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The Integration of Technology and Human Activities During the Structural Forensic Engineering Process

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Abstract

Structural forensic engineers specialise in identifying the causation of structural failures within the multidisciplinary field of forensic engineering. This article explores the 17 stages of the forensic engineering process for investigating catastrophic failures and the associated human activities. It aims to identify the challenges professionals face in facilitating the forensic engineering process and the technologies that could minimise human error. Data was gathered through structured interviews with forensic engineers and a legal expert, focusing on several key activities: professional engagement, investigation and inquiry, documentation analysis, hypothesis testing, process planning, document management, and ethical compliance. Process challenges identified in the research include ineffective communication with clients, knowledge gaps with clients, integrity issues in evidence, restricted site access, and cognitive bias. The technologies explored in the article include UAVs, 3D printing, MAT, cameras, non-destructive testing (NDT), AI, CAD, and photogrammetry, to enhance human activities in the forensic engineering process and reduce human error.

Keywords
Structural Forensic Engineers, Forensic Engineering, Human Activities, Human Challenges and Technology

1. Introduction
Forensic engineering is an industry that investigates the causation of property loss and potential human injuries or fatalities due to major and minor engineering failures (Cappelletti et al., 2019). The industry is multidisciplinary, consisting primarily of fire detection experts, who apply their skills to report on their findings to manufacturers, building companies, insurance companies, and law institutions after a fire has damaged a building (Cappelletti et al., 2019). Structural forensic engineers, who have the challenging task of determining the causation of a disastrous incident after structural failure. Their findings may lead to a legal claim from the owner of an insured facility which has fallen victim to the forces of man or nature (Mitolo et al., 2021).

The forensic engineering process may involve supplementary professionals such as attorneys, registered engineering experts, and law enforcement, who will need input from the structural forensic engineer to settle an insurance claim or hold third parties accountable for the structural failure of an entity (Barrow et al., 2018). The work conducted by a forensic engineer involves evidence gathering, hypothesis formulation, data analysis and simulation of what could have potentially taken place at an incident site (Galante et al., 2023). Failure of a structural forensic engineer to inspect an incident site promptly may lead to key evidence being removed from an incident site, which then decreases the likelihood of the root cause of failure being discovered (Barrow et al., 2018). The failure of the structural forensic engineer to reach a decisive conclusion on the proximate cause increases the likelihood of a repetition of the failure incident, as a result, endangering ordinary citizens (Barrow et al., 2018). The human factor introduced by the forensic engineer (practitioner) has been identified as a limiting factor in the accurate facilitation of the forensic engineering process (Mitolo et al., 2021). This research aims to develop an understanding of how to introduce technologies that can assist forensic engineers in addressing the challenges encountered when facilitating human activities during the forensic process.

2. Literature Review

The forensic engineering process is a methodological approach used to determine the cause of property damage, which may result in the potential loss of human lives or facilities due to major or minor engineering failures (Cappelletti et al., 2019). The objective of the process is to identify both technical and non-technical causes of failure by gathering valuable incident site information and evidence using approved scientific methods (Brady, 2012). Various systems and approaches, such as the National Academy for Forensic Engineering, outline the scope of facilitating the forensic engineering process (Liptai, 2009). Similarly, the Guidelines for Failure Investigations (Barrow et al., 2018) and the Delft Forensic Engineering Approach (Terwel et al., 2018), outline different approaches to the forensic engineering process. The steps presented in the Forensic Engineering Handbook, which is a widely accepted baseline approach to structural forensic engineering investigations (Ratay, 2010) has similarities with the steps in Guidelines for Failure Investigations (Barrow et al., 2018). The forensic engineering process must be conducted based on impartial information so that the resulting findings can be utilised by a South African court in litigation or trials, while also serving the public interest (Liptai, 2009).

The forensic engineering process comprises 17 stages of human activities, as referred to in Table 2, ranging from the forensic engineer's initial engagement with the client to the drafting and release of the final report (Ratay, 2010) . The human activities involved in the process are multifaceted and require advanced technical competence, analytical reasoning, and interpersonal skills (Barrow et al., 2018). The human activities involved in the forensic engineering process can be categorised as professional engagement and stakeholder management, fieldwork and data collection, advanced reasoning, and technical functions (Barrow et al., 2018). The final human activity which holds the greatest responsibility is legal compliance and documentation (Barrow et al., 2018). The common limiting factors are that there are limited human resources to support the forensic engineer, the limitation to staffing affects the amount of billable work and time on site, as investigations can be time consuming, and some findings cannot be spotted on the initial site visit (Barrow et al., 2018). As illustrated in Table 1, confirmation bias, contextual bias, and availability bias affect the forensic engineer's interpretation of the information gathered. This can, at times, downplay the complexity of the failure incident (Terwel et al., 2018).

