DOI: 10.1478/AAPP.101S1A15

AAPP | Atti della Accademia Peloritana dei Pericolanti
Classe di Scienze Fisiche, Matematiche e Naturali
ISSN 1825-1242

Vol. 101, No. S1, A15 (2023)

THE TECHNOLOGIES OF LASER SCANNING AND STRUCTURED BLUE LIGHT SCANNING APPLIED TO CRIMINAL INVESTIGATION: CASE STUDIES

Roberta Somma [ab*], Alessio Altadonna [c], Filippo Cucinotta [c],
Marcello Raffaele [c], Fabio Salmeri [c], Gennaro Baldino [d],
Elvira Ventura Spagnolo [d] and Daniela Sapienza [d]

Abstract. The use of non-destructive methods guaranteeing high standards of accuracy, speed, simplicity of use, and low costs may be crucial during judicial inspection aimed to reconstruct the spatial arrangement of crime scenes. Three-dimensional (3D) laser scanning and structured blue light scanning are two modern and advanced technologies widely used in many sectors of the sciences, included forensic sciences. Limiting itself to forensic applications, these technologies may be successfully used for acquiring point clouds in 3D space and reconstruct 3D virtual models of large-, medium-, and small-scale forensic scenarios. These two technologies were applied for reconstructing 3D virtual models from real crime scenes and geological evidence, respectively. Different investigative places and items were investigated and discussed. The research evidenced the advantages of using these modern techniques in order to assist investigators in: i) providing 3D virtual models for reconstructing even complex crime scenes occurred outdoor; ii) reconstructing of the dynamics of events, and iii) individuating possible interactions between the actors of the scene and the surrounding places.

1. Introduction

In complex crime scenes, occurred outdoor in the countryside, a multi-disciplinary approach (Cecchi *et al.* 2022; Baldino *et al.* 2023a; Byrd and Sutton 2023; Somma *et al.* 2023b) in the study of the territory and physical evidence may be crucial for the successful results of criminal investigation (Picozzi and Intini 2009; Saferstein 2017). Experts involving criminalistic fields (Carella Prada and Tancredi 2010; Chen *et al.* 2021), such as forensic geology (Ren *et al.* 2018), engineering (Reed 2001), botany (Morabito, Mondello, and Somma 2023; Morabito and Somma 2023), and entomology (Byrd and Sutton 2023; Somma, Sutton, and Byrd 2023) may work in team assisting coroners and anthropologists (Christensen 2004) for providing useful data on the characteristics of the places and biotic and abiotic components of the environment (Murray and Tedrow 1975; Lombardi 1999; Ruffell and McKinley 2008; Somma *et al.* 2018; Caccianiga *et al.* 2021; Donnelly *et al.* 2021; Fitzpatrick and Donnelly 2021; Spoto, Somma, and Crea 2021; Somma 2022; Somma and Costa 2022; Marra 2023; Marra, Di Silvestro, and Somma 2023; Somma 2023a,b,c; Somma *et al.* 2023a,b; Somma and Costa 2023; Somma and Maniscalco 2023; Somma *et al.* 2023c; Somma, Sutton, and Byrd 2023; Spoto 2023; Spoto, Barone, and Somma 2023; Tagliabue *et al.* 2023). In particular, forensic geologists may need the involvement of experts in forensic engineering or physics to be assisted in the reconstruction of three-dimensional (3D) virtual models of the landscape or geological objects of interest. The use of this type of reconstructions is increasingly among experts in forensic sciences and police forces (Mangi, Khan, and Jatoi 2020) and the laser and structured blue light scanning are the most common, non-destructive, and repeatable 3D technologies.

