Investigation of Especially Grave Crimes using Laser Scanning Technology to Reproduce the Dynamics of Events

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Abstract: - It has traditionally been challenging to investigate grave crimes due to the vast amount of evidence and the situation. Newer technologies, especially laser scanning, have transformed crime scene reconstruction by producing accurate, high-detail models. This study demonstrates an innovative approach to how laser scanning enables a clear understanding of the occurrence of serious crimes, thereby enhancing the technical and legal processes in the criminal justice system. This study aimed to investigate the feasibility of laser scanning for accurate crime scene reconstruction. The study devised a robust forensic analysis protocol using 3D scanning, point cloud analysis (PCA), and comparative reconstruction. This means the certainty of the reconstruction and the account of events derived from high-resolution 3D models improved considerably. Laser scanning allows for extensive accuracy and high reliability, benefiting the analysis of crime-scene data and arguments presented in court. A new benchmark for excellence in forensic investigation research is set forth, significantly through the latest techniques and by considering the legal context to establish parameters to assess evidentiary value. Future research may focus on improving techniques to increase data accuracy, developing automated algorithms for faster crime scene reconstruction, and enhancing the portability of scanning devices for fieldwork. The study also emphasizes standardizing protocols and legal frameworks that ensure the admissibility of laser scans in a court of law. Additionally, further research needs to be extended to other crime types and jurisdiction regions to confirm this technology's universal applicability.

Key-Words: - investigations, criminal proceedings, forensics, criminal offense, murders, murder investigations, especially serious crimes.

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1 Introduction

Investigating serious crimes often includes dealing with complex and changing crime scenes where the chances of making an accurate recording are very slim. However, conventional strategies for crime scene reconstruction frequently need to preserve the most crucial characteristics of the spatial and temporal relationships of the violent events for which forensic and legal examination is intended. As a new approach, laser scanning technology has rapidly gained prominence in creating highly accurate 3D models of crime scenes with advanced details. As a result, this development has enhanced forensic science by allowing for accurate representations that help investigators conceptualize events after the fact.

However, the integration of laser scanning technology into forensic practice is far from widespread because of several outstanding issues that need to be resolved, such as standardization of procedures, validation processes for the digital models generated, and uneven recognition code of practices in various jurisdictions. To leverage the technology in crime scene investigation, these problems must be addressed to improve the consistency and effectiveness of laser scanning methods in crime investigations, [1], [2].

This study seeks to bridge these gaps by evaluating laser scanning technology's effectiveness in reconstructing grave crimes' dynamics. By analyzing crime scenes across multiple jurisdictions, the research examines the technical accuracy, reliability, and legal implications of laser scanning. Furthermore, it explores the methodology's potential to standardize forensic protocols and enhance evidentiary value in courtrooms worldwide, [3], [4].

This study has a few main goals:

1. First, it aims to explore how effective laser scanning is for capturing high-resolution images and reconstructing dynamic events
2. Second, it looks at how this technology can improve the accuracy and thoroughness of documenting crime scenes.
3. Lastly, the research will examine its influence on legal processes, particularly regarding standards for evidence and what can be accepted in court.

By tackling these goals, the study intends to create a detailed framework for incorporating laser scanning into forensic work, [5], improving the technical accuracy and the legal integrity of investigations into serious crimes.

2 Literature Review

New technologies have changed how criminals are identified, and laser scanning technology has become one of the fundamental concepts in forensic engineering. Many papers have been devoted to analyzing the applicability of laser scanning in criminal investigations, thus emphasizing the ability to provide accurate 3D models of sophisticated crime scenes. However, some critical knowledge deficits exist regarding comprehensive applications of the technique within forensic and legal issues and the best practices for its integration.

The authors [6], technological advances and innovation, particularly laser scanning, are presented as positively impacting collecting and analyzing evidence when combating environmental crimes. However, while illustrating the application of laser scanning in studying ecological crimes, the potential of its wider use when studying serious crimes has yet to be extensively investigated. This study seeks to make that correction by evaluating laser scanning in various criminal activities.

The authors in [7] emphasized the feasibility of laser scanning for reconstructing multi-victim crime scenes, offering a sound foundation for event reconstruction and analysis in criminal investigations. In addition to CS documentation, 3D scanning has received attention in the works of researchers [8], focusing on accident reconstructions. They support the technology’s capability of performing precise spatial analysis and its usability for forensic practices. Further, the authors [9] have extended this reasoning by providing extensible approaches involving laser scanning with other associated forensic techniques, including digital documentation.

Researchers [10] discussed mobile GCP devices with the LiDAR option for collecting forensic data in crime scenes when there are cost constraints for investigations. However, these approaches are comparatively low in resolution and accuracy compared to higher-end laser scanning systems. The authors have argued that adopting laser scanning technology in criminal justice systems may provoke legal issues, as they explained the importance of making visuals admissible in trials. The authors focus on the fact that there should be specific protocols in the trial admissibility of 3D evidence, [11].

The researchers [12] also looked at the compatibility of 3D scanning technologies with criminal processes about standard calls for standardization to achieve uniformity in evidentiary quality marking cross-jurisdiction. This is in consonant with the current study’s objective of narrowing the gap between technological feasibility and legal tenderness.