There is available research that links expert decision making to implicit cognitive biases rather than intentional misconduct, impacting every stage from data collection to final interpretation. This vulnerability is often obscured by six fallacies (ethical issues, bad apples, expert immunity, technological protection, blind spot and illusion of control). These biases are driven by eight distinct sources : Data, reference materials, contextual information, base rate, organizational factors (Table 1), education and training, personal factors , human and cognitive factors, and the brain. (Dror,2020)

Table 1.Forensic engineering: human activities and challenges

Challenges	Human activities and process functions
Availability bias	Problem definition - Engage with witnesses and note-taking unless a recorder is allowed for capturing testimonials. - Potentially redefinition of the problem. Data collection - Communicate with other peers to get criticisms on the methods used to collect information. - Hypothesis generation. - Pattern recognition and timeline sequencing.
Confirmation bias	Data analysis - Application of human expert discretion in the application of scientific and engineering principles.
Contextual bias	Testing protocol and sample collection - Thorough following of testing protocols and sample collection methods.

2.1 Technology tools

Traditional forensic investigation methods are part of the data collection stage, which involves capturing images and taking live measurements with tools such as measuring tapes or laser rangefinders (Mohsan et al., 2023). These tools are inherently prone to inaccuracies, time consuming, and highly susceptible to human introduced errors (Kim et al., 2024). These errors are then documented in the forensic engineer's report, the ultimate product of the forensic investigation. Other deficiencies include the difficulty for a human being to accurately identify the laser dot emitter with a laser range meter over long distances (Mohsan et al., 2023). Measurements on non-reflective surfaces are prone to inaccuracies; the geometry of warped or curved surfaces may not be accounted for, and environmental factors, such as changes in atmospheric density, can introduce refraction over long distances, reducing measurement accuracy (Bender, 1967).

To address these deficiencies and human errors, modern technologies such as Unmanned Aerial Vehicles or Systems (UAV/UAS), 3D printing, and Motion Amplification Technology (MAT) potentially can reduce human error. UAVs utilise various sensors, including infrared (IR) thermal, Red-Green and Blue (RGB) sensors, multispectral, and hyperspectral detectors, as well as Light Detection and Ranging (LIDAR) and Synthetic Aperture Radar (SAR) (Tynan, 2024). UAV photogrammetry based methods have been applied in geochemical, structural, and water infrastructure engineering. This technology accelerates access to incident sites, enabling data collection, and provides an immediate improvement over relying on satellites or human ground based interventions (Tynan, 2024). In structural forensic engineering, UAVs help monitor structural stability (deformation) and durability (ability to withstand external forces), and they can help bridge the gap between accuracy and measurement range across different investigation approaches (Tynan, 2024). The limitations of UAV operation are influenced by factors such as weather, the UAV's structural design, and battery technology (modern lithium-polymer batteries provide an average flight time of 20–30 minutes) (Tynan, 2024). Other limitations include region-specific regulatory restrictions, sensor measurement ranges and accuracy issues, and the need for human intervention to control parameters such as scanning speed (Tynan, 2024).

3D printing technology builds a digitally constructed object along the x, y, and z axes by successive layering of materials such as Polyactic Acid (PLA), Polyethene Terephthalate with Glycol (PETG), and Acrylonitrile Butadiene Styrene (ABS) (Maneli, 2022). The process involves image acquisition, image processing, 3D model creation, and printing. In forensic engineering, 3D printing serves as a tool for reconstructing accident scenes or artefacts, allowing large sites to be scaled down for presentation in court (Maneli, 2022). It can also be used to reconstruct and print burned human remains following a fatality to establish causation. This technology is helpful in the hypothesis formulation, hypothesis testing, and reporting stages of the forensic engineering process (Maneli, 2022). The limitations of its use as evidence depend on the modeller's competence to depict the artefact accurately, and it is currently categorised as contemporary evidence (Maneli, 2022).