The 3D laser scanning is a technology (Flor 2011; Komar, Davy-Jow, and Decker 2012; Almerich-Chulia and Moreno-Puchalt 2022), firstly applied in the field of the earth sciences (Telling *et al.* 2017) for reconstructing the spatial features of the rocky outcrops, quarries, landslides, slopes (Guo *et al.* 2022). Successively, it was used in many other sectors, such as architecture (C. Wu *et al.* 2021), archaeology (Barrile *et al.* 2022), cultural heritage (Luhmann *et al.* 2019) , industry (Cucinotta *et al.* 2018; Mohamed 2018), civil engineering (T. H. Wu 1993; Chias *et al.* 2019), ergonomic studies (Barberi *et al.* 2023), and forensic sciences (Park *et al.* 2018; INTERPOL 2023). Another technology used in forensic science that takes advantage of laser scans is the confocal microscope for the analysis of cartridge case (Puleio *et al.* 2020). Limiting itself to forensic applications, the laser scanning has been successfully used for large-scale scenarios, as a tool for surveying large post-disaster areas (Olsen and Kayen 2012), medium-sized scenarios, such as indoor crime scenes (Ebert *et al.* 2014), or small-sized scenarios, such as the detail of a trace related to a bite mark (Naether *et al.* 2012), or the Blood Pattern Analysis (Yokoi, Aizu, and Uozumi 2018; Singh, Gupta, and Rathi 2021).

Laser scanning is used for accurately capturing in short times large amounts of data (point cloud), which can be used to create detailed models of crime scenes for later reconstructions and analyses (Pavliuk 2018). This technique may also be used for creating virtual crime scenes and bodies for training purposes in the field of biomedical (Puccini 2003) and forensic sciences (Baldino *et al.* 2023b; Somma *et al.* 2023a). The 3D structured blue light scanning is a relatively recent technology. It is based on projecting a grid-like pattern of structured light onto the surface of the target to scan, emitted by a high-intensity source of blue light. This latter has a shorter wavelength than white light, which allows for higher spatial resolution and measurement accuracy. The technology has several advantages over other 3D scanning techniques, including high measurement accuracy, the ability to acquire objects of different shapes and sizes in short time, and to detect even the darkest or most reflective surfaces. Due to these advantages, it has become an essential tool for many 3D sensing applications and a popular technology in various fields, such as engineering, including rapid prototyping (Cucinotta, Raffaele, and Salmeri 2021a; González-Merino *et al.* 2021; Barberi *et al.* 2022), robotics, quality control, manufacturing, design, architecture, archaeology, cultural heritage conservation, medicine, and many others (Brown 2000).

The usage of 3D scanning technologies offers a groundbreaking approach that enhances earlier imaging methods, such as Computer Tomography (CT) and Magnetic Resonance Imaging (MRI) scans, which are already well-established in forensic procedures (Carew and Errickson 2019). This allows for a more accurate representation and preservation of data that closely resembles reality. Unlike prior techniques, 3D scanning enables on-site capture, providing three-dimensional resolution and the capacity to create lifelike models. In comparison to photographic and two-dimensional information, three-dimensional reproductions offer a significantly higher degree of realism. This is achieved by concurrently collecting data from both the victim's body and the crime scene in 3D space, enabling the simulation of interactions within the environment (Baldino *et al.* 2023b). Undoubtedly, this paves the way for future virtual realities and the emerging "metaverse" which is increasingly influencing technological research, encompassing biomedical fields as well.

In forensic science, Life Cycle Analysis (LCA) and laser scanning can be combined to evaluate the environmental impact of different forensic techniques and to identify opportunities for improvement (Barone, Cucinotta, and Sfravara 2017; Cucinotta, Raffaele, and Salmeri 2021b; Cucinotta *et al.* 2021; Prestipino *et al.* 2021). For example, LCA can be used to evaluate the environmental impact of traditional forensic techniques (such as fingerprinting, DNA analysis, and ballistics) and compare them with newer techniques (such as laser scanning).

The present research reports the results of the application of these 3D technologies in five real case studies concerning geological investigations carried out for a kidnapping case occurred outdoor, in the countryside. The research was aimed to evidence the possible advantages of using the afore-mentioned modern techniques, in order to assist investigators and coroners in criminal investigations.