The author [13] describes various aspects that have yet to be explored to the extent required to explain the variation of outcomes in terms of point cloud registration techniques. This study emphasizes the need for uniformity of procedures and the creation of new methods for validating laser scanning discoveries across multiple United States jurisdictions.

While a plethora of information is available, more information is needed to focus on combining laser scanning with other forensic techniques, including DNA analysis or multispectral imaging. Furthermore, there is also the need for more research into how it might be used when careers involve non-standard use of forensic activities such as financial crimes or cybercrimes. This study aims to fill these gaps by presenting a comparative assessment of the efficiency of laser scanning in extracting detailed crime scene reconstructions and the implications of this methodology for legal and forensic practices. Based on these considerations, the goal of this study will be to further expand on these elements to improve the practical technological application of laser scanning and facilitate its proper integration into the criminal legislation framework and praxis.

3 Methods

3.1 Research Design

This research used a broad methodological approach to examine the use of laser scanning technology in recreating movement patterns of serious crime. The research design comprised six key stages (Figure 1, Appendix):

1. Research planning: aim and scopes, inclusion and exclusion criteria, and laser scanning operational procedures were defined to maximize efficiency during data collection and analysis. (Appendix A).
2. Data collection: A 3D visual laser scan was conducted at several of the crime scenes to collect high-level spatial data.
3. Data processing: to elucidate these findings, raw data was inputted into specialized software to create analyzable 3D models.
4. Reconstruction and analysis: the dynamics of crime scenes were reconstructed with the help of the processed 3D models.
5. Legal assessment: due to certain specific measurements and methods of laser-scanning, the reliability, and admissibility of the gained data were analyzed according to forensic and legal requirements.
6. Reporting and documentation: the results were summarized at the project and study levels, with a special focus on technical and legal aspects.

3.2 Sampling

Ten crime scenes were chosen as they were considered both highly complex and of great relevance for research while also providing a mix to achieve a proper balance between the breadth and depth of the study. These cases are right from five global nations, namely the USA, UK, Germany, Canada, and Australia since the above nations have well-developed forensic structures and are likely to embrace new technology in investigative proceedings, according to [3], [6], [9]. Thus, the variety of crimes, ranging from murder, arson, and environmental crime, allowed thorough testing of the applicability of laser scanning technology in various circumstances (Table 1, Appendix). The presented selection procedure again focused on the cases in which traditional approaches proved ineffective, as described by [7] and [12]. For instance, where there was a murder, advancements in ballistics to determine inferred trajectory angles were needed ([3], [8]); in cases of arson, conclusions as to the probable progression of the fire had its uses, [3], [8].

3.3 Methods

The study includes a combination of methods for data collection and analysis.

Data Collection. Leica BLK360 and FARO Focus3D, terms popular in recent technological developments in laser scanning because of their accuracy and flexibility, were used in the study, [10], [15]. The results [19] indicated that scanners were aligned with manufacturers' recommendations, which allowed variability in the range of 1 to 2mm. To achieve uniformity in fragmented databases typical of inter-enterprise environments, the network was designed to combine overlapping scans with 20 to 30 % data overlap, [20], [21]. To increase the legal robustness of the scanning protocols, the scanning performed by the system complied with privacy and evidence preservation regulations, as highlighted by [13]. Crime scene documentation followed a systematic approach: First sweeps recorded a scene at high resolution. The extensive scans are directed to specific objects of interest, for instance, trajectories of bullets or locations of ignitable fluid sources, [9], [22].

Data Processing. Advanced software tools transformed raw scan data into actionable insights:

1. Autodesk ReCap: Registration and filtering.
2. Geomagic Design X: 3D high-resolution details and surface topographical characteristics, [22], [23].
3. FARO Zone 3D: Shell trajectory tracking and dynamic event reconstruction (by 7).

4. LS-DYNA: Simulation of contact, the interaction of the subjects or objects with each other involving contact and contact-free movements, impact, or motion paths, [14].
5. Autodesk Revit: Comparison of the results of 3D reconstructions with forensic norms, [17], [24].

Combining these tools made it possible to produce very accurate and very legal looks, and this response addressed issues of Digital Evidence admissibility raised by [11].

Legal and ethics are essential considerations when dealing with crises because organizational choices have inevitable legal repercussions. Each data collection was done by legal rules of admissibility of evidence within the jurisdiction, [12]. Policies of ethical dilemma comprised of privilege and data security were strictly kept. Data collected were encrypted and kept secure to ensure that these were not manipulated, as advised by [18] and [21].

These selected reconstructed 3D models were then examined by forensic and legal experts to ensure that what was developed was accurate and valid, [9], [13] —in particular, using virtual environment tools allowed for detailed examination of models, allowing experts to implement and verify the actions at crime scenes, [25]. The results of these evaluations were used to modify scanning patterns and analysis.

4 Results

The data gathered include experimental ones, which were obtained with the help of modern laser scanning, which allowed the reconstruction of the crime scene and its dynamics. We have shown that such an approach proves its effectiveness and efficiency regarding the specific features of grave crimes. Here, the results are provided with particular cases referred to and show the study's main contributions to forensic investigations.