Motion Amplification Technology utilises a high-speed resolution camera to capture and detect subtle motion (represented as image pixels), which is then amplified for human perception (Roque, 2018). The collected data is converted into a video of the measured displacements of a building structure or a pump-and-motor assembly. The camera is placed on a tripod, and its movements are controlled from a tablet used for storage (Roque, 2018). The most significant benefit is that there is no physical contact between MAT – Iris M and the monitored equipment (Roque, 2018).

Data collection and processing are quick, and the recorded video enables time-series displacement measurements. The technology's limitation is that the camera's frames-per-minute setting determines the sampling frequency; it performs well at low frequencies but poorly at high frequencies (Roque, 2018).

2.2 Ethical and legal considerations

Forensic engineers must serve as technical experts and provide testimonials to legal representatives (such as lawyers or attorneys) to meet legal requirements (Azmoodeh et al., 2019). Ethical considerations must encompass the safety, health, and welfare of the public, and professional duties must be performed only in fields for which accredited knowledge has been acquired. Statements must be guided by objective truth, and deceptive works must be avoided (Maneli, 2022). Table 2 is a summary of the research findings relating the 17 stages of the forensic engineering process to the identified human activities, process challenges and limitations, applicable technologies.

Table 2. Summary of processes, human aspects and technological integration

Structural forensic engineering handbook process	**Human activities**	**Challenges and limitations**	**Applicable technology integration**
1. Commissioning of a forensic engineer	Travel to site. Engage with clients either via mail, text, phone call or face-to-face interaction.	-	-
2. Definition of the investigation objective	Use measuring instruments to capture data such as wind speed, images, thermal imagery and distances.	Availability bias	Motion amplification technology
3. Collection of background information	Communicate with peers to obtain criticisms of the methods used to collect information.	Availability bias	Motion amplification technology
4. Preliminary document review	Communicate with peers to obtain criticisms of the methods used to collect information.	-	-
5. Initial site visit	Conduct surveys, take measurements on site, take photographic evidence	Availability bias	UAV integration
6. Eyewitness testimonials	Gather information from nearby bystanders or the insured staff members.	Availability bias, confirmation bias	Motion amplification technology,3D printing
7. Formulation of an investigation plan	Client engagement and peer forensic engineer engagement.	Confirmation bias	Motion amplification technology
8. Formulation of project plan	Client engagement and peer forensic engineer engagement.	Confirmation bias	Motion amplification technology; UAV
9. Comprehensive collection plan	Develop a sample collection plan and collect sample.	Confirmation bias	Motion amplification technology; UAV
10. Document review	Forensic engineers read, analyse and critique the validity of documentation and comment on irregularities.	-	-
11. Second site visit	Conduct surveys, take measurements on site, take photographic evidence, and track reinstatement progress.	Availability bias, confirmation bias	Motion amplification technology; UAV
12. Sample collection	Collect, store, and analyse samples.	Contextual bias	Motion amplification technology; UAV
13. Theoretical analysis	Develop causation models.	Contextual bias	3D printing
14. Laboratory analysis	Use laboratory equipment, such as eddy-current testing, thickness gauges, and ultrasonic testers, for non-destructive testing.	Contextual bias	Motion amplification technology
15. Hypothesis generation and testing	Expert usage of software packages to run scenarios for incident causation.	Contextual bias	Motion amplification technology; UAV
16. Determining timeline and sequence of events.	Expert usage of software packages to run scenarios for incident causation.	Contextual bias	Motion amplification technology
17. Report writing	Use information gathered in steps 1 to 16 to draft a comprehensive report presenting the causation of the failure incident.	Availability bias, confirmation bias, contextual bias	Motion amplification technology, UAV integration, 3D printing

3. Method and Design

A qualitative method was chosen to extract knowledge from individuals lived experiences, and interviews are well-suited to this purpose. To broaden the scope of solutions and lived experiences, an approach was taken to include multiple forensic engineering disciplines within the targeted population. The targeted population presented in Table 3 describes each of the participants' profiles. The selection criteria for these professionals were academic credentials, years of active participation in the forensic engineering industry, and the ability to demonstrate the application of engineering principles or techniques in the investigation of materials, products, structures, or components that fail or do not perform as intended (Hainsworth, 2007). Their daily responsibilities had to involve investigating the physical causes of accidents or other sources of a submitted claim or litigation (Hainsworth, 2007). The only outlier in the interview target population was the legal profession in the South African context (Table 3).