2. Materials and methods

Two event scenes (case studies 1 and 2), two places of investigative interest (case studies 3 and 4), and one specimen of investigative interest (case study 5) were investigated in occasion of a case for which some of the authors were uncharged as experts and auxiliaries by the judicial authority.

The sites of case studies 1-2-3-4 were investigated in the field by means of laser scanner (Figure 1a), in order to acquire the clouds of points for reconstructing the related virtual 3D models.

In both technologies above mentioned, markers are used to align scans made from different angles so that the three-dimensional model can be generated (Cucinotta, Raffaele, and Salmeri 2019, 2020; Lo Giudice *et al.* 2022) .

The technology of laser scanning consists in detecting the spatial coordinates of a point cloud by launching a laser pulse and measuring the elapsed time until its reflected pulse returns (the so-called flight time) (Ogawa and Hori 2019) (Figure 1b). A moving head (Figure 1a), with two degrees of freedom, is capable of measuring hundreds of thousands of points in space, detecting their relative distance. The moving head is fixed on a tripod fixed to the ground (Figure 1a). The technology used by the laser scanner is the LiDAR (Light Detection And Ranging), which uses a Time-Of-Flight (TOF) to acquire up to 360,000 points per second. This allows to generate highly accurate point clouds, where the accuracy depends on the distance between the acquisition station and the surveyed target (Nelis *et al.* 2018). Before starting the scan, the laser performs a photographic overview. The scanner obtains two types of images: panoramic and spherical. Both types of images have an acquisition range of 300°-360° thanks to the three integrated HDR cameras. In addition, thermographic images can be also obtained (Saha *et al.* 2022).

The 3D laser scanner used in the present research was the LEICA BLK360 model (Figure 1a). The tool has a range of 60 meters in diameter and a point positioning accuracy of 4 mm at 10 m and 7 mm at 20 m. For each station of measure of the scans carried out in the present research, each point of the cloud was associated with spatial coordinates (x, y, z) and colour. It was possible to connect more point clouds related to different stations, by means of a computer postprocessing, in order to obtain a complete 3D virtual model. Detailed repeatable measurements of quantitative parameters were also accomplished in the 3D model. Each measurement was certified by an error less than 15 mm, as required.

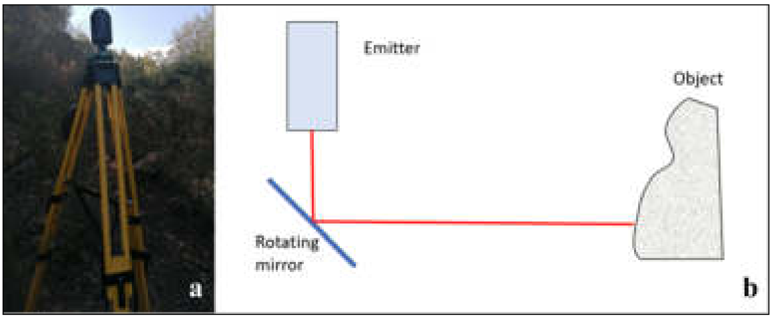

FIGURE 1. a) Leica BLK360 laser scanner of the Department of Engineering of the University of Messina placed on the investigated area. b) Operation scheme of the laser scanning technology.

The specimen of investigative interest (case study 5) consisted of a block of rock. It was surveyed in laboratory by means of structured blue light scanning, in order to acquire the clouds of points for reconstructing the related virtual 3D model.

This technology is used for acquiring three-dimensional data by means of a scanner that uses the triangulation method for obtaining point clouds from the acquired surfaces (Barone, Paoli, and Razionale 2012). The camera (Figure 2a) is positioned at different angles to capture the image of the distorted pattern from the surface of the object. The technology consists of illuminating the target with a pattern of structured light (usually lines or dots) and measuring the deformation of this pattern on the surface of the object. The light source emits a pattern of structured light, projected onto the target to be scanned (Figure 2b). The deformations of the pattern on the surface are used to calculate the 3D coordinates of each point of the object. In this way, structured light scanning makes it possible to acquire a large number of three-dimensional points precisely and quickly, and to reconstruct the three-dimensional shape of the object with high resolution.