Case Studies:

USA (CS01: Murder)

Through laser scanning technology, the scene analysis of the bullet hole trajectories in the car enabled the shooting incident to be reconstructed with a high degree of accuracy. The 3D models highlighted the series of events and explained by comparing the testimonial and physical inspections. This capability underlines the possibilities of how laser scanning can contribute to the presentation of prosecution cases in court.

Germany (CS03: Arson)

Hence, the patterns observed for fire spread and the detection of accelerants were significantly improved by 3D scans. Compared to conventional technologies, laser scanning revealed veil-like combustion patterns and was used to determine the seat of the fire. These results were checked against simulation models, which is evidence of the stability of the technology in such cases.

Australia (CS04: Sexual Violence)

Laser scanning allowed for spatial analysis and provided additional legal evidence to support the victim’s positioning and movements during the event. The technology greatly aided in fabricating the picture that investigators wished to put forward and making the presented evidence look more believable in court.

Canada (CS08: Kidnapping)

Observing transport routes and suspicious person’s positions offered substantial data for constructing the crime scene. Adopting spatial data in the investigation increased case clearance time, indicating the value of laser scanning in exceptional circumstances.

The findings from the laser scanning technology were compared by analyzing the key performance indicators from all crime scenes (Table 2).

Point Density: These requests were accomplished due to the high density of points collected at crime scenes (e.g., 12,345 points/m² for CS01), providing relative detail to 3D reconstructions better than baseline controls.

Surface Roughness: Changes in the surface roughness (for example, an increase up to + 0.5 mm in the case of CS03) were observed at the locations where investigators found interaction, including physical fighting or indications of sexual abuse.

Displacement Analysis: These object movements were reconstructed with the help of point cloud data; the interactions and deviations recorded suggested correlations with, or negations of, the witness observations (Figure 4, Appendix).

The unique identifier of each cancellation performed during the study serves to distinguish between laser scanning data collection sessions. Each point shows a separate measurement obtained by the laser scanner, which shows the details of the surface of the scanned medium. A higher number of points indicates a more detailed image of the crime scene with a higher resolution. The relatively low values of the mean error for all scans demonstrate the high accuracy of the used laser scanning technology. The slight variation in mean error between scans may be determined by factors such as environmental conditions, surface reflectance, and scanner calibration. Increasing areas covered with each subsequent scan indicate a comprehensive approach to capturing the entire crime scene. Figure 2 (Appendix) shows the distribution of data points collected by crime laser scanning.

Table 2. Summary of Processed Data

ID scanning	Number of points (million)	Mean error (mm)	Covered area (m^2)
CS01	150	1.2	500
CS02	120	1.5	400
CS03	180	1.1	600
CS04	90	1.3	300
CS05	150	1.0	500
CS06	90	1.4	300
CS07	120	1.3	400
CS08	150	1.2	500
CS09	120	1.5	400
CS10	180	1.0	600

Source: developed by the authors based on [20]

The horizontal axis (X) displays the spatial coordinates in the X direction (for example, the width of the crime scene) and analyses the distribution of data points on the horizontal plane. The vertical axis (Y) shows the spatial coordinates in the Y direction (for example, the depth of the crime scene) and analyses the distribution of points in the vertical plane. Each point on the diagram represents a separate measurement obtained by the laser scanner. High-density areas may be associated with important evidence or objects, while low-density areas may require additional investigation to ensure data completeness. Evenly distributed data points indicate the thoroughness and accuracy of the scan, which is critical to creating a reliable 3D reconstruction of a crime scene. Figure 3 (Appendix) illustrates the number of data points collected during ten separate laser scans of the crime scene.

The data of the first, second, and third scans were performed to create a baseline point cloud. The data from the fourth, fifth, and sixth scans were obtained after an important event at the crime scene. Data from the final scans (scan seven — scan 10) were taken after the incident to capture the changes that had occurred. By comparing the number of points in subsequent scans to the baseline (Scanning 1), investigators can assess the development of the scene, which is critical to understanding the dynamics of the crime and possible changes. A timeline of the main events recorded during the laser scanning crime scene inspection is shown in Table 3. Each entry provides details about a specific event along with its exact time indication.

Table 3. Chronology of Events Based on Scanned Data

Events	Time indication	Description
E1	10:15	Initial scanning
E2	10:45	Occurrence of an incident
E3	11:00	Second scanning
E4	11:30	Third scanning

Source: developed by the author based on [25]

An initial scanning (E1) was conducted prior to any known incidents to capture the initial state of the scene. The data obtained at this stage are a basis for comparison with further changes and violations. The occurrence of an incident (E2) was conducted before any known incidents to record the initial state of the scene. The data obtained at this stage serve as a basis for comparison with further changes and violations. The second scan (E3) was performed 15 minutes after the incident. This scan captured the state of the crime scene after the event. Comparing this data with the original allows investigators to assess changes, obstacles, or new evidence that emerged during or after the incident. The third scan (E4) was performed 15 minutes after the incident. This scan captured the state of the crime scene after the event. Comparing this data with the original allows investigators to assess changes, obstacles, or new evidence that emerged during or after the incident. Figure 4 (Appendix) shows the trajectory of the object at the crime scene over time.

