene reconstructions.

Conceptual reconstruction relies on initial observations at the crime scene and the evaluation of witness testimonies. Both objective and subjective factors influence the effectiveness of an investigation, requiring investigators to consider three primary limitations:

- Offender Behavior Under Stress – Perpetrators often act irrationally due to stress or emotional influences, complicating reconstruction efforts.
- Deliberate Misdirection – Offenders may intentionally mislead investigators, further hindering the accurate reconstruction of events.
- New Evidence Consideration – Investigators must remain open to new evidence, as it may alter initial conclusions.

Misinterpretation of facts can lead to faulty assumptions, making it essential for investigative strategies to be flexible and adaptable to newly emerging information. During investigations, it is common for early versions of events to require modifications

in light of later evidence. Dynamically evolving situations can provide critical insights that contribute to a more accurate reconstruction of the crime. Ultimately, it is the collective responsibility of investigators to recognize and address the limitations of conceptual reconstruction, ensuring that the most precise conclusions are drawn in criminal investigations.[4]

Fenyvesi draws a parallel between the strategic elements of a chess game and the phases of criminal investigation. According to this analogy: the crime scene examination corresponds to the opening phase, the investigation process representing the middlegame and the court proceedings equate to the endgame. The crime scene examination initiates the investigation through primary measures, including evidence collection and the reconstruction of events. This phase requires rapid responses, error prevention, and meticulous evidence gathering and identification to ensure accuracy and reliability. The first decisive move, as a fundamental principle in criminalistics, holds critical importance. Establishing preliminary versions of past events during the crime scene examination is particularly essential. By formulating early hypotheses, investigators can guide the collection of physical traces and material evidence, ensuring that these elements are preserved and can later be effectively used in the endgame — the courtroom proceedings.[5]

The seven fundamental questions of forensic science (What happened? Where did it happen? When did it happen? How did it happen? Who committed the crime? With whom? And finally, why?) have now become a theoretical cornerstone of criminal investigations. Providing precise answers to these questions enables investigators to reconstruct past events and draw accurate legal conclusions. Without a thorough understanding of the facts, it is impossible to legally qualify a case. If an investigator lacks clear and well-defined answers, they cannot fully comprehend the event, making it difficult to formulate the case accurately and assess it from a legal standpoint. Without addressing these seven key questions, we cannot claim to have a complete and accurate understanding of the relevant facts, past events, and the legal situation to be adjudicated. The greatest danger in failing to answer these questions properly is judicial error, commonly known as "justizmord"—a wrongful conviction. Preventing and avoiding such errors is one of the most critical responsibilities of any legal practitioner.[6]

The substantive resolution of a case requires evidentiary procedures, which function as distinct cognitive processes. The reconstruction of events relies on evidence, which preserves traces of past occurrences and can thus be linked to the original chain of events. By applying rational thinking and logical principles, well-founded conclusions can be drawn from the known facts about what actually transpired.

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[4] G. Gárdonyi, *A gondolati rekonstrukció korlátai [The Limitations of Conceptual Reconstruction]*, in Belügyi Szemle, 2013/10., pp. 65–71.

[5] C. Fenyvesi, *A kriminalisztika, mint a bűnügyi sakkjátszma tudománya [Criminalistics as the Science of the Criminal Chess Game]*, in G. Gaál, Z. Hautzinger (eds.), *A határrendészettől a rendészettudományig [From border policing to police science]*, Pécs, Magyarország: Magyar Hadtudományi Társaság Határőr Szakosztály Pécsi Szakcsoport, 2016, p. 332, pp.189-201, p. 13.

[6] C. Fenyvesi, *A kriminalisztika alapkérdései [The Fundamental Questions of Criminalistics]*, in G. Gaál, Z. Hautzinger (eds.), *A rendészettudomány határkövei II. Válogatás a Pécsi Határőr Tudományos Közlemények második évtizedéből [The frontiers of police science II. Selections from the second decade of the Pécs Border Guard Scientific Bulletins]*, Pécs, Magyarország: Magyar Hadtudományi Társaság Határőr Szakosztály Pécsi Szakcsoport, 2022, p. 247, pp. 209-218, p. 10.

