

# 3D Reconstruction in Crime Scenes Investigation: Impacts, Benefits, and Limitations

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**Abstract:** Crime scene investigations are constantly changing, so need innovative technology to increase their efficiency and precision. An example of such a technology is 3D reconstruction technology, which captures the physical attributes of real-world crime scenes and digitizes them into comprehensive three-dimensional models. This provides a more detailed, accurate, and interactive representation of crime scenes than traditional documentation techniques have done. In this study, we explore the transformative potential of 3D reconstruction. Drawing from diverse case studies and technological evaluations, we show the marked benefits of 3D reconstruction on the efficiency, safety, and overall effectiveness of crime scene investigations. To ensure the technology is used ethically and optimally, inherent problems must be addressed. This research highlights the significant implications of 3D reconstruction, paving the way for future forensic investigations.

**Key words:** Computer Vision, Neural Radiance Fields (NeRF), 3D reconstruction

## 1. Introduction

The main aim of investigating crime scenes is to reconstruct and understand what happened at the place of a crime and gather as much as possible evidence to prove or disprove hypotheses, answering key questions of the investigation. This task is challenging, because only the results and the aftermath of a crime is evident, and various interpretations can arise from it. The crime scene investigators need to identify and analyse both obvious and hidden evidence at a crime scene in order determine its origins and the reasons behind them[1], [2]. However, traces by themselves are insufficient amount of information to fully outline the sequence of events. Most of the times they are giving mainly hits and directions. Making sense of these hints requires interpretation, connecting them to actions and therefore creating a narrative about the crime. Since multiple theories can be drawn from this evidence, more information is always needed such as police reports at the scene, witness

accounts, victim details, forensic data, and the crime scene investigator's own experience, is utilized to form interpretations.

In the realm of crime scene investigation, classic methods still play major role. These traditional techniques involve securing the scene, conducting a systematic search, collecting physical evidence, and extensively photographing the area for documentation purposes. Crime scene investigators carefully sketch the scene and gather evidence such as fibers, hair, footprints, tire marks and others[3], [4]. This conventional approach, forming the bedrock of modern investigative techniques, is crucial in the initial stages of an investigation and in theory ensures that no piece of evidence gets missed.

Building upon these fundamental methods, the focus then shifts to identifying specific types of evidence at the crime scene. Fingerprints, for instance, are sought after due to their unique ability to link individuals to the scene. Crime scene investigators also look around for things related to the crime like personal items or tools that might help understand what happened that could provide insights into the events. Weapons, when found, are not only crucial in understanding the nature of the crime but may also directly connect a suspect to the act. The careful gathering and study of these different pieces are important in reconstructing the crime sequence of events.

There are various of methodologies used worldwide for criminal investigation. But one of the most commonly used and popular are the scenario-based and evidence-based approaches. Scenario-based methods [5], [6] involve creating plausible sequences of events based on the gathered evidence, while evidence-based policing [7]–[11] relies on data and analytics for directing investigative efforts. Integrating these methodologies, the narrative approach[12]–[15] strives to weave a coherent story from the evidence, aiming to make sense of the crime. However, a significant challenge in this process is the risk of tunnel vision, where investigators might become excessively focused on a single theory or suspect, potentially leading to biased conclusions. This issue underscores the importance of maintaining objectivity and an open-minded perspective throughout the crime scene analysis, ensuring a comprehensive and unbiased investigation.

Crime scene investigations (CSIs) are an important component of the justice system, providing concrete evidence and significant insights to uncover and understand the complexity of the criminal activities. These investigations have evolved as crime scenes have become more complex, shifting from basic observations and manual documentation to the use of cutting-edge technology. This shift has increased the precision and efficiency of CSIs.

This technological progression has opened the door to a potential new resource for interpreting crime scenes: the rapid analysis of trace evidence for identification purposes. These advanced identification tools enable immediate analysis of DNA and fingerprints, facilitating swift comparisons with existing databases[16]–[18]. Such a tool is from great importance for crime scene investigators as they allow for the prompt identification of individuals linked to the evidence, even during the ongoing investigation.

One notable study highlighted the impact of this technology on crime scene analysis[19]. In this experiment, crime scene investigators were tasked with creating scenarios after examining a crime scene, with all participants receiving identical base information,

primarily eyewitness accounts. But only half of them quickly found out who it was from clues at the spot. The study showed that having ID details greatly changed how crime scene investigators thought about the crime place. This was shown by making different ideas based on being able to get these details or not.

Despite these advancements, a critical area that remains underexplored in such studies is 3D reconstruction technology. While rapid ID tools have received considerable attention, the role and importance of 3D reconstructions in crime scene investigations are not as remarkably addressed. 3D reconstructions offer a powerful means to visualize crime scenes in a more detailed and spatially accurate manner, which can be crucial for understanding complex crime scenes. This oversight highlights a gap in the current focus of crime scene investigation research and practice, suggesting that more emphasis should be placed on integrating and recognizing the value of 3D reconstruction technologies alongside standard techniques.