The structured blue light scanner used in the present research was the ATOS Compact Scan 500-2M (GOM) (Figure 2a). With the configuration used, the scanner guaranteed a resolution of 0.02 mm and a volume box of about 0.3 m of side. The technical data for the GOM ATOS hand scanner system includes a measuring field of 500x380 mm^2, a camera resolution of 1624x236 pixels, and measuring point distances ranging from 75 to 309 µm. The system uses a power factor correction of 95 % and a resolution of 0.02 mm.

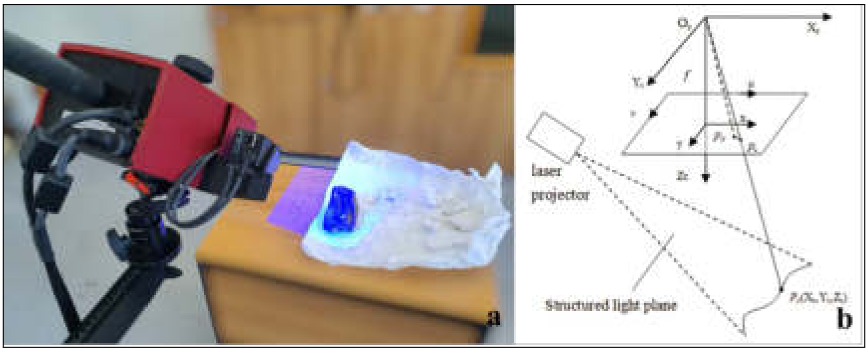

FIGURE 2. a) ATOS Compact Scan 500-2M (GOM) of the Department of Engineering of the University of Messina. b) Operation scheme of the blue structured light technology.

The cleaning of the data related to the point clouds acquired by means of both technologies, *i.e.* the removing of points that can be considered "noise" (such as vegetation if the target is only the ground) or that do not belong to the surface of the object, may be realized manually or with the aid of automatic data processing algorithms (Wand *et al.* 2008). There are several techniques that can help reduce or mitigate the noise caused by vegetation movement in outdoor laser scans:

i Data filtering: applying filters to raw laser scan data can help remove noise caused by moving vegetation. For example, distance-based or intensity-based filters can be used to remove points that do not meet certain *criteria*. Additionally, advanced filtering algorithms such as density-based outlier filters can be employed to specifically identify and remove vegetation-related noise (Wand *et al.* 2008).

ii Noise reduction through smoothing: smoothing involves applying a moving average or weighted average to scan data to reduce noise. This technique can help preserve the overall features of the scene while eliminating minor fluctuations caused by vegetation movement (Wand *et al.* 2008).

iii Multiple acquisition: conducting multiple scans of the same area at different times and combining them can help reduce noise due to vegetation movement. By comparing different scans, discrepancies caused by temporary vegetation movements can be identified and removed (Wand *et al.* 2008).

By considering these techniques, it was possible to manage and reduce the noise caused by vegetation movement in outdoor laser scans, thereby improving the quality and reliability of the acquired data. Once the three-dimensional reconstruction of the target is carried out, considering also the eventual noises, it is possible to elaborate topographic maps from the models. This can be realized by using triangulation algorithms or by using 3D modelling software (Rusman and Popova 2020). Once the surface of the object has been reconstructed, the desired topographical information provided of quantitative parameters (such as altitude) can be extracted.

3. Case studies

The investigated sites of case studies 1-2-3-4 were located in the open countryside of the Mediterranean bush, where the geological outcrops were characterized by siliciclastic terrains (yellow ochre quartz arenites and pelites) belonging to the domain of the Numidian Flysch. The places were characterized by a hilly landscape with gentle slopes. For each study place, the survey by means the laser scanner was carried out in the field using a different number of measure stations on the ground, based on the shape and size of the site in order to guarantee a complete cover of the area. The stations were reported in the figures with red dots, whereas dotted lines were used to represent the connections among the stations, allowing to merge the different clouds acquired in the various stations in a same spatial system by using of dedicated software. The investigated block of rock, reported in case study 5, was composed of quartz arenites collected at crime scene and examined by structured blue light scanning in laboratory. For each survey, 3D point clouds and 360° photos were acquired.