Just as Gárdonyi highlighted the limitations of cognitive reconstruction, it is equally important to recognize the constraints of judicial decision-making. Judges must not only be aware of their own psychological predispositions but also carefully assess personal evidence, such as witness testimonies. Even though we all perceive the same physical world, individual perception varies significantly, as it is shaped by neurological processes. Perception is a symbolic process linked to the brain's cognitive functions and relies on a continuous flow of external stimuli. If this flow is disrupted or ceases altogether, distortions in perception can occur, potentially leading to hallucinations. A judge's cognitive process differs from direct observation of past events; instead, it is an indirect and reversed process, in which conclusions about causes are drawn from effects based on the available evidence. These characteristics introduce uncertainty factors, making absolute mathematical certainty impossible in judicial reasoning. Neither logical deductions nor mathematical models can fully eliminate this uncertainty. Only a judge with experience and critical reasoning skills can apply an appropriate standard of judgment, considering real-life plausibility and typical patterns of correlation.

Uncovering reality is essential for the judicial process, but it does not inherently guarantee justice. Even if the facts of a case are established correctly, errors in legal application or the enforcement of laws perceived as unjust may lead to a verdict that appears unfair. Conversely, if a judge's decision is not based on factual reality, the ruling will inevitably deviate from the truth and fail to achieve justice. Therefore, the proper functioning of the judiciary fundamentally depends on the accurate establishment of facts. Psychological and perceptual differences in evidentiary procedures, along with the inherent uncertainties stemming from the indirect nature of evidence, significantly impact legal cognition and the effectiveness of the justice system. In this context, 3D models, crime scene reconstructions, and courtroom demonstrations play a crucial role, as they provide visual and spatial tools to present past events more accurately and comprehensively. Three-dimensional visualization enables judges, attorneys, and jurors to go beyond theoretical descriptions and photographs by examining the crime scene and event dynamics in spatial and interactive perspectives. This approach helps to reduce subjective misinterpretations arising from perception biases, while also enhancing the transparency and persuasiveness of evidentiary proceedings.[7]

Just as *Fenyvesi* defined the investigation as the middlegame in a chess match, it is clear that all necessary tools and methods must be employed to successfully reconstruct the past. This process must also keep pace with technological advancements and emerging trends. New forensic technologies, such as rapid identification systems, have revolutionized crime scene investigation. Instant DNA and fingerprint analysis now allows for immediate database comparisons, providing investigators with a highly effective tool. The ability to quickly identify individuals linked to evidence, even in the early stages of an investigation, significantly enhances both efficiency and accuracy in criminal inquiries. Beyond digital forensic analysis and the use of artificial intelligence, this study explores the role of 3D modeling and its applications in forensic investigations.

[7] Kúria Büntető-Közigazgatási-Munkaügyi és Polgári Kollégiumai Joggyakorlat-Elemző Csoport: Összefoglaló vélemény. Az ítéleti bizonyosság elméleti és gyakorlati kérdései [Summary Opinion. Theoretical and Practical Issues of Judicial Certainty], available at https://kuria-birosag.hu/sites/default/files/joggyak/osszefogl_velemeny_iteleti_bizonyossag.pdf (accessed on 19.01.2025).

III. Modern Technologies: The Application of 3D Models

3D reconstruction technology has become widespread across various industries, demonstrating exceptional flexibility and practical utility. In medicine, it has become an indispensable tool, particularly in surgical planning and medical education, as it allows for detailed visualization of anatomical structures. Surgeons can better understand patients' unique anatomical features before procedures, improving surgical precision and outcomes. Beyond healthcare, the real estate industry has also been revolutionized by 3D technology, enabling virtual tours that provide immersive and detailed visualizations of properties. This innovation allows potential buyers to explore properties remotely, facilitating more informed decision-making. These examples highlight the diverse applications of 3D modeling across different fields.