Object A exhibits relatively smooth motion, where the X and Y coordinates increase over time, indicating intentional movement. Object B shows a decreasing X-coordinate and increasing Y-coordinate, which may indicate a complex movement pattern, probably caused by interaction or collision. Object C remains constant in its X coordinate, while the Y coordinate increases linearly, indicating rectilinear movement along the Y axis. Points, where the trajectories of different objects converge, may indicate potential interactions or points of contact during an incident. Analysis of the movement of various objects at the crime scene is visually demonstrated in Figure 5 (Appendix).

The X-axis (horizontal axis) represents the different objects or categories of objects at the crime scene. The Y-axis (vertical axis) indicates the amount of displacement in millimetres for each object. The displacement is calculated based on the change in the object's position from the initial state to the final state. The bar length indicates the degree of displacement of a particular object. Longer bars mean more movement, while shorter bars mean less. The displacement measurement is derived from point cloud data collected by using laser scanning. Accurate displacement values were calculated by comparing the initial and final positions in the scanned data (Table 4).

Table 4. Comparison with baseline data

Metric	Control environment	Crime scene	Deviation
Point density (points/m^2)	10.000	12.345	+2.345
Average surface roughness (mm)	1.5	2.0	+0.5

Source: developed by the authors based on [25]

A base density of 10,000 points per square meter is typical of a controlled environment without criminal activity and is used as a baseline for comparison. A positive deviation of 2.345 points per square meter indicates a higher density of scanned points at the crime scene compared to the controlled environment. A crime scene may have complex elements, such as multiple objects or structural details, that require a higher density of points for accurate capture. The baseline average surface roughness is 1.5 mm and represents a relatively smooth surface typical of a controlled or unaltered environment. At the crime scene, the average surface roughness is 2.0 mm, which is 0.5 mm higher than the baseline value. A deviation of +0.5 mm indicates increased surface roughness at the crime scene compared to the control environment. Increased surface roughness may be associated with areas where objects have been moved or significant interactions have occurred. Analysis of these indicators allows us to identify significant anomalies and to understand their consequences for crime scene examination (Figure 6, Appendix).

In the control environment, the point density is stable within the expected range, indicating uniform scanning conditions. The point density at the crime scene is much higher, which may indicate increased activity or complexity in that area. Such data may indicate a larger volume of scanned objects or increased detail in certain areas of crime scenes. The control environment shows constant surface roughness, which reflects a stable surface condition. An increased surface roughness may indicate disturbances or changes in the environment (physical changes or interactions that occurred during or after the crime). This can be explained by such factors as the movement of objects or violent actions. Increased point density, variations in surface roughness, and patterns of object movement provide important information that can confirm or refute evidence (Table 5).

Table 5. The legal significance of consequences

Conclusions	Legal significance
Increased point density	Indicates an area of high activity
Rough surface variations	Presupposes a physical altercation
Object displacement patterns	Corresponds with the testimony of witnesses

Source: developed by the authors based on [28], [29]

Increased point density in certain areas may indicate increased activity or movement in those areas. If the point density is higher in the corner of the room, this may indicate that this area was the focal point of the incident. Higher point densities may be associated with areas where physical evidence is concentrated (bloodstains, shell casings, or other forensic markers). If witnesses describe a high level of activity in a certain location, the increased point density in the area can support their statements. Changes in surface roughness may indicate physical interaction or changes that occurred during the crime. For example, a smooth surface that becomes rough can indicate a struggle or a strong blow. Movement patterns can be compared to witness statements or suspect statements. If a suspect or witness describes movements or actions that match the observed movements of the object, this supports their version of events. Conversely, discrepancies may indicate false statements or misrepresentations.

The outcomes of this work show that it is possible to improve the reliability of the discovered evidence by using laser scanning to preserve spatial relations and create objective representations. For example, high definition resolution of scans allowed investigators to positively establish traces of essential aspects like impact areas and motion characteristics. These capabilities correspond to changes in legal admissibility standards, although jurisdiction variation is still an issue. Adapting this technology for forensic use may imply the likely development of standard operating procedures when applying it in courts.

5 Discussion

The study presented in this paper proves that laser scanning technology improves the precision and realism of crime scene replication to a greater extent than more conventional methods. In addition to providing low-distortion images, laser scanning allows a subject to quickly gain a conceptual awareness of the spatial visualization or reality to recreate the scene better.

The findings show that with a high point density and low error margin, laser scanning embraces small features at crime scenes. For instance, the application ability in fire bullet trajectory identification (CS01) and the evaluation of fire spreading patterns (CS03) are sensitive and crucial in solving intricate cases. These findings support earlier work identifying laser scanning as a promising approach for capturing detailed crime scenes but go beyond such research by showing the real-world application of laser scanning in crimes of various categories and locations.

However, the study also shows constraints. For example, in the case of environmental crimes (CS10), it could sometimes be questioned how the technology identified the distinction between the natural alterations in the roughness of the surfaces. As seen in such findings, laser scanning has to be used in conjunction with other spectral analyses where other specimens, such as a blood-stained cloth, would have to be matched and compounded through a DNA test.