3D reconstruction technology has become a common tool in many industries and has demonstrated remarkable flexibility and utility. In medicine, it is important for complex surgical planning and medical training because it allows for detailed visualization of anatomical structures[20], [21]. This technology helps surgeons to understand the specific anatomical complexities of patients before actual procedures, thus improving surgical precision and outcomes. Additionally, 3D reconstruction is widely used in real estate, changing the way properties are presented and sold. It allows for virtual tours that give potential buyers immersive and detailed views of properties, making remote viewing and decision-making easier. These are just two of the various fields that the 3D reconstruction technology is already adopted.

3D reconstruction technology, though widely used in various sectors, is rapidly evolving with immense potential, particularly for crime scene investigation. Its ability to create accurate, detailed representations of physical spaces can be invaluable in reconstructing crime scenes. This technology offers investigators a comprehensive understanding of the events, enhancing evidence collection, interpretation, and presentation in court. It positively impacts all stages of the criminal investigation process. The integration of 3D reconstruction in crime scene analysis marks a significant advancement in adopting advanced technologies in law enforcement and forensic science.

Overall, 3D reconstruction is a crucial part of this technological progression in forensic investigations. It can precisely capture real-world environments, reconstructing them into digital 3D models. In contrast to the limited perspective provided by traditional 2D photos or sketches, 3D reconstructions represent crime scenes in a dynamic, detailed, and interactive way. This innovation not only improves crime scene visualisation but also assists in numerous aspects of the investigative process, from evidence collection to courtroom presentations.

Despite these advantages, it remains unclear whether current CSI procedures match the ongoing rapid evolution of these technologies, and whether a gap is starting to widen between current technological capabilities and the technology used in CSIs. There is a clear demand for technological solutions that are not only more efficient but also safer and more effective.

This paper primarily investigates the broader implications, societal impacts, and synthesizes existing literature on the application of 3D reconstruction technology in crime scene investigations (CSIs) while placing less emphasis on the technical details. It aims to clarify the integration of 3D technology within forensic science by assessing ethical, legal, and social considerations to anticipate the future direction of CSIs in the digital age. By evaluating the transformative potential of new approach based on 3D reconstruction on accuracy, efficiency, and effectiveness this research underscores the significance of its adoption against the backdrop of contemporary legal frameworks. Through a concise reviews and case study analysis the paper seeks to inform readers about the pivotal role of 3D reconstruction in enhancing the crime investigation domain and pursuit of justice. Thereby encouraging a deeper engagement with its implications and applications.

## **2. Methods**

Building upon the foundational knowledge outlined in earlier chapters regarding the evolving role of 3D reconstruction technology in crime scene investigations (CSIs), this research paper now delves into the methods and methodologies used in it. The first task before even discussing the methods is the in-dept examination of relevant studies and cases. The careful selection of these studies is crucial for our goal of investigating implications, benefits, and limitations of 3D reconstruction in CSIs. In order to achieve this, we have adopted a systematic approach in selecting the studies. Ensuring that each one of them significantly contributes to our understanding of the current state and future trajectory of CSIs in the era of advanced 3D reconstruction technology.

### **2.1. Criteria for Selecting Studies**

To ensure the relevance, quality, and contemporary relevance of the studies included in this research, the following criteria were applied in the selection process:

1. Direct relevance to 3D reconstruction in CSIs or/and crime investigation methodologies/techniques: Each study selected must explicitly address or incorporate 3D reconstruction techniques within the context of crime scene investigations or to show currently used good practices in the crime investigation field. This criterion makes sure that the research is directly applicable to the field of forensic science and gives insight specific to the use of 3D reconstruction techniques in the crime investigation process.
2. Recency and technological advancement: Given the rapid evolution of technology, special preference was given to research published in the last decade. This approach incorporates the latest advancements and innovations in crime investigation and forensics. It ensures our analysis is based on the most current practices. Therefore, keeps our methods up to date in the field.
3. Peer-reviewed research: To keep the academic integrity and scientific accuracy of our analysis, only studies that have undergone a peer-review process were

considered. This guarantees that the methods, results, and conclusions of each study are of high quality and reliable.

By following these criteria our goal is to deliver a precise current analysis of 3D reconstruction's role in crime scene investigations. The studies we have chosen to present a variety of viewpoints and outcomes are adding depth to our understanding of the opportunities and hurdles in incorporating advanced 3D reconstruction technologies in forensic science.

The 3D reconstruction in the field of crime investigation is a topic of a lot of studies[22]–[25] nowadays. Because of that is it crucial to create an analysis of it benefits, limitations and implications is more and more important to be created.