The continuous development of 3D reconstruction technology is creating new opportunities, particularly in crime scene investigations. The ability to accurately and comprehensively represent physical crime scenes is crucial for reconstructing criminal events. By integrating 3D reconstruction into forensic investigations, investigators gain a more comprehensive understanding of events, enhancing evidence collection, interpretation, and courtroom presentation. The adoption of 3D technology in forensic science represents a significant advancement, reinforcing the role of cutting-edge digital tools in criminal investigations and law enforcement. This innovation improves investigative efficiency and increases the reliability of forensic evidence in judicial proceedings.[8]

3D modeling is an advanced technology in forensic investigations that enables the detailed, three-dimensional reconstruction of crime scenes, accidents, or other significant events. These models function as computer-generated animations, providing a comprehensive, multi-angle visualization of the incident. Traditional crime scene documentation, such as photographs and video recordings, has now been enhanced with 3D scanning and laser scanning technologies, revolutionizing forensic processes. By collecting millions of data points, the crime scene can be captured with high precision and detail in a matter of minutes. Unlike traditional photography, where factors such as lighting conditions and distortion issues can affect image quality, 3D scanning eliminates these limitations while providing additional valuable information.

3D modeling is becoming increasingly essential in forensic examinations, especially in cases where available evidence is incomplete or insufficient. Forensic expert evaluations are often necessary when new evidence or circumstances emerge or when the original crime scene has changed over time. In such situations, 3D reconstruction allows for the recreation of the scene and events using publicly available sources such as Google Maps, Google Street View, and architectural or construction archives. This technology enhances investigative accuracy, supports legal proceedings, and helps ensure that key forensic details remain preserved for future analysis.

The analysis of spatial relationships between different elements of a crime scene and the individuals involved is crucial in forensic investigations. Since both the spatial and temporal aspects of events are key factors in criminal analysis, three-dimensional

[8] D. Rangelov, J. Knotter, R. Miltchev, *3D Reconstruction in Crime Scenes Investigation: Impacts, Benefits, and Limitations*, in K. Arai (ed.), *Intelligent Systems and Applications. IntelliSys 2024. Lecture Notes in Networks and Systems*, vol 1065, 2024, Springer, Cham, https://doi.org/10.1007/978-3-031-66329-1_4.

models provide a far more precise and detailed representation compared to traditional methods.

A notable example comes from the 3D Analysis Laboratory at the Wroclaw Medical University, which conducted a 3D reconstruction of a homicide case that had occurred nine years earlier. The primary objective was to support or refute conflicting witness statements. During the proceedings, the court accepted the 3D modeling as a visual aid to assess the credibility of testimonies, demonstrating the increasing forensic relevance of such reconstructions.

In another case, a 3D model was used to experimentally reconstruct events and compare different investigative scenarios. A woman was found dead in her home with multiple injuries and traces of two different weapons, yet no direct evidence pointing to the perpetrator was discovered. Investigators developed several possible hypotheses regarding both the manner of the crime and the identity of the offender. Through 3D modeling, forensic experts were able to test these hypotheses, reconstruct the sequence of events, and ultimately identify a single perpetrator who used two weapons simultaneously. The court accepted the model as valid forensic evidence, further emphasizing the growing role of 3D technology in modern criminal investigations.[9]

In another case, a 3D model was instrumental in reconstructing the sequence of events and comparing different investigative scenarios. A woman was found dead in her home, with multiple injuries and traces of two different weapons identified on her body. However, no direct evidence leading to the perpetrator was found at the scene. Investigators formulated several possible scenarios, exploring the "how?" and "who was involved?" aspects of the crime. The 3D modeling process enabled forensic experts to test these hypotheses, verify the plausibility of different versions, and ultimately reconstruct the crime scene. This led to the identification of a single perpetrator who had used two weapons simultaneously. The court accepted the 3D model as forensic evidence, further demonstrating the increasing role of three-dimensional reconstructions in modern criminal investigations.[10]

A research team analyzing publications from 2005 to 2021 reviewed 258 studies and concluded that research on 3D reconstruction has grown significantly in recent years. The study also found that nearly two-thirds of researchers in this field are based in Europe or North America. In Europe, countries such as Switzerland, Italy, England, and the Netherlands are particularly engaged in crime scene reconstruction and forensic research, highlighting the increasing adoption of 3D modeling technologies in forensic investigations.[11]

It is also necessary to briefly mention photogrammetry technology, which enables the three-dimensional reconstruction of objects and crime scenes based on

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[9] K. Maksymowicz, W. Tunikowski J. Kościuk, *Crime event 3D reconstruction based on incomplete or fragmentary evidence material – Case report*, Forensic Science International, Volume 242, September 2014, pp. e6-e11.