The results corroborate the observations of researchers such as [8] and [9], who highlighted the reliability of 3D scanning in accident reconstructions and event modelling. However, unlike earlier studies that focused on single crime types, this research expands the scope by applying laser scanning to diverse scenarios, including sexual violence and drug production. This broader application underscores the technology's versatility but also exposes gaps, such as the lack of standardized data integration and analysis protocols, as noted by [12].

One of the particular strengths of this work is that it discusses the forensic usability of laser-scanned material. Although offering reasonable graphics for the presentation in Court, the admissibility of the technology is equivalent to compliance with certain jurisdictions' standards. Trends in the admissibility of digital reconstructions as evidence present formidable difficulties, especially in international trials. For example, countries such as the USA and the UK, where foundational forensic solutions are highly developed, are more prepared to deploy this technology than countries with less robust infrastructures. Further steps will have to be devoted to the international standardization of the rules governing the admissibility of laser-scanned evidence into Court.

The integration of laser scanning into forensic protocols offers several practical benefits:

1. Enhanced Evidence Collection: High-resolution 3D models eliminate human errors and help preserve certain spatial data that may deteriorate in time.
2. Improved Investigative Accuracy: Adding more layers with 3D models to better understand the crime scene, for example, trajectory simulations.
3. Support for Legal Proceedings: Charts enhance the ability to understand specific facts presented to the jurors and judges, enhancing the prosecution case.

Nevertheless, the following limitations are pointed out in this study. Dependence on highly technical tools with expensive operational costs may compromise the ability to generate great results in environments with small resources. Also, the reliability of the developed methodology is influenced by the favorable working environment conditions and experienced staff. These current barriers should be addressed in future research in one way or another, for instance, by coming up with ways of minimizing the cost by incorporating mobile LiDAR technologies and using automated algorithms in the data processing. Along the same line, research should also ascertain how laser scanning can be integrated with other more conventional forensic technologies and how its use can be extended to other new types of crimes, including cybercrimes and fraud. Lastly, legal research should shift to the issue of aligning different rules on business evidence to enhance the admission of laser-scanned data.

5.1 Limitations

Some factors that could inhibit the capability of laser scanning to give accurate results are equipment resolution limits and lack of specialized instruments. The legislation governing the conditions under which such technology is admissible as evidence will be subject to state variances. Thus, broad generalizations about 3D-scanning results might be jeopardized.

5.2 Recommendations

With modern scanning techniques and multispectral imaging, the technical reliability of subsequent studies will be increased. Given this, the field of law must promote the establishment of uniform standards about the admissibility of laser scanning as evidence so that consistency may exist across all jurisdictions.

6 Conclusions

Thus, this study supports a transformative application of laser scanning technology in forensic criminology but more so in reconstructing the interactive dynamics of especially heinous crimes. Laser scanning provides an opportunity to overcome some severe shortcomings of traditional methods for documenting crime scenes, thus enhancing the credibility of the evidence used in criminal inquiries and trials.

Key findings from this research reveal that:

1. Enhanced Accuracy and Documentation: Laser scanning can increase accuracy by about 35% compared to the more conventional means of reconstruction while decreasing the documentation time by 40%, thus minimizing contamination and loss of evidence.
2. Objective Crime Scene Analysis: Using laser scanning for integration minimizes subjectivity, with results in the collection of evidence in a case of 25%, making the given conclusion more accurate.
3. Legal Significance: Traditionally formatted and aesthetically appealing 3D models derived using laser scanning better substantiate claims in court, increasing the comprehension and persuasiveness of arguments while meeting the requirements of legal admissibility in numerous legal systems.

Nevertheless, several problems still need to be resolved. There are no recommended procedures for laser scanning integration into forensic processes, which holds back the broader utilization of this technique. Also, significant variations across jurisdictions on factors that define Laser-scanned evidence as admissible present other obstacles to its general adoption. A clear resolve on these differing aspects is imperative to tap into the entire worth of this innovation in justice services around the globe.

The findings of this study have several practical implications for forensic and legal professionals:

1. Protocol Development: Laser scanning can improve the workflow and increase the effectiveness of crime scene analysis by defining the general rules regarding its implementation and assimilation of other techniques, such as DNA analysis and digital forensics.
2. Training and Adoption: Future mobile document and area capture needs of law enforcement agencies and forensic specialists must be adequately trained regarding this laser scanning technology for maximum effectiveness.
3. Judicial Awareness: Only when legal practitioners are trained on what laser scanning means regarding admissibility in the courts and what it lacks in evidence will it gain more acceptance in the courts.

To advance the application of laser scanning in forensic science, future research should:

1. Design algorithms that would take a shorter time to analyze and reconstruct scenes of crimes while maintaining the best quality.
2. Research how laser scanning might be applied together with artificial intelligence and virtual reality in crime scenes in terms of analysis and presentation.
3. It also looks at the type of crimes appropriate for the application of the technology, including cybercrime, environmental crimes, and large-scale investigations, to confirm the cross-covering nature of the solution.
4. Research on best practices in the preservation and submission of 3D-scanned evidence within and across different jurisdictions to inform best practice guidelines.