## **2.2. Benefits of 3D reconstruction techniques in crime investigations process**

After the proper literature review and selection of studies have been done the focus has been moved to the benefits of 3D reconstruction in crime scene investigations. They are multifaceted and significant. One important benefit of 3D reconstruction is laying on its capacity to offer a detailed and precise representation of crime scenes. Unlike traditional 2D imagery the 3D models are allowing a detailed examination of the spatial relationships and dimensions within a crime scene to be performed. In another hand this is offering the crime scene investigators a more immersive and informative view. This expanded viewpoint is leading to a deeper understanding of the events. Therefore, assisting in the precise interpretation of evidence. Also, this method greatly lowers the likelihood of tunnel vision [26]–[30] in crime investigations. It ensures every piece of evidence is carefully considered and correctly understood. By steering clear of narrow viewpoints, this approach upholds objectivity and precision throughout the investigative process.

Another significant benefit of 3D reconstruction is that it allows permanent preservation of crime scenes. Traditional methods, like photography and measurements, tend to capture limited details. In contrast, 3D models provide a comprehensive capture of the entire scene with intricate detail. This means investigators can revisit and analyse the scene even after the physical location has changed or been cleared. This lasting record is especially useful in complex cases. Such cases often need prolonged periods of investigation and review, where returning to the scene, virtually, can be crucial for uncovering new insights or verifying existing evidence.

The 3D reconstruction technology can be crucial for revisiting cold cases. With the aid of 3D models the crime investigators have the opportunity to re-examine old scenes, potentially discovering evidence that were initially missed. Its impact is particularly profound in cases that might have been initially misinterpreted. Reanalysing with 3D reconstruction offers fresh viewpoints that potentially may lead to retrials or appeals.

For instance, in situations where the path of a projectile is unclear, 3D reconstruction clarifies the angles and distances involved. This is especially useful in complex scenarios, like chaotic crime scenes with multiple individuals. The technology aids in accurately piecing together each person's movements and actions. Such detailed reconstructions can unlock new leads in investigations that were hindered by the constraints of traditional

methods. This marks a significant stride forward in the pursuit of justice, shedding new light on complicated cases.

Furthermore, 3D reconstruction enhances courtroom proceedings. It offers jurors and judges a tangible and realistic view of the crime scene. Traditional methods of presenting evidence often fall short in capturing a crime scene's complexities. However, a 3D model excels in visualizing the spatial dynamics of the scene. This can lead to more informed decision-making in the judicial process.

For example, in cases where the positioning of objects and victims is crucial, 2D photos may not accurately convey depth or the relationship between various elements. This can lead to misinterpretations and misunderstanding of the sequence of events. With 3D reconstruction, a more accurate spatial representation is available, which can clarify these crucial details. There are instances where key evidence like the trajectory of a bullet[31] or the placement of a weapon are initially misinterpreted due to the limitations of 2D imagery. In such scenarios 3D models can provide a clearer and more accurate depiction. Therefore, this will lead to a deeper understanding of the crime and aiding in fairer verdicts. This highlights the practical advantages of 3D technology in real-world legal scenarios. It enhances the clarity and trustworthiness of evidence in court. Each case benefits from the detailed and accurate representation of crime scenes. This leads to a more transparent and reliable judicial process.

In addition to the benefits mentioned, 3D reconstruction technologies bring improvements in efficiency and safety. They allow for quick and comprehensive data collection, reducing the time investigators need to spend at crime scenes, which can often be hazardous. This speedy process also decreases the likelihood of evidence contamination. The technology typically requires minimal interaction with the physical elements of the scene, further preserving the integrity of the evidence. These aspects make 3D reconstruction not only a smarter choice but also a safer one in modern crime scene analysis.

For instance, in the aftermath of traffic accidents, 3D reconstruction can swiftly map the entire scene, capturing details like vehicle positions and debris distribution. This is crucial for reconstructing events and determining causes without exposing investigators to prolonged traffic risks. In scenarios like crimes in unstable structures, such as buildings damaged by explosions, 3D models allow for a safe examination without the need for physical entry, which could be risky due to potential collapses. Similarly, in cases involving radioactive materials, 3D technology enables thorough documentation while keeping personnel at a safe distance from harmful exposure. These examples underscore how 3D reconstruction is not only a smarter approach but also a safer one in contemporary crime scene analysis.

### **2.3. Limitations of 3D reconstruction techniques in crime investigations process**

Despite the notable advantages of 3D reconstruction in crime scene investigations, it is crucial to acknowledge its limitations and challenges. These issues span from technical difficulties to wider impacts on law enforcement methods. In following section, we will delve into these challenges, offering a comprehensive perspective on the role of 3D reconstruction in contemporary forensic science. This analysis aims to shed light on the

present strengths of this technology and pinpoint opportunities for future research and improvement.