[10] I. Aquila, M.A. Sacco, G. Aquila, R. Raffaele, A. Manca, G. Capoccia, F. Cordasco, P. Ricci, *The Reconstruction of the Dynamic of a Murder Using 3D Motion Capture and 3D Model Buildings: The Investigation of a Dubious Forensic Case*, J. Forensic Sci., 2019 September, vol. 64(5), pp. 1540-1543, doi: 10.1111/1556-4029.14041.

[11] M.A. Maneli, O.E. Isafiade, *3D Forensic Crime Scene Reconstruction Involving Immersive Technology: A Systematic Literature Review*, in *IEEE Access*, 2022, vol. 10, pp. 88821-88857, doi: 10.1109/ACCESS.2022.3199437.

photographs. This method is increasingly recognized in international literature as an alternative to 3D laser scanning. The principle of photogrammetry lies in creating 3D models using a series of overlapping images taken from different perspectives, processed through specialized software. The required images can be captured with almost any imaging device, ranging from aerial drone photography to interior documentation of buildings, and even to smaller objects, such as bodies, crime scene evidence, or microscopic objects. Properly scaled 3D models are not only capable of high-precision measurements but also provide lifelike visual representation due to their photo-realistic textures. The detail and resolution of the generated models can be optimized without reducing the polygon count, making them easily displayable even on lower-performance computers, including those without dedicated graphics cards. Because photogrammetry does not require specialized equipment, it is highly accessible for forensic professionals and can be effectively used to document crime scenes, bodies, and physical evidence in three dimensions. One of the major advantages of photogrammetric imaging is its ease of use, as it can be executed using nearly any still or video recording device. In the absence of professional cameras, a compact digital camera, action camera, or even a smartphone can suffice for capturing the necessary images. For example, applications such as RealityScan can generate a highly accurate 3D model of a crime scene from a series of photographs taken with a mobile device. The resulting models can then be integrated into various software, such as the Unity game engine, allowing for dynamic reconstructions where virtual animated figures simulate movements based on real-world physics parameters. Moreover, photogrammetry enables the digital reconstruction of various objects, including damaged bones or forensic evidence, providing detailed analysis for forensic investigations. These models can be stored in a forensic database for future reference or even reproduced in physical form using 3D printing technology.[12]

While photogrammetry offers numerous advantages, it is crucial to acknowledge its limitations in forensic applications. The software processing of images can encounter difficulties or even become entirely unfeasible under conditions that complicate the accurate alignment of common points and overlapping areas from images taken at different angles. Particularly problematic factors include:

- Reflective or glossy surfaces, as these cannot be reliably captured using photogrammetric methods due to their tendency to distort light reflections.
- Uniform, monochromatic surfaces and transparent objects, such as glass, which lack distinct features necessary for precise alignment.
- Vegetation-covered areas, such as grass or leaves, pose additional challenges, as even the slightest air movement can shift plant elements, leading to distortions and inaccuracies in the 3D reconstruction.

These factors highlight the importance of selecting appropriate environments and objects for forensic photogrammetry and, when necessary, combining it with

[12] P. Fülöp, *Az igazságügyi fizikus szakértői terület jelene és jövője [The Present and Future of Forensic Physics Expertise]* in G. Gaál, Z. Hautzinger (eds.), *A biztonság védelme a rendészetben: Jubileumi kötet Zámbó Péter ny. rendőr ezredes 70. születésnapjára [Protecting security in law enforcement: an anniversary volume for the 70th birthday of Péter Zámbó, retired police colonel]*, Pécs, Magyarország: Magyar Hadtudományi Társaság Határőr Szakosztály Pécsi Szakcsoport, 2023, p. 406, pp. 309-314, p. 6.

other technologies such as 3D laser scanning to ensure accurate and reliable documentation.[13]