Table 3. Interviewee demographic

Professionally registered	Discipline	Forensic engineering experience
Yes	Structural	Practising structural engineer, structural forensic engineer specialising in modern technology.
Yes	Principal forensic scientist (digital and cyber)	Practising digital forensic professional since 1998.
N/a	Mechanical (fire)	10 years of industry experience, transitioned into forensic engineering consultancy.
N/a	Mechanical (vehicle dynamics and collisions)	Acting as a mechanical engineer since the early 1990s, dealing with vehicle collision investigations.
Yes	Metallurgical	Metallurgical engineer since the 1980s and practising as a metallurgical forensic engineer since 1996.
Yes	Structural	Operating since 1987 as a consulting engineer and forensic engineer.
Yes	Mechanical	Specialist forensic mechanical engineer with 15 years of experience.
Yes	Structural	42 years of working experience and still active as a structural forensic engineer.
Yes	Attorney and legal liability specialist	20 years of experience in handling legal liability claims. An admitted attorney of the High Court.

4. Data Analysis

The nature of qualitative data analysis is such that it classifies and interprets linguistic material to arrive at statements of meaning for the benefit of academic findings and knowledge acquisition (Alem, 2020). It is a range of processes that allow the researcher to move from the qualitative data collected to explanations and interpretations of what the interviewee has provided during the interview process (Alem, 2020). Content analysis was used to analyse the collected data because it is flexible, cost-effective, enables researchers to process large volumes of information, and is applicable across diverse disciplines. Data from nine interviews with forensic engineers and legal professionals were transcribed verbatim and aligned with interview questions and the 17 forensic engineering stages. To reduce the data it were categorized into three themes: human activities by forensic engineers, their challenges and limitations, and technologies to address those challenges. Response frequencies were tabulated, compared with existing literature, and visualized with a colour coded system to interpret data and draw conclusions.

5. Results and Discussion

Following the completion of the data analysis described in Section 4, the results of the categorisation and data reduction were consolidated in Table 4 to illustrate the extent of involvement in the forensic engineering process for human activities. When comparing the literature with the collected data, the forensic engineer's functions appear more complex and demanding. The lessons learned about human activities, challenges, and applicable technologies during the process are described in the tables below.

Table 4. Human activities during the forensic engineering process

1 Commissioning of a forensic engineer	**2 Definition of the investigation objective**	**3 Collection of background information**	**4 Preliminary document review**
Stakeholder interaction and trust development. Initiation protocols and role assignment procedures. Inquiry design and scope definition. Field assessment scheduling and oversight. Data management and message delivery.	Time construction and validation. Root cause and incident inquiry. Engagement and information gathering. Technical inspection and process adherence.	Relationship building and trust development. Field-level engagement and dialogue. Technical and contextual information gathering.	Document acquisition and format management. Regulatory and system contextualisation. Analytical review and relevance filtering. Multiple sources and visual analysis techniques.
5 Initial site visit	**6 Eyewitness testimonials**	**7 Formulation of an investigation plan**	**8 Formulation of project plan**
UAV operation and aerial oversight. Planning, co-ordination and stakeholder engagement. Safety protocols and compliance. On-site investigation and evidence collection.	Cognitive reconstruction and scene rebuilding. Interview techniques and questioning strategy. Witness identification and selection. Documentation and reporting Analysis and validation.	Strategic planning and co-ordination. Analytical and interpretive work. Communication and framing. Field engagement and observation.	Strategic planning and co-ordination. Analytical and interpretive work. Communication and framing. Field engagement and observation.
9 Comprehensive collection plan	**10 Document review**	**11 Second site visit**	**12 Sample collection**
Procedural oversight and instruction. Investigative planning and decision-making. Technical execution and tool application. Physical sampling technique. Material-specific sampling. Human resource and skill deployment. Hazard detection and chemical screening. Legal compliance and sample integrity. Strategic alignment and scenario mapping. Analytical framework and root cause mapping. Laboratory testing and data interpretation. Laboratory testing and structural assessment.	Document acquisition and format management. Regulatory and system contextualisation. Analytical review and relevance filtering. Multiple sources and visual analysis techniques.	Planning, co-ordination and stakeholder engagement. Safety protocols and compliance. On-site investigation and evidence collection.	Procedural oversight and instruction Investigative planning and decision-making Technical execution and tool application Physical sampling technique. Material-specific sampling. Human resource and skill deployment. Hazard detection and chemical screening. Legal compliance and sample integrity. Strategic alignment and scenario mapping. Analytical framework and root cause mapping. Laboratory testing and data interpretation. Laboratory testing and structural assessment.
13 Theoretical analysis	**14 Laboratory analysis**	**15 Hypothesis generation and testing**	**16 Determining timeline and sequence of events**
Preliminary assessment and field judgement. Diagnostic strategy and problem isolation. Domain-specific technical knowledge. Knowledge acquisition and reference validation. Inquiry and scenario mapping.	Legal compliance and evidence integrity. Laboratory selection and reliability. Procedural gaps and resource constraints. Sample transfer and logistics. Evidence gathering and fieldwork. Material-specific sampling.	Collective intelligence and strategic dialogue. Technical diagnosis and causal assessment. Temporal and systems-based reasoning. Structured inquiry and evidence-based testing. Strategic planning and investigative control.	Strategic communication and alignment. Communication and legal preparedness. Data gathering and human insight. Field investigation and evidence validation. Analytical reasoning and scenario mapping.