3D reconstruction technology while beneficial in criminal investigations comes with its own set of limitations and challenges. One significant limitation is the high cost and resource intensity associated with the technology. High expenses for advanced 3D scanners have been a hurdle, notably for smaller law enforcement agencies with tight budgets. This has led to uneven investigative abilities in different areas. But recent technological breakthroughs are transforming this field. Techniques like photogrammetry[32]–[36] and neural radiance fields (NeRF)[37] use regular cameras, which are much less costly than traditional 3D scanners. NeRF marks the beginning of a new evolution in 3D reconstructions and is the beginning of a family of algorithms that includes SNeRF[38], Tetra-NeRF[39], NeRFacto[40], Instant-NGP[41], SPIDR[42], NeuS-facto[43], MERF[44] and many others. As these new methods spread, the cost-related barriers of 3D reconstruction are expected to decrease. This shift suggests that budget issues may soon become less of a concern, making 3D technology more accessible to a wider range of law enforcement bodies.

Moreover, these newer techniques are generally easier to use and don't require as much specialized knowledge. This user-friendliness could result in broader and more accurate use of 3D reconstruction in investigations. Therefore, the future of 3D technology in forensics appears bright, with prospects for more consistent quality in investigations across various regions, fueled by ongoing innovations and the growing availability of new, more affordable technologies.

Using 3D reconstruction technology in crime scene investigations comes with its challenges. Primarily, operating the equipment and interpreting data correctly requires technical know-how. Not every law enforcement team has access to this level of specialized training. Also, the intricate nature of the technology might cause errors in understanding the data, which could affect investigation results.

Nevertheless, the situation is improving with new and simpler techniques becoming available. These innovations are easier to use and understand, which means more accurate and widespread use of 3D reconstruction in investigations. Looking ahead the future of forensics and 3D technologies is bright. We anticipate more uniform quality in investigations across various regions, driven by these advancements and the growing availability of cost-effective technologies. This shift is tackling previous concerns about complexity and expertise while enabling more police forces to adopt this cutting-edge approach in their investigative work.

Furthermore, the admissibility of 3D reconstruction evidence in court is a contentious issue. While these visualizations can be compelling, there's a risk that they might be perceived as prejudicial or overly persuasive. Legal frameworks and standards for the admission of such evidence vary, and there can be challenges in convincing courts of the scientific validity and reliability of 3D reconstructions.

Furthermore, the admissibility of 3D reconstruction evidence in court is a contentious issue. While these visual aids are often impactful, there's a concern that they could be seen as too influential or even biased. The rules and criteria for allowing this kind of evidence

differ from place to place. Courts may have reservations about how scientifically valid and reliable these 3D reconstructions are. This uncertainty can make it challenging for legal professionals to use this evidence effectively in trials. As results of the potential use of 3D reconstruction technology in forensics highlights the need for well-defined guidelines and standards. These are essential for incorporating this technology into legal procedures both smoothly and justly. For example, when presenting 3D reconstructions as evidence in court, clear standards would ensure that such evidence is both reliable and understandable to all parties involved, including judges and juries. These guidelines could also address how to handle the data, ensuring consistency and accuracy in its use across different cases. Moreover, they would help in training law enforcement personnel and providing a uniform approach to the technology's application. As this technology gains widespread use, it is vital to create and follow clear guidelines. This will ensure its effective and equitable use within the legal system.

In 3D reconstruction, data storage and management pose significant challenges and limitations. The large volumes of data created require ample storage and effective data management systems. These systems are crucial for maintaining data integrity and security. It is essential to preserve the chain of custody for evidence and protect sensitive data. Additionally, cybersecurity threats and potential data leaks are real concerns. A system breach, for example, could expose confidential crime scene details, jeopardizing the investigation. As a result, the implementation of strong security measures is imperative to reduce these risks.

#### **2.4. Implications of 3D reconstruction techniques in crime investigations process.**

The limitations in 3D reconstruction technology underscore the urgency for continued research and development in this field. As we examine the broader effects of 3D reconstructions in criminal investigations, the urgency to address these challenges becomes evident. It's crucial to navigate these issues effectively for optimal results. The key to unlock the full potential of this technology is to address them. In the following section we will examine how 3D reconstruction affects various aspects of criminal investigations. This includes legal, ethical, and procedural aspects, providing a holistic view of its role in reshaping forensic investigations and its future in law enforcement.

The implications of 3D reconstruction in crime scene investigations are both significant and varied. It is influencing different elements of the criminal justice system. Legally, 3D reconstruction is changing how evidence is presented and interpreted in courtrooms. The dynamic and detailed nature of 3D models offers a clearer and more complete view of crime scenes. This could potentially improve the decision-making of juries and judges. However, this is raising important questions. It concerns potential biases in interpretation due to such realistic depictions. Also, it questions the criteria needed for admitting these as evidence.

Ethically, employing 3D reconstruction in criminal investigations raises privacy issues and concerns about intrusive data gathering. The detailed nature of 3D models extends beyond crime scenes. They often encompass surrounding areas, possibly capturing sensitive details. Striking a balance between comprehensive investigation and privacy respect is crucial. It is important to consider data protection alongside investigative thoroughness.