It is also important to highlight another area where modern forensic technologies can be effectively applied: network analysis. In criminal investigations, network analysis can help uncover connections between events, perpetrators, and locations. The application of network analysis techniques, especially when combined with crime mapping methods and 3D reconstruction technologies, allows for a more precise identification of the spatial and temporal patterns of criminal activities. As a result, investigations can become more efficient, while also enabling law enforcement to track offender movements, social connections, and identify potential crime hotspots.[14]

3D printing is increasingly becoming an integral part of forensic medical practice, offering new possibilities for injury reconstruction, comparing injuries with suspected weapons or objects, and providing visual demonstrations and identification tools. Additionally, 3D-printed models serve as highly effective tools for courtroom demonstrations, aiding judges and juries in better understanding the presented evidence. Modern 3D printers have now reached a level of accuracy suitable for forensic applications, providing a cost-effective solution for supporting forensic investigations. Beyond forensic demonstrations, it is also crucial to highlight the role of 3D printing in education. In forensic medicine, 3D-printed models are successfully used in: anatomy education, simulation-based training for investigating sexual assault cases (particularly for obstetrics and gynecology residents), skull trauma analysis and bone pathology training. Modeling skeletal and organ injuries presents a valuable opportunity for forensic education, as 3D-printed models serve as realistic visual tools. Since post-mortem imaging is a widely applied method in forensic investigations, the necessary 3D models can be easily produced and made widely available, thereby enhancing forensic training and case analysis.[15]

IV. 3D Reconstruction: Advantages and Limitations

As demonstrated above, 3D modeling and reconstruction can be applied in numerous fields. Summarizing its main advantages, the following points can be highlighted:

- Scale-accurate reconstructions are possible due to precise spatial representation, reducing distortion. The recorded scene can be zoomed in and examined at different levels of detail.
- Reconstruction of missing or altered crime scenes is feasible, even when the original site has significantly changed over time.
- Virtual crime scene walkthroughs can be created, allowing legal professionals to interactively explore the environment, making it a powerful investigative tool.

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[13] M. Metzger, Z. Újvári, G. Gárdonyi, *A fotogrammetria kriminalisztikai célú alkalmazása: helyszínek, holttestek, tárgyak rekonstrukciója három dimenzióban [The Forensic Application of Photogrammetry: Reconstruction of Crime Scenes, Bodies, and Objects in Three Dimensions]* in Belügyi Szemle, 2020/11, pp. 57-70.

[14] E. Nyitrai, *A hálózatkutatás és a bűnözésföldrajz kapcsolata [The Relationship Between Network Research and Criminal Geography]*, Bűnözésföldrajzi Közlemények 2024/5, pp. 3-4, pp. 65-80, p.16.

[15] S. Gábor, V. Soma Poór, *Applications of 3D printing in forensic medicine and forensic pathology. A systematic review*, Annals of 3D Printed Medicine, Volume 8, 2022, no. 100083.

- Publicly available sources, such as Google Street View, can assist in mapping crime scenes more accurately, filling in gaps where evidence may be incomplete.
- Eyewitness testimonies can be verified against the reconstructed 3D scene to determine whether the described events align with the physical evidence.
- Enhances comprehension of spatial and temporal relationships between past events for attorneys, prosecutors, judges, and jurors, particularly when used as a courtroom demonstrative tool.

In cases where the exact positioning of objects or victims is crucial, traditional 2D photographs may fail to convey depth or the spatial relationships between key elements. This can lead to misinterpretations that may distort the sequence of events and affect the investigation's outcome. By contrast, 3D reconstruction offers a clearer and more precise spatial representation, reducing ambiguity and providing a more comprehensive analysis of critical information.

- 3D reconstruction technologies not only enable more precise evidence analysis but also significantly contribute to increasing the efficiency and safety of investigations.

These tools allow for the rapid and detailed recording of crime scenes, minimizing the time investigators need to spend in potentially hazardous environments.

- The fast and accurate documentation process also reduces the risk of evidence contamination, as the technology requires minimal physical interaction with the crime scene.

As a result, crime scenes and the traces left behind remain as undisturbed as possible, preserving the integrity of the evidence. Collectively, these factors make 3D reconstruction not only more efficient but also safer for modern forensic investigations.