Procedural and financial documentation. Foundational reasoning and deductive logic. Professional judgement and ethical reasoning. Structured problem-solving and causal mapping. Analytical depth and conceptual modelling.	Professional coordination and expertise access.	Deductive reasoning and analytical validation.	Temporal reconstruction and causal mapping.
17 Report writing			
Layout planning and document structuring. Clear expression and accessible language. Message framing and engaging content creation. Progressive editing and thoughtful evaluation. Insight integration and information reframing. Mental focus and articulate reasoning. Targeted messaging and contextual adaptation. Compliance partnership and investigative preparedness.			

The lessons learned from Table 4 is that there is a comprehensive and multifaceted involvement of the human being in the forensic engineering process, and that this involvement requires advanced technical and forensic engineering skills. *"You conduct an initial consultation to get the feel of the incident. Once the initial consultation has taken place, we can then do a deep dive which we again ask on the root cause of the incident. We then take into consideration legal objectives."* The activities range from client engagement and effective human communication to thorough planning for the execution of evidence collection and site visits. The forensic engineer must apply scientific methods like root cause analysis and hypothesis testing to reach conclusions, carefully evaluating documents and selecting accredited laboratories for testing. Beyond technical skills, they need soft skills such as patience, respect, and understanding court procedures. *"You must come in with a very soft approach. Those people are normally traumatised, they could have been mortalities, or even just financial losses in the form of assets."* Literature and data show that stakeholder engagement and effective communication are vital early in the process. They must balance technical expertise with human insight, ensuring their work is rooted in continuous analysis and validation.

The results show that forensic engineering faces challenges mainly due to clients' limited understanding of the scope and poor communication at the start of investigations. Additional issues include delays in getting documentation because of poor archiving or retrieving documents from third parties, as well as deception, contamination, and sample mishandling. Biases like cognitive, availability, contextual, and confirmation biases exist, with cognitive bias representing 41% (Stages 4, 6, 7, 8, 10, 14 and 15) of the problem in the execution of the forensic engineering process as derived from Table 5. *"The clients have a fixed internal dialogue about the problem; therefore, it's necessary to revisit the system fundamentals to restart problem redefinition and reach a common understanding."* Key challenges include evidence integrity, client documentation, communication, site access, and time constraints.

Table 5. Human challenges and limitations during the forensic engineering process (Practitioner responses)