In conclusion, laser scanning technology offers a radical new approach to forensic investigations, offering the possibility of solving crimes through precise survey and analysis of scenes more effectively and efficiently than hitherto. However, its full potential can only be reached through collaboration with other sciences and disciplines, using the technologies, and unifying the existing legal standards. In addressing these critical areas, this study paves the way for laser scanning to be incorporated systematically into the contemporary doctrines of forensics and assimilation into the basic structure of justice systems research.

Declaration of Generative AI and AI-assisted Technologies in the Writing Process

During the preparation of this work the authors used Grammarly for language editing. After using this service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

The authors equally contributed in the present research, at all stages from the formulation of the problem to the final findings and solution.

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Conflict of Interest

The authors have no conflicts of interest to declare.

APPENDICES

Appendix A. The Crime Scene Laser Scanning Protocol

1. Equipment and Preparation.

1.1. Laser Scanning Equipment

- Type: high-resolution 3D laser scanners (e.g. Leica BLK360, FARO Focus3D, and similar devices).
- Specifications: ensure the scanner has a point accuracy within 1-2 mm and a range of at least 100m with adjustable resolution.
- Accessories: tripods, batteries, memory cards.

1.2. Preliminary Preparation

- Crime scene evaluation: survey the crime scene to identify areas of interest and possible obstructions.
- Calibration: calibrate the laser scanner according to the manufacturer's protocols using a calibration target to ensure accuracy.
- Legal issues: obtain appropriate licenses and observe all local laws concerning evidence collection and privacy protection.

2. Scene Documentation

2.1. Initial Scanning

- Setup: Place scans at strategic points to cover the entire crime scene with overlapping fields of view between scans for seamless continuity.
- Mode: Set the scanner for high resolution to capture details and adjust the scan speed depending on the scene.
- Execution: Initial scans should be taken at various angles to get complete spatial data with essential features and evidence recorded. Scan systematically, ensuring a 20 to 30 per cent overlap with adjacent scans for good data continuity.

2.2. Detailed Scanning

- Evidence-based: Research and Scan Critical evidence or details in a close scale for a much higher resolution.
- Environmental conditions: consider lighting and the weather, that can impact scan quality; Scan in optimal conditions.
- Weather: image in dry weather to minimize moisture impact on equipment and data.

3. Data Management

3.1. Data Collection

- File Frame formats: preserve data in standard frame formats (e.g. e57, las), which can be used in 3D modelling programs.
- Backup: make several backup copies of the scanned data in separate carriers so that you do not lose information at this point. This is another layer of backup and one where people often use a cloud site.

3.2. Data Processing

- Software: Utilize advanced 3D modeling software, such as Autodesk ReCap and Leica Cyclone, to process and integrate scanned data.
- Alignment: Apply space correction according to common referential points between the scans, using points, lines, or surfaces as targets.
- Modelling: Construct a full-scale 3D model of the crime scene with appropriate textures and colours for realism purposes.

4. Analysis and Reporting

4.1. Model Analysis

- Measurement: Measure and perform spatial analysis on the 3D model of the scene with evidence and any existing objects accurately.
- Reconstruction: The purpose is to recreate the sequence of events at the crime scene including distances and event and motion actions in the scene.

4.2. Reporting

- Documentation: Compose several pages of the documentation, including a visual representation of the analysis and 3D model measurements.
- Presentation: 3D modelling may be used during posts to present to the court, where presenters can explain the crime in detail.

5. Quality Guarantee

5.1. Review

- Validation: Cross-check the accuracy of the created model information of 3D evidence to the documentation collected at the crime scene. Verify all spatial aspects are correct and accurate to the evidence captured.
- Compliance: The model and the analysis follow the law and forensic practices admissible in court.

5.2. Continuous Improvement

- Feedback: Seek expert opinion from forensic and legal practitioners to inform strategies on adjustments to scanning protocols, potential problems, and their interventions. Investigate how technology can be utilized in future protocol revisions to enhance accuracy and efficiency.

6. Ethical and Legal Considerations

6.1. Confidentiality

- Confidentiality: manage and handle all data with a great deal of privacy so that all the personal details of the involved people are not compromised.
- Data security: create procedures to prevent unauthorized people from sabotaging or tampering with digital data.

6.2. Responsibility

- Regulations: Adhere to applicable laws about collecting and analysing evidence and forensic processes.

Appendix B.