- Reevaluating Cold Cases

3D reconstruction plays a crucial role in reassessing unsolved criminal cases. Three-dimensional models allow investigators to re-examine old crime scenes, identifying previously unnoticed details that could be critical to the case. This is particularly valuable when misinterpretations or missing data in the original investigation prevented clear conclusions.

3D reconstruction can introduce new perspectives, potentially leading to new evidence, appeals, or retrials. For example, if the trajectory of a bullet is unclear, 3D modeling can precisely determine angles and distances, helping reconstruct the shooting dynamics. This is especially useful in complex crime scenes, such as crowded or chaotic environments, where the movements and actions of multiple individuals must be reconstructed. The technology enables a highly detailed and accurate sequence of events, potentially revealing new investigative leads that traditional methods could not uncover.

Ultimately, 3D reconstruction represents a significant advancement for the justice system, as it sheds new light on complex cases, contributing to more precise and fair legal decisions.[16]

3D crime scene reconstructions not only provide a more detailed visual representation of events but also offer interactive analytical possibilities. Investigators and legal professionals can examine the scene from different perspectives, cross-check witness

[16] D. Rangelov, J. Knotter, R. Miltchev, *3D Reconstruction in Crime Scenes Investigation: Impacts, Benefits, and Limitations*, in K. Arai, (ed.), *Intelligent Systems and Applications. IntelliSys 2024. Lecture Notes in Networks and Systems*, vol 1065. Springer, 2024, Cham. https://doi.org/10.1007/978-3-031-66329-1_4 .

statements, and verify suspect testimonies. Due to its interactive nature, a 3D model allows investigators to revisit the crime scene virtually without the need for a physical return. Moreover, forensic analyses that would be challenging or impossible with traditional documentation methods become feasible through 3D reconstruction. These include bloodstain pattern analysis, trajectory reconstruction for ballistic investigations, body position modeling and movement analysis, enhancing jury understanding with 3D Modeling

In the past, jurors were often taken to crime scenes to better understand the evidence, but this process was time-consuming and costly. 3D modeling eliminates this need, allowing jurors to examine the scene multiple times and gain a clearer understanding of spatial relationships within the crime scene. This is particularly crucial in complex cases, where the accurate interpretation of witness testimonies and scene conditions plays a decisive role in determining the outcome of the case. By integrating 3D models into forensic investigations, crime scene reconstructions elevate traditional forensic procedures to a new level by ensuring greater accuracy in scene documentation, enhanced reliability of forensic analysis and interactive and repeatable investigation methods that traditional approaches cannot fully provide. Ultimately, 3D forensic reconstructions contribute to a more effective, transparent, and scientifically robust justice process, improving both investigative accuracy and courtroom evidence presentation.[17]

Over the past two decades, significant advancements have been made in forensic pathology and crime scene investigations, driven by the increasing application of imaging technologies such as CT, MRI, surface scanning, and photogrammetry. These methods range from traditional visualization tools to high-performance, three-dimensional crime scene reconstructions. A multimodal and multi-scale approach to crime scene documentation—where 3D models integrate the digital reconstruction of both victims and crime scenes—offers numerous advantages. Capturing all relevant evidence within a single 3D environment not only aids investigators in verifying hypotheses but also enhances the intuitive understanding of the scene and events during courtroom proceedings. Moreover, advanced computational models can be employed to analyze the dynamics of the crime, such as virtually reconstructing a victim's movement within the original environment. This enables a more precise reconstruction of possible event sequences, benefiting both investigators and legal experts in forming clearer, evidence-based conclusions.[18]

V. Limitations and Challenges

While 3D reconstruction technology offers numerous advantages in forensic investigations, it is essential to acknowledge its limitations and challenges. These include:

- The adoption and application of 3D reconstruction require significant resources, which can limit its widespread use.

[17] D. Notowitz, *Using 3D Scans and Modeling as Evidence in Court*, Law Technology Today, 2023, https://www.americanbar.org/groups/law_practice/resources/law-technology-today/2023/using-3d-scans-and-modeling-as-evidence-in-court/ (accessed on 2.02.2025).