Structural forensic engineering handbook process steps	**Categorisation (Derived from practitioners' responses)**
1. Commissioning of a forensic engineer	Client knowledge and understanding gaps; Communication and engagement barriers; Organisation and cultural constraints; Time pressure and operational urgency.
2. Definition of the investigation objective	Collaboration and communication barriers; Documentation and data integrity issues; Time constraints and pressure; Technical misjudgement and analytical errors.
3. Collection of background information	Resource and infrastructure limitations; Communication and psychological barriers; Bureaucratic and stakeholder bottlenecks Documentation and expectation misalignment.
4. Preliminary document review	Documentation integrity and availability issues; Process delays and format barriers; Cognitive overload and relevance filtering Human error and capacity constraints; Concealment and legal sensitivity; Technological limitations
5. Initial site visit	Human factors and engagement; Logistical and access barriers; Time and scheduling constraints; Evidence integrity and sense control; Technical definition and clarity.
6. Eyewitness testimonials	Temporal and access constraints; Cognitive limitations and memory distortion; Witness behaviour and psychological resistance Narrative inconsistency and information filtering; Personnel and professional competence; Verification and procedural integrity.
7. Formulation of an investigation plan	Behavioural and cognitive bias; Technical definition; Data integrity; Professional judgement; Stakeholder engagement; Procedural; Bureaucratic; Communication barriers; Data integrity.
8. Formulation of project plan	Behavioural and cognitive bias; Technical definition; Data integrity; Professional judgement; Stakeholder engagement; Procedural; Bureaucratic; Communication barriers; Data integrity
9. Comprehensive collection plan	Stakeholder engagement and communication; Logistical restriction and site management; Procedural clarity and role assignment Evidence integrity and environmental risk; Legal compliance and evidence integrity; Comparative context and scenario framing Evidence gathering and operational barriers; Evidence loss and investigation limitation; Timing and investigative readiness.
10. Document review	Documentation integrity and availability issues; Process delays and format barriers; Cognitive overload and relevance filtering Human error and capacity constraints; Concealment and legal sensitivity; Technological limitations.
11. Second site visit	Human factors and engagement; Logistical and access barriers; Time and scheduling constraints; Evidence integrity and sense control; Technical definition and clarity
12. Sample collection	Stakeholder engagement and communication; Logistical restriction and site management; Procedural clarity and role assignment Evidence integrity and environmental risk; Legal compliance and evidence integrity; Comparative context and scenario framing Evidence gathering and operational barriers; Evidence loss and investigation limitation; Timing and investigative readiness.
13. Theoretical analysis	Stakeholder alignment and expectation gaps; Technical accuracy and computational rigour; Capacity gap and professional development; Performance anxiety and professional identity; Procedural integrity and workflow breakdown; Epistemological weakness and source credibility; Evidence quality and investigative limitation.
14. Laboratory analysis	Cognitive gaps and investigative uncertainty; Evidence integrity and procedural negligence; Interpretive conflict and stakeholder discrepancy; Environmental risk and testing reliability; Logistical barrier and evidence availability; Procedural gaps and oversight Interdisciplinary misalignment and communication.
15. Hypothesis generation and testing	Stakeholder integrity and ethical risk; Cognitive bias and analytical objectivity; Evidence gaps and source credibility; Procedural integrity and evidence quality; Capacity gap and analytical competence.
16. Determining the timeline and sequence of events	Documentation gaps and historical integrity; Time pressure and investigative readiness; Analytical flaws and technical misjudgement Relational breakdown and communication gaps; Epistemological risk and source credibility.
17. Report writing	Process adherence and regulatory alignment; Mental prejudices and impartial reasoning; Consensus building and anticipation of discrepancies; Standards validation and methodological precision; Clear messaging and inclusive collaboration; Workflow optimisation and asset utilisation; Message precision and text accessibility; Layout architecture and visual structuring; Tailored messaging and contextual relevance.

Using technology to address these biases and issues could make forensic investigations more accurate, precise, and credible, especially if they lead to court proceedings. The results indicate that forensic engineering primarily relies on telecommunications and documentation tools, such as cell phones, email, OneDrive, and Google Drive. *" During this stage, the best approach is good old-fashioned education, educating the client on our forensic procedure and aligning expectations through normal means of communication – email, cell phone, or meeting (Live or Teams)."* The field has embraced AI to accelerate analysis, hypothesis development, and testing, with 6 of 17 steps (35%) incorporating AI, suggesting limited widespread adoption. Participants highlighted the importance of technical training and the need for discretion in filtering AI outputs. *"The use of AI at times saves a lot of time, in the context of searching textbooks and finding formulas. Again, I just asked what formulas are useful and how do you do this and it gives me an example."* When AI isn't enough for site data collection, physical tools such as microscopes, measuring tapes, laser devices, DSLR cameras, laboratory equipment, and grinders, along with vehicles, support evidence gathering.