This involves setting clear guidelines on what is captured and how it is used. Safeguarding individual privacy while ensuring effective crime scene analysis is a key ethical challenge in this field.

The implementation of 3D reconstruction technology calls for major procedural changes. These include shifts in training, resource distribution, and investigative methods. Law enforcement personnel need to enhance their digital literacy and forensic skills. Additionally, this technology requires a rethink of conventional crime scene management. The goal is to smoothly incorporate digital data collection into existing practices. This transition is essential for maximizing the benefits of 3D technology in crime investigations.

These changes significantly influence the criminal justice system. They could lead to more efficient and precise investigations. However, they also demand a thorough evaluation of legal and ethical limits. As technology evolves, it is vital to regularly review and revise policies and procedures. This ensures they stay in sync with emerging tools and capabilities. Keeping up with these advancements helps maintain the balance between innovation and responsible practice in the field.

### **3. Results and discussion**

#### **3.1. Results**

This chapter explores the profound changes 3D reconstruction technology brings to crime scene investigations (CSIs). Our research has identified a paradigm shift in forensic analysis. This change is driven by the advent of advanced, affordable, and easy-to-use 3D reconstruction methods. Photogrammetry and neural radiance fields (NeRF) are key examples. These technological advancements have not only refined the quality of crime scene reconstructions but also broadened their applicability across various law enforcement agencies. We examine how these improvements make evidence clearer. They give investigators a more dynamic, thorough view of crime scenes. This helps them understand the events more deeply and accurately. Another key point is how 3D reconstruction helps preserve and revisit crime scenes. This is especially useful in complex or unsolved cases. This chapter presents our findings on the integration of 3D reconstruction in forensic investigations. We explore its role in turning real-world scenes into detailed digital models. Also, we see how current CSI methods are adapting to these fast-paced tech changes. Last but not least, we tested these technologies in labs and simulated crime scenes. Our results show 3D reconstruction's great promise in understanding forensic evidence better.

##### **Advancements in 3D reconstruction**

In this section, we delve into the evolution and impact of 3D reconstruction technologies on crime scene investigation techniques. Our research indicates a noteworthy shift in the approach to investigating crime scenes. This change is largely due to the integration of advanced 3D reconstruction tools. The emergence of cost-effective and user-friendly

methods has been pivotal. Technologies like photogrammetry and neural radiance fields (NeRF) stand out because they have made high-quality 3D reconstructions more accessible than ever before.

These technological strides are doing much more than just enhancing the quality of crime scene reconstructions. They are revolutionizing the field. Nowadays a wider range of law enforcement agencies can use these advanced tools. This expanded accessibility means that agencies of different sizes and resources are adopting these methods. As a result, the standard and scope of crime scene analysis are improving globally. This progress marks a significant leap forward in forensic science, opening new avenues for thorough and accurate crime scene investigation.

### **Enhanced evidence interpretation**

The application of 3D reconstruction has substantially improved the interpretation of crime scenes. Investigators now have access to detailed and immersive recreations of crime scenes, offering a dynamic and comprehensive perspective that was previously unattainable. This advancement has paved the way for a richer and more precise comprehension of events. It contributes significantly to analyses that are both more objective and better informed. By providing a clearer picture, it aids in unravelling the complexities of a crime scene with enhanced accuracy.

This section explores the enriched interpretation of crime scenes made possible through 3D reconstruction technology. The shift toward using 3D tools has revolutionized how investigators approach evidence. With the ability to create detailed, immersive replicas of crime scenes, investigators are now equipped with a dynamic and encompassing view. Such a perspective was once beyond reach.

This enhanced viewpoint is not just about visual depth. It is about clarity and context. Investigators can now walk through the scene virtually, examining angles and details that might have been overlooked in a 2D environment. This immersive approach fosters a deeper and more intricate grasp of what transpired. It's akin to possessing a time machine, enabling revisits and analyses from various perspectives. This method allows for a layered and detailed comprehension of the events, offering insights that were previously unattainable.

Consequently, this depth of detail contributes to more objective and informed analyses. Investigators can piece together evidence with a higher degree of confidence. The end result is not just a reconstruction of the physical space but a reconstruction of the truth, pieced together with precision and care. As we embrace these technological advancements, the forensic field is witnessing a transformative era of enhanced accuracy and reliability in crime scene investigation.

### **Preservation and revisitation of crime scenes**

In discussing the preservation and revisitation of crime scenes, 3D reconstruction emerges as a game-changer. This technology offers an enduring snapshot of the crime scene, locking it in time. Such preservation is invaluable, especially for intricate or cold cases that may languish unsolved for years. Investigators can delve into these virtual time capsules, dissecting and analyzing every aspect as needed.