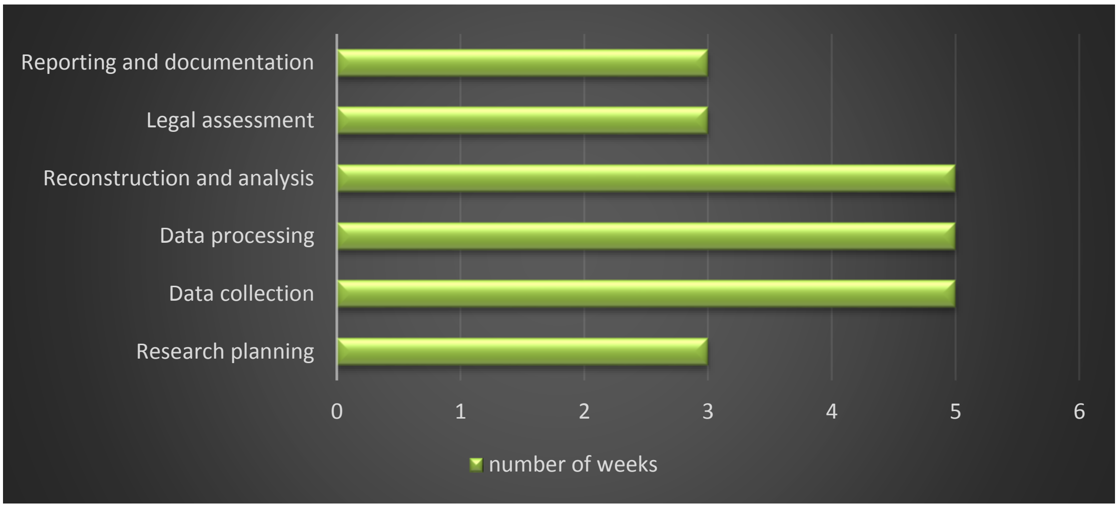

Fig. 1: Research Stages

Source: Developed by the authors based on [14], [15]

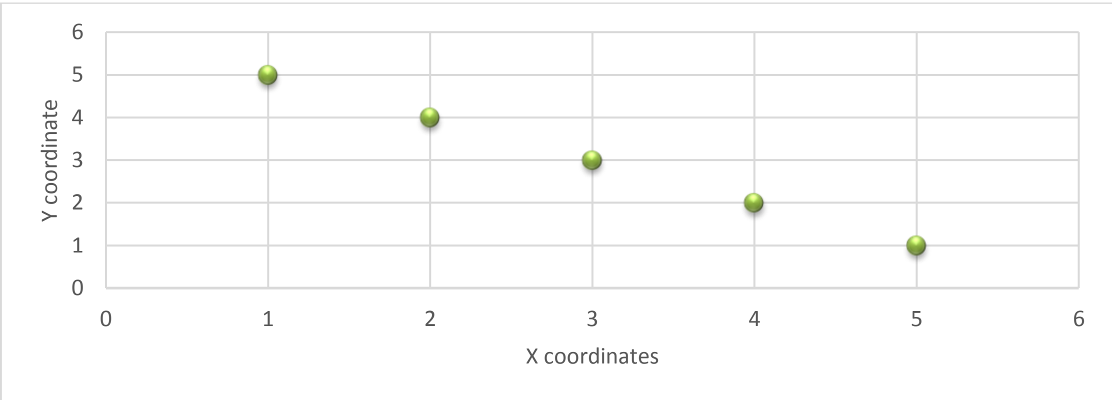

Fig. 2: Crime Scene Data Point Analysis

Source: Developed by the authors

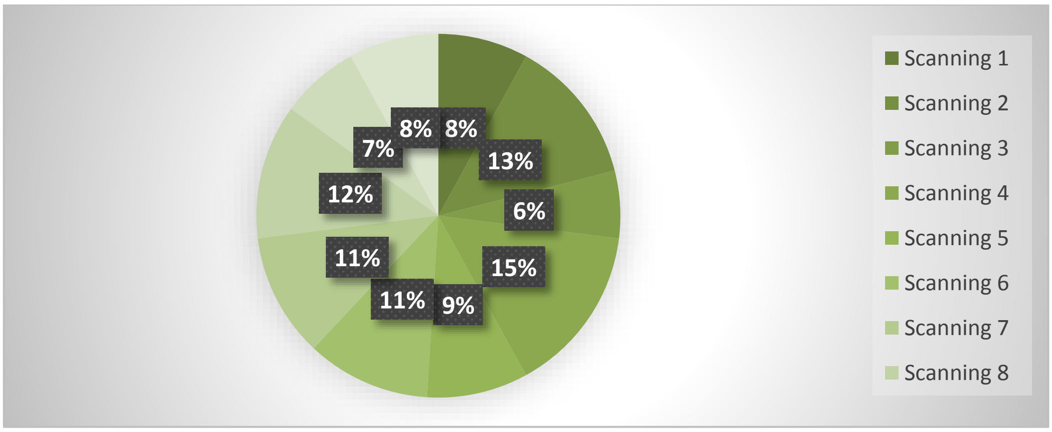

Fig. 3: Point Cloud Comparative Analysis

Source: developed by the authors based on [13], [26]