Some technologies, like UAV/UAS and ground-penetrating radar (GPR), are less frequently used but remain important for revealing subsurface anomalies. Other techniques related to laboratory analysis facilitate detailed, non-destructive testing. Technologies such as 3D printing and motion amplification were absent, possibly due to the scope of work or the timing of forensic intervention, which is typically after an incident. Common technology categories include document capture, field data collection, digital analysis, material testing, spatial mapping, and computational analysis, these lessons are well summarised in Table 6. All the lessons learned throughout the research path and the digestion of data collected are summarised by the visual illustration Figure 1.

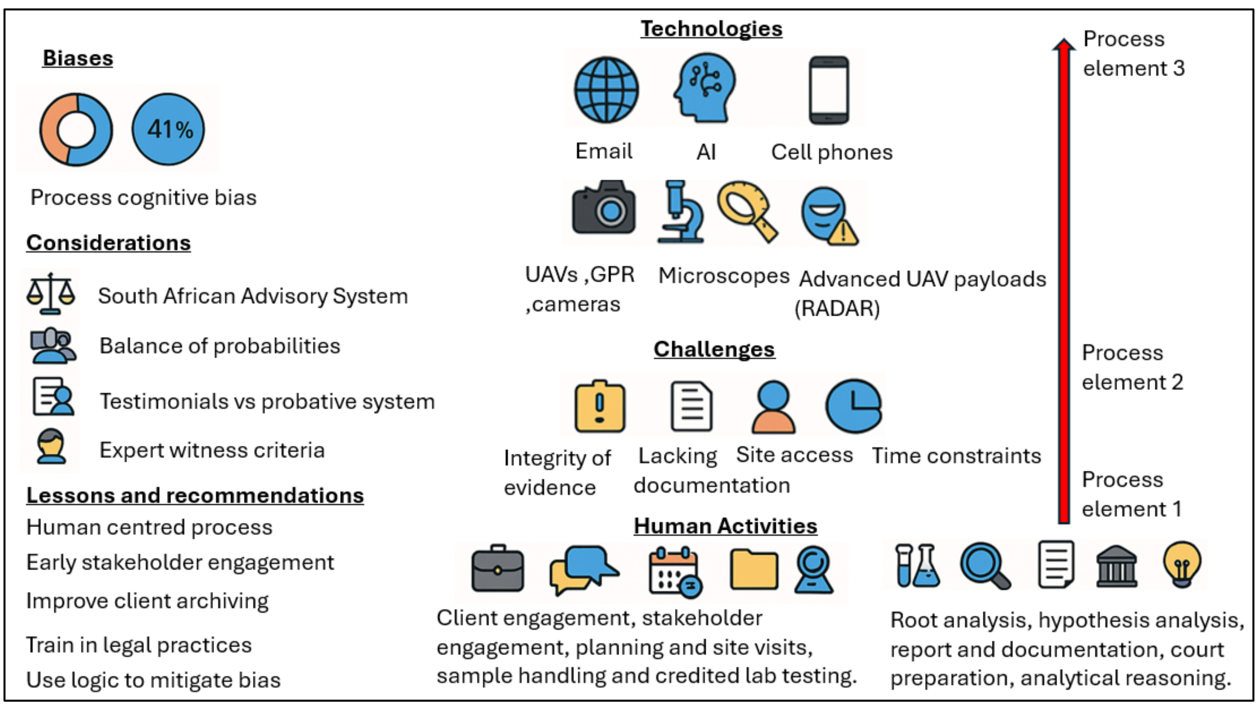

Figure 1. Visual representation of lessons learned (Visuals generated using AI)

6. Research contributions

Based on the literature review and the structured interview results, it is preferred that the forensic engineer adopt a hybrid technological approach, including both existing and emerging tools. This is due to the excessive cost of entry for advanced, innovative technologies and the need for advanced training. Surprisingly, the results showed that the practising forensic engineers interviewed still preferred established tools such as MS Office, email, and a high-quality camera. The results indicate a heavy focus on the forensic engineer to prioritise legal principles training and modern technology training. Most traditional engineers are sound in their careers but lack legal training and experience; consequently, they do not transition to forensic engineering because they lack the depth of knowledge and the confidence to testify in court and therefore require legal training.