With this technology, it's as if the crime scene is frozen, allowing for repeated visits without the risk of contamination or loss of evidence. Each revisit can uncover new evidence or prompt a re-evaluation of earlier findings. This iterative process is vital, as it can breathe new life into stagnant cases or provide the missing piece in a complex puzzle.

Moreover, this capability greatly enhances the investigative process. This method paves the way for a more meticulous and thoughtful approach. It guarantees that every detail is examined, ensuring a comprehensive investigation. By revisiting and reassessing with fresh eyes and new technologies, investigators can significantly improve the accuracy and depth of their conclusions. In essence, 3D reconstruction provides a robust platform for sustained inquiry, ensuring that justice has every tool at its disposal.

#### **Role of 3D reconstruction in forensic investigations**

Our research reveals that 3D technology has become a cornerstone in modern forensic work. Its ability to accurately replicate real-world scenes into detailed digital models is transformative.

This advancement goes beyond mere replication. It introduces a heightened level of accuracy into forensic study. By transforming intricate crime scenes into their precise digital twins, investigators can examine each aspect in unprecedented detail. Such precision is key in revealing subtle evidence that conventional methods might miss.

Furthermore, the added depth from these 3D models enhances the overall quality of forensic examinations. Investigators, moving through these digital realms, access viewpoints impossible in the physical world. This not only sharpens the accuracy of their findings but also expands the range of their analysis.

In essence, 3D reconstruction is revolutionizing forensic investigations. It blends traditional techniques with state-of-the-art technology, resulting in more trustworthy and exhaustive investigations. This significant technological stride is a milestone in the quest for forensic accuracy and justice.

#### **Alignment of CSI procedures with technological advancements**

Our research delves into the integration of these new tools within standard forensic practices. Our findings reveal a noticeable gap. There is a clear disparity between the capabilities of 3D reconstruction technologies and their complete incorporation into routine CSI workflows.

This disparity sheds light on a growth opportunity for law enforcement bodies. The capabilities of 3D reconstruction are acknowledged, yet their comprehensive integration is still developing. Some agencies lead the way, integrating these technologies smoothly into their investigations. However, others lag behind, hindered by factors such as limited resources, training, or lack of awareness.

This scenario highlights a critical need for ongoing development and standardization in forensic practices. As 3D reconstruction technologies advance, so should the methods and training of crime scene investigators. It's crucial to close this gap to fully harness the potential of 3D reconstruction in forensic science. The goal extends beyond just adopting new technologies. It involves redefining the whole approach to crime scene investigations.

to keep pace with technological progress. This evolution is vital to ensure that forensic investigations remain as precise, efficient, and effective as possible, adapting to the dynamic nature of technological advancements.

### **Laboratory and crime scene testing**

Our hands-on experiments in labs and simulated crime scenes have produced encouraging outcomes. Applying 3D reconstruction in these settings has yielded insightful data, deepening our understanding of forensic evidence. These results powerfully demonstrate what 3D technology can bring to forensic science.

The laboratory tests, in particular, have demonstrated the impressive quality of images achievable with current algorithms and hardware. Inclusion of laboratory photos will illustrate this quality. These images showcase the level of detail and accuracy that can be captured, providing a clear view of how evidence can be analysed more effectively.

In particular, the lab tests have showcased the remarkable image quality current algorithms and hardware can achieve. These images reveal the impressive detail and precision we can capture, offering a clearer pathway for more effective evidence analysis.



**Fig. 1.** Lab experiments of 3D reconstructions

Figure 1 presents an exemplary 3D reconstruction created within a laboratory setting. It is showcasing the remarkable detail and clarity that this technology brings to the forensic investigation process. The image vividly demonstrates the intricate level of detail captured by 3D reconstruction, where even the smallest elements such as the digits on equipment are visible. This impressive resolution hints at the future potential of the technology where minute details like numerals and characters on monitors or text on paper could be discernibly visualized. Furthermore, the legibility of labels and names on various pieces of equipment is testament to the current capabilities of 3D reconstruction. While these are preliminary tests, they are indicative of the significant advancements we can anticipate in the near future, promising even greater refinement and clarity in the quality of 3D crime scene reconstructions.

Furthermore, we are also approaching a significant leap in technology. The advent of new algorithms and stronger hardware is imminent, promising to enhance 3D reconstructions even more. Such progress is set to bring a level of clarity and accuracy to forensic analysis that was previously unimaginable.

Our experiments with crime scenes set up at the Police Academy of the Netherlands have been particularly revealing. These scenes, arranged by professional crime investigators, were designed to mimic real-life cases, allowing us to test the efficacy of 3D reconstruction in actual investigative scenarios. This setup was not mere simulation. It was a deliberate staging to evaluate how this technology performs in true-to-life situations.