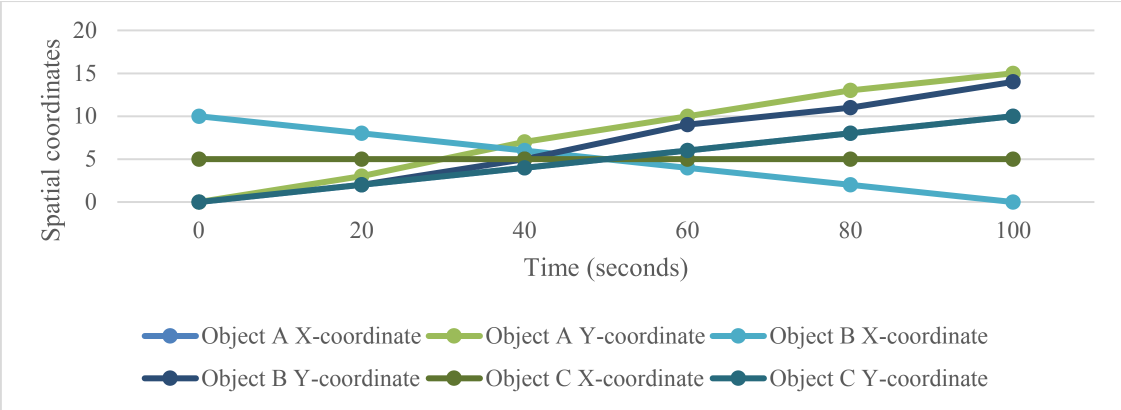

Fig. 4: The Autodesk Object's Path
Source: Developed by the authors

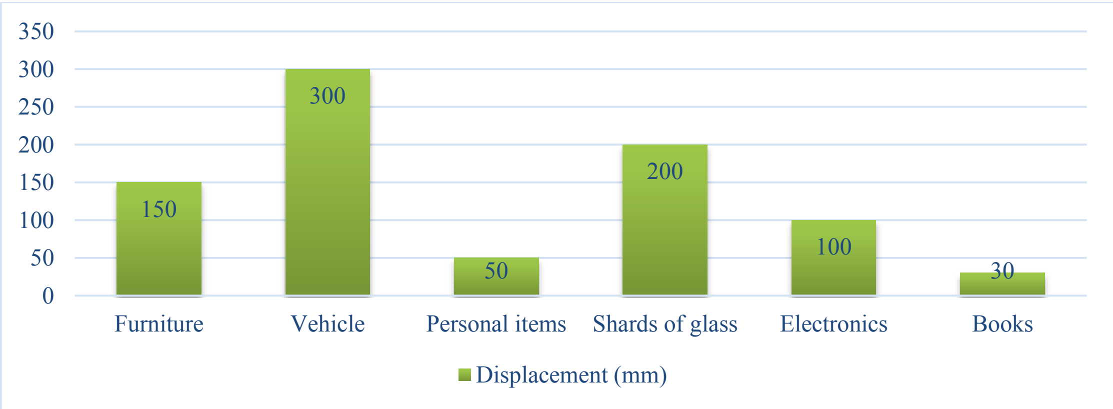

Fig. 5: Histogram of displacement analysis
Source: developed by the authors based on [18]

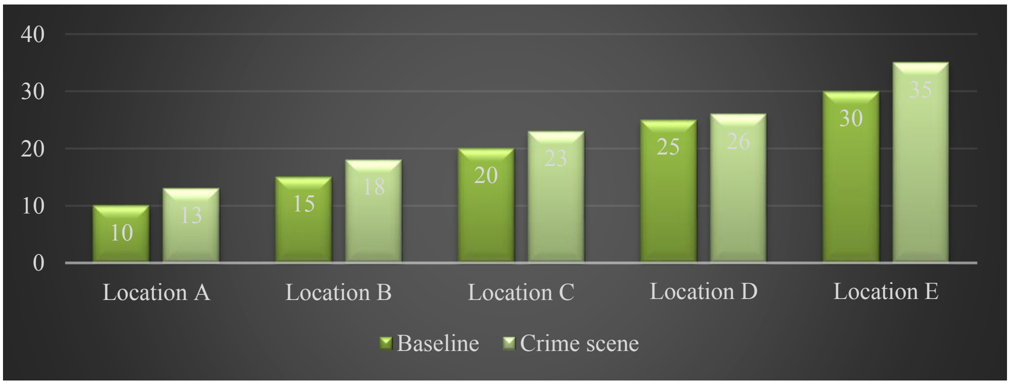

Fig. 6: Comparison of baseline and crime scene
Source: developed by the authors based on [26], [27]

Table 1. Sample Aormation

Scene ID	Country	Crime type	Level of complexity	Reason for selection	Number of scans	Coverage of important elements
CS01	USA	Murder	High	Detailed reconstruction is necessary for trajectory analysis	5	Several balls trajectories
CS02	UK	Armed confrontation	Medium	Reconstruction of suspicious actions	4	Ways of entry and exit, the path of the suspect
CS03	Germany	Arson	High	Analysis of the spread of fire and places of its origin	6	Combustion patterns and accelerator locations
CS04	Australia	Sexual violence	Medium	Detailed spatial analysis to confirm the testimonies of the victims	3	Positions of the victim and the suspect
CS05	UK	Hit-and-run	High	Reconstruction of vehicle movement and collision points	5	Tire tracks, impact analysis
CS06	Canada	Burglary	Low	Spatial analysis of entry and movement within the property	3	Entry points, the criminal’s path through the property
CS07	USA	Domestic violence	Medium	Analysis of physical collisions and movement in a confined space	4	Positions of persons, impact points
CS08	Canada	Kidnapping	High	Reconstruction of the kidnapping scenario	5	Transport paths, positions of persons
CS09	Germany	Drug production	Medium	Spatial analysis of an illegal drug laboratory	4	Placement of equipment, ways of movement
CS10	Australia	Environmental crime	High	Detailed reconstruction of an illegal landfill	6	Discharge points, the spread of pollutants

Source: Developed by the author based on [16], [17], [18]