The legal training for the forensic engineer may cover the rules governing evidence, including hearsay, and the handling of electronic data so that it may be considered legitimate evidence under the Electronic Communications and Transactions Act 25 of 2002. The use of UAV/UAS with photogrammetry is encouraged and provides a permanent, georeferenced record of a site, which is less susceptible to subjective interpretation. To enhance client relations, forensic engineers can develop an engagement guide to improve communication. The engagement guide may include the scope of work, available communication channels, and a document outlining the required information. The forensic engineering industry can take ownership in promoting pre-incident technology such as Motion Amplification Technology. This may sound counter intuitive to the traditional purpose of the function of the forensic engineer, however, in taking on a potential new service that scans structural buildings for signs of failure; the forensic engineer would have saved the client money for reinstating a failed building and would have fulfilled the ultimate public service which is to prevent the loss of job or the loss of lives.

7. Research limitations

The main limitations identified are the limited number of interviews and the limited range of nationalities; only South African forensic engineers were interviewed. Only eight forensic engineers consented to the , and only one legal expert was available for legal views. Due to the nature of the industry, most interviewees were not young people; therefore, the data is skewed towards the perspectives of the elderly or those who have been in the industry longer. Even though the legal element of the emerged as the progressed, future should broaden legal practitioners' perspective beyond a single individual. This could also indicate how some laws, at the national or international level, incorporate and accommodate technology.

8. Conclusion

The study examined forensic engineering, focusing on human activities and the need for technological improvements, especially for structural forensic engineers. It covered multiple disciplines to provide a comprehensive answer. The process involves 17 stages and faces challenges like human biases, causing errors and judgment mistakes. Structured interviews showed key activities include site visits, investigation, documentation analysis, technical testing, planning, management, and ethics. Challenges identified are poor communication, knowledge gaps, evidence issues, limited access, miscommunication about site visits, and biases. Technologies like UAVs with RGB, thermal, multispectral sensors, SAR, LiDAR, and photogrammetry can improve accuracy and efficiency, allowing site surveying and model creation. Limitations include battery life and skills. 3D printing helps recreate scenes for court, but it's secondary evidence and depends on skill. Motion Amplification aids in monitoring and analysis without contact, useful in industrial settings. Besides literature, tools like AI, NDT, CAD, and cameras are used in practice. Combining approaches helps reduce inefficiencies within budgets. The modern forensic engineer should be tech-savvy but aware of legal issues, relying on training and experience discernment (Table 6).

Table 6. Summary of research findings

Item	Description or category	Research outcomes
1	Human Activities	**Multifaceted Engagement:** Involves professional engagement (site visits), detailed enquiries, analysis of documentation, and technical functions like hypothesis generation. **Analytical Reasoning:** Requires advanced technical skills, the application of the scientific method, and root cause analysis. **Soft Skills:** Success depends on "human soft skills" such as patience, respect for stakeholders, and effective communication to manage power dynamics during investigations. **Legal Preparedness:** Engineers must prepare for court proceedings, requiring knowledge of South African law and the ability to act as an expert witness
2	Challenges and limitations	**Cognitive Biases:** These pose a major hurdle, affecting approximately 41% of process stages. **Client Knowledge Gaps:** Clients often lack understanding of the required scope of work, resulting in ineffective communication and delayed documentation. **Evidence Integrity:** Practitioners frequently encounter difficulties when evidence is discarded, contaminated, or removed before they can inspect the site.

		Site Access: Physical restrictions and misalignment between the engineer and client regarding site visits are common logistical barriers.
3	Applicable Technologies	**Communication & Documentation:** Standard tools such as email, mobile phones, and Microsoft **Office** are still preferred for day-to-day coordination and report writing. **Innovative Tools: UAVs (Drones)** equipped with photogrammetric sensors are highly valued for rapid data collection and 3D scene reconstruction. **Artificial Intelligence:** AI is used in approximately 35% of process steps to expedite theoretical analysis, although engineers must manually validate all AI outputs. **Inspection Equipment:** Reliable use of **DSLR cameras**, **microscopes**, **laser range meters**, and **non-destructive testing (NDT)** remains critical for physical evidence gathering.

Practitioners emphasized balancing traditional tools and new technology to manage costs and training. They highlighted that, despite technological advances, forensic engineering remains human-driven, with the engineer's discretion central to investigations. Feedback indicated that all information collected must be admissible and legitimate in South African courts.

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