**Fig. 2.** 3D reconstruction of the staged crime scene

Figure 2 unveils a compelling 3D reconstruction of a crime scene, meticulously set up by the Police Academy. This reconstruction vividly captures every element of the scene from the layout of the furniture to the minutest details in the room. Such comprehensive visibility offers crime investigators new perspectives. Crucial for thorough analysis. Notably, when executed with precision this technology enables investigators to view areas often hidden from plain sight such as spaces beneath the furniture. This representation is not only a testament to the technology's current capabilities but also provides a glimpse into what future 3D reconstructions of crime scenes might encompass. It exemplifies the depth and detail that can be achieved, significantly enhancing the investigative process.

These staged scenes at the academy have provided invaluable insights into the future application of 3D reconstruction in CSI. They demonstrate convincingly how 3D technology can be integrated into real-world investigations, offering vivid, detailed, and comprehensive views of crime scenes unlike the traditional methods like 2D photos. Such integration is set to revolutionize the field of crime scene analysis. It equips investigators with a toolset that enhances their ability to understand and interpret events with greater depth and accuracy. This approach promises a significant step forward in forensic investigation, bridging the gap between hypothetical application and real-world efficacy.



**Fig. 3.** 3D reconstruction of staged crime scene – arson

In a collaboration with the Firefighting Department in Twente, Netherlands, we conducted another experiment to set up and analyse a staged arson crime scene using 3D reconstruction of it. This experiment is presented in Figure 3. This project, involving a meticulously designed mock crime scene, aimed to mirror the complexities of a real arson case. The 3D reconstruction offered astonishing insights, presenting a rich, multi-dimensional view that significantly enhanced our understanding of such incidents. This successful endeavour not only proved the effectiveness of 3D reconstruction in various forensic contexts but also expanded its potential applications to include arson and related crimes. The project's triumph marks a significant advancement in forensic science, demonstrating the transformative impact of 3D technology in offering detailed, accurate crime scene analyses and setting a new standard for efficiency and depth in criminal investigations.

### **3.2. Discussion**

In the discussion chapter, we delve into the multifaceted aspects of 3D reconstruction technology in forensic investigations. While acknowledging the significant strides made in enhancing crime scene analysis, we also confront the challenges and limitations inherent in this technology. Issues such as cost, technical expertise requirements, and the admissibility of 3D evidence in courtrooms point to ongoing barriers. Ethical considerations, particularly around privacy due to the detailed nature of 3D reconstructions, necessitate stringent guidelines. Procedurally, the integration of this technology within law enforcement demands changes, including specialized training and resource allocation. Looking forward, the role of 3D reconstruction in CSIs is expected to grow, but this advancement must be tempered with careful consideration of its legal, ethical, and practical implications. Despite its transformative potential, the disparity in access and the challenge of integrating these tools into standard procedures highlight a gap in realizing its full potential in forensic science. The impact on investigations and legal considerations, such as the influence on jury perceptions and privacy concerns, underline the need for a balanced approach in leveraging 3D reconstruction in forensic contexts.

## **Ethical and procedural implications**

The depth and detail captured by 3D reconstructions pose considerable ethical questions, particularly regarding privacy. These models have the capacity to reveal details that extend well beyond the crime scene, potentially encroaching upon private areas. This raises concerns about unintentional privacy breaches. To manage this, it's imperative to establish strict guidelines and protocols. These measures are vital to balance the investigative benefits of 3D technology with the critical need to protect individual privacy rights.

Furthermore, incorporating 3D technology into crime scene investigations necessitates significant changes in law enforcement procedures. This goes beyond merely adding a new tool. It represents a fundamental shift in investigative approaches. This shift demands enhanced training to ensure personnel are adept at using this sophisticated technology. It also requires careful resource management to maximize the technology's effectiveness while maintaining responsible usage. Addressing these ethical and procedural aspects is essential. It ensures that the implementation of 3D reconstruction technology is not only efficient but also aligns with legal and ethical standards.

## **Future trajectory**

Looking towards the future, 3D reconstruction is poised to become a cornerstone in crime scene investigation. This evolving technology is set to establish itself firmly within forensic science. With its increasing relevance comes the responsibility of integrating it thoughtfully.

The advancing trajectory of 3D reconstruction in CSIs calls for a heightened awareness of its legal and ethical implications. As it becomes more integral to investigations, navigating its legal aspects, particularly how it influences evidence presentation and privacy issues, is crucial. Ethical considerations are paramount too, like respecting individual privacy and managing the detailed nature of the reconstructions.

The practical side of this technology also demands careful consideration. It is not just about the tech itself, but how it fits into and enhances current forensic procedures. For 3D reconstruction to be effectively adopted, it requires a cycle of continuous innovation and adaptation. This includes regularly updating the technology and crafting solid policies and procedures to guide its application.

Ultimately, fully leveraging 3D reconstructions in crime scene investigations depends on a balanced, thoughtful approach. It involves blending technological progress with comprehensive and well-considered policies and practices. This balanced strategy is key to ensuring that as we move forward, 3D reconstruction not only advances forensic investigations but does so in a way that is legally, ethically, and practically sound.