[18] C. Villa, N. Lynnerup, C. Jacobsen, *A Virtual, 3D Multimodal Approach to Victim and Crime Scene Reconstruction*, Diagnostics (Basel), 2023, August 25; vol. 13(17), p. 2764, doi: 10.3390/diagnostics 13172764.

The acquisition and operation of advanced 3D scanners and other equipment are costly, posing challenges, particularly for law enforcement agencies with limited budgets. This disparity in resources can lead to unequal investigative capabilities across different regions.The high cost of equipment and software can hinder the accessibility of 3D reconstruction technology. However, recent advancements, such as photogrammetry and neural radiance fields (NeRF), have introduced more affordable and widely accessible alternatives. These technologies enable cost-effective 3D reconstructions using standard cameras and computational models, reducing financial barriers for forensic applications.

- The Use of 3D Reconstruction Evidence in Court Proceedings Remains Controversial**:** While 3D visualization tools **can** greatly enhance the understanding of evidence, there is a potential risk that judges and jurors may find them overly persuasive, which could unintentionally influence verdicts. The realism and interactivity of 3D models might create an illusion of certainty, leading to bias in legal decision-making. Therefore, strict guidelines and judicial oversight are necessary to ensure that 3D reconstructions are used responsibly and evaluated critically within the context of forensic evidence.

Different legal systems regulate the acceptance of 3D reconstructions differently, making it essential to develop clear and standardized guidelines for their use in court. The legal recognition of the scientific reliability and credibility of 3D reconstruction technology is a crucial step toward its broader application in judicial proceedings. These regulations should aim to ensure objectivity, prevent the presentation of misleading or manipulated evidence, and establish standards for forensic accuracy. By implementing consistent legal frameworks, courts can maximize the benefits of 3D reconstructions while minimizing potential biases in criminal investigations and trials.

- The application of 3D reconstruction technology generates vast amounts of data, leading to significant storage and management challenges.

To preserve the integrity of evidence, an effective and secure data management system is essential. Unauthorized access to data or potential data leaks can severely impact the outcome of an investigation. Protection against cybersecurity threats is crucial when using 3D reconstructions, as a data security incident could expose confidential crime scene details, jeopardizing the investigation or the fairness of the proceedings. To prevent this, strict access and data management protocols must be implemented.[19]

Since digital modeling and reconstructions can be edited and manipulated, an important ethical and legal question is to what extent the presented 3D models correspond to the original evidence. To ensure the authenticity of reconstructions, standards and verification mechanisms must be applied.

VI. Conclusion

The technological advancement of crime scene investigation creates new opportunities for more accurate documentation and analysis of evidence. One of the most promising methods is 3D reconstruction, which enables the detailed digitization

[19] D. Rangelov, J. Knotter, R. Miltchev, *3D Reconstruction in Crime Scenes Investigation: Impacts, Benefits, and Limitations*, in K. Arai (ed.), *Intelligent Systems and Applications. IntelliSys 2024. Lecture Notes in Networks and Systems*, vol 1065, Springer, 2024, Cham. https://doi.org/10.1007/978-3-031-66329-1_4.

of crime scenes and the creation of three-dimensional models. This technology represents a significant improvement over traditional documentation methods, providing interactive and more precise visual representation for investigators and the court.

The application of 3D models and digital simulations in court trials allows jurors and judges to better understand the evidence and the dynamics of events. However, their legal admissibility is subject to strict regulations, and special attention must be paid to data protection and procedural legal requirements during their use.

3D modeling is becoming an essential tool in forensic analysis, particularly in the reconstruction of altered or no longer accessible crime scenes. The use of publicly available data and alternative sources can aid in supplementing evidence; however, their authenticity and applicability must always be thoroughly examined. In judicial proceedings, 3D technology is not merely a supplementary tool but is increasingly becoming indispensable. This study highlights that 3D modeling and reconstruction technologies are becoming a crucial part of forensic and legal practice, enhancing investigative efficiency and the accuracy of the justice system. While forensic investigations increasingly rely on technological innovations, success ultimately depends on the human factor. Experience, foresight, and strategic thinking continue to play a key role in the effectiveness of investigations.

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