## **Benefits of 3D reconstruction**

Using 3D reconstruction in solving crimes is really changing the game of crime investigation. It lets investigators see crime scenes in amazing detail and accuracy like never before. This tech is a big help in understanding exactly what happened at a crime scene.

3D reconstruction is great for keeping a lasting digital copy of crime scenes. This is from great help in tricky and complex cases where you need to go back and look at the scene

again to find new evidence. Having this detailed digital record lets the crime investigators keep analyzing the scene, even if the real place has changed or cannot be accessed anymore.

Also, 3D reconstruction gives a clearer and more detailed view of crime scenes. It helps investigators understand things better by letting them look at the scene from different angles. This way they can dig deeper into the evidence. The extra detail and accuracy of this tech really help in investigations. It can reveal things you might miss otherwise, helping investigators make smarter decisions.

### **Limitations and Challenges**

Despite its advantages, 3D reconstruction technology is not without its limitations. It remains a resource-intensive tool, necessitating specialized equipment and expertise that might not be readily available in all investigative bodies. This disparity in access can lead to inconsistencies in crime scene analysis across different jurisdictions.

Furthermore, integrating these advanced technologies into standard crime scene investigation procedures poses a significant challenge. Many agencies are still grappling with the task of harmonizing traditional methods with these new technological capabilities, creating a gap in the full realization of the technology's potential in forensic science.

### **Impact on Forensic Investigations and Legal Considerations**

The emergence of 3D reconstruction in forensic science marks a transformative moment that drastically altering how crime scenes are examined. This technology breathes new life into crime scene analysis. Enabling a deeper and more layered understanding by unfolding data in an immersive, multi-dimensional manner. However, this leap forward brings its own set of challenges. Introducing such intricate reconstructions into the judicial sphere, particularly in courtrooms, ignites important debates about their validity and the potential influence they might have on jurors, considering their strikingly realistic representations.

Additionally, this technology stirs up ethical questions, particularly around privacy. Its capacity to meticulously document every nook and cranny of a crime scene and its surroundings calls for a nuanced evaluation of privacy concerns. At the crossroads of technological breakthroughs and ethical considerations, there's a pressing need for a balanced, prudent approach in weaving 3D reconstruction into forensic practices. Maintaining this equilibrium is crucial to ensure that the technological benefits are leveraged effectively, while simultaneously addressing possible risks and maintaining ethical standards.

## **4. Conclusion**

In conclusion our analysis of 3D reconstruction in the realm of forensic investigations, it becomes clear that this technique represents a substantial advancement. The technology characterized by its ability to meticulously capture and model crime scenes in 3D, transcends the limitations of traditional 2D methods. It furnishes investigators with a dynamic, interactive portrayal of crime scenes, effectively capturing their complexities.



The ability of 3D reconstruction to permanently archive crime scenes stands out as a significant benefit, particularly for intricate or extended investigations where the actual scene may not be preserved. This feature allows for repeated, detailed scrutiny of the digitalized scene, ensuring comprehensive evidence analysis. Additionally, the technology revitalizes the examination of cold cases, providing new perspectives and the possibility of uncovering previously overlooked evidence. This is reflecting on the current pace of procedural adaptation to these technological advancements.

Nevertheless, the deployment of 3D reconstruction is not devoid of challenges. Notably the technology demands considerable investments in both financial and training aspects. Although recent developments have enhanced accessibility, there remains a requirement for specific expertise to proficiently manage the equipment and interpret the data. This aspect raises concerns about its feasibility for smaller law enforcement entities or scenarios with constrained resources.

Another vital aspect is the technology's adaptability to diverse users, including novices, IT professionals, and law enforcement officers. The user interface and functionality of 3D reconstruction tools must be straightforward and accommodating. Furthermore, the technology should be flexible enough to adapt to varying conditions of crime scenes, considering elements like lighting, the presence or absence of people, and other external and internal factors.

The legal acceptance of 3D reconstructed evidence in courtrooms also remains a contentious topic. The compelling realism of these reconstructions has the potential to sway jury opinions, necessitating a judicious and balanced use in legal contexts.

To sum up, the contributions of 3D reconstruction to crime scene analysis are indeed significant, yet they come with intricate technological, operational, and legal considerations. The effective integration of this technology into forensic science hinges on a nuanced comprehension of these aspects, ensuring its reliability and efficacy in justice pursuit. Moving forward, ongoing research and development in this domain are crucial for overcoming these challenges and fully realizing the potential of 3D reconstruction in forensic investigations.

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### **Conflicts of interest**

The authors declare no competing interests that could influence the content of this paper.

### **Consent to participate**

Informed consent was secured from all individual participants who took part in the study.

### **Consent to publish**

Participants provided informed consent for the publication of their data in an aggregate manner. The authors have the necessary consent to publish the paper and all associated data and materials.

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