3.1. Case study 1. For the acquisition of this area, six different scans were carried out (Figure 3). The distribution of the stations was irregular on the slope. The ground was irregular and stations were aligned mostly along the slope, with stations SW3, SW4, and SW6 defining a triangle in the area of major investigative interest. The first station was 4.44 meters from the second one, the second station was 1.72 meters from the third one, the third station was 4.41 meters from the fourth one, the fourth one was 2.56 meters from the fifth station, and this latter was 3.38 meters from the sixth station. The connections between the second and fourth, third and sixth, third and fifth stations were further strengthened. The robustness of the survey acquired, with a value of 65%, was sufficiently satisfactory. The maximum error relative to the entire group was 0.011 meters with an overlap between the various clouds equal to 24%.

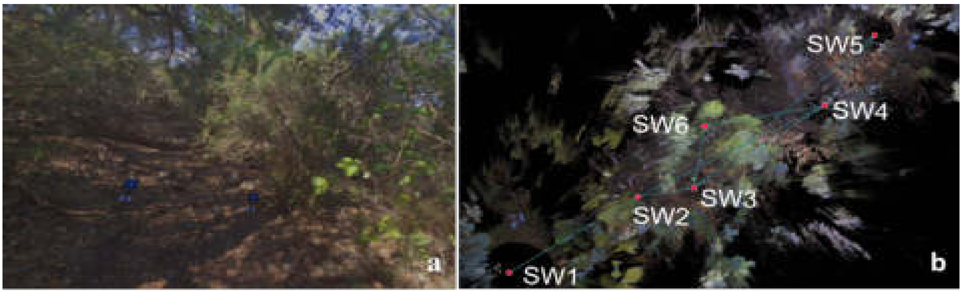

FIGURE 3. Case study 1. a) Photograph of some areas of the scene. b) Orthographic view of the point cloud of case study with stations. Symbol: the red dot indicates the station of measure of the scanner.

3.2. Case study 2. For the acquisition of this area, three different scans were carried out (Figure 4). The distribution of the stations was irregular on the slope and were placed defining a triangle in the area of major investigative interest. Station one was 4.48 meters from station two, station two was 1.62 meters from station three, and station three was 3.47

meters from station one. The robustness of the survey acquired, with a value of 90%, was very satisfactory. The maximum error relative to the entire group was 0.012 meters with an overlap between the clouds equal to 24%.

The relief, represented by an irregularly shaped triangle, frames the area of interest within it.

FIGURE 4. Case study 2. a) Photograph of some areas of the scene. b) Orthographic view of the point cloud of case study with stations. 2. Symbol: the red dot indicates the station of measure of the scanner.

3.3. Case study 3. For the acquisition of this area, nine different scans were carried out (Figure 5). The distribution of the stations was irregular on the slope. The stations 1-4 were aligned along the slope, whereas stations 5-9 were arranged along an irregular polygon, delimiting the area of investigative interest (Figure 6). The first station was placed in the highest zone of the surveyed area and was at 8.76 meters from the second one, the second station was 8.15 meters from the third one, the third station was 9.05 meters from the fourth one, the fourth station was 14.48 meters from the ninth one and 9.84 meters from the fifth one, the fifth one was 9.63 meters from the sixth one and 14.39 meters from the ninth station, the sixth station was 18.36 meters from the seventh station, the seventh station was 13.91 meters from the eighth station, the eighth station was 16.44 meters from the ninth one, the ninth station closed with the fourth, fifth, and sixth stations in order to strengthen the connections and further reduce errors. The robustness of the survey acquired, with a value of 81%, was very satisfactory. The maximum error relative to the entire group was 0.012 meters with an overlap between the various clouds equal to 33%.

Topographic map (Figure 6b) and cross section (Figure 6c) were elaborated from the 3D model (Figure 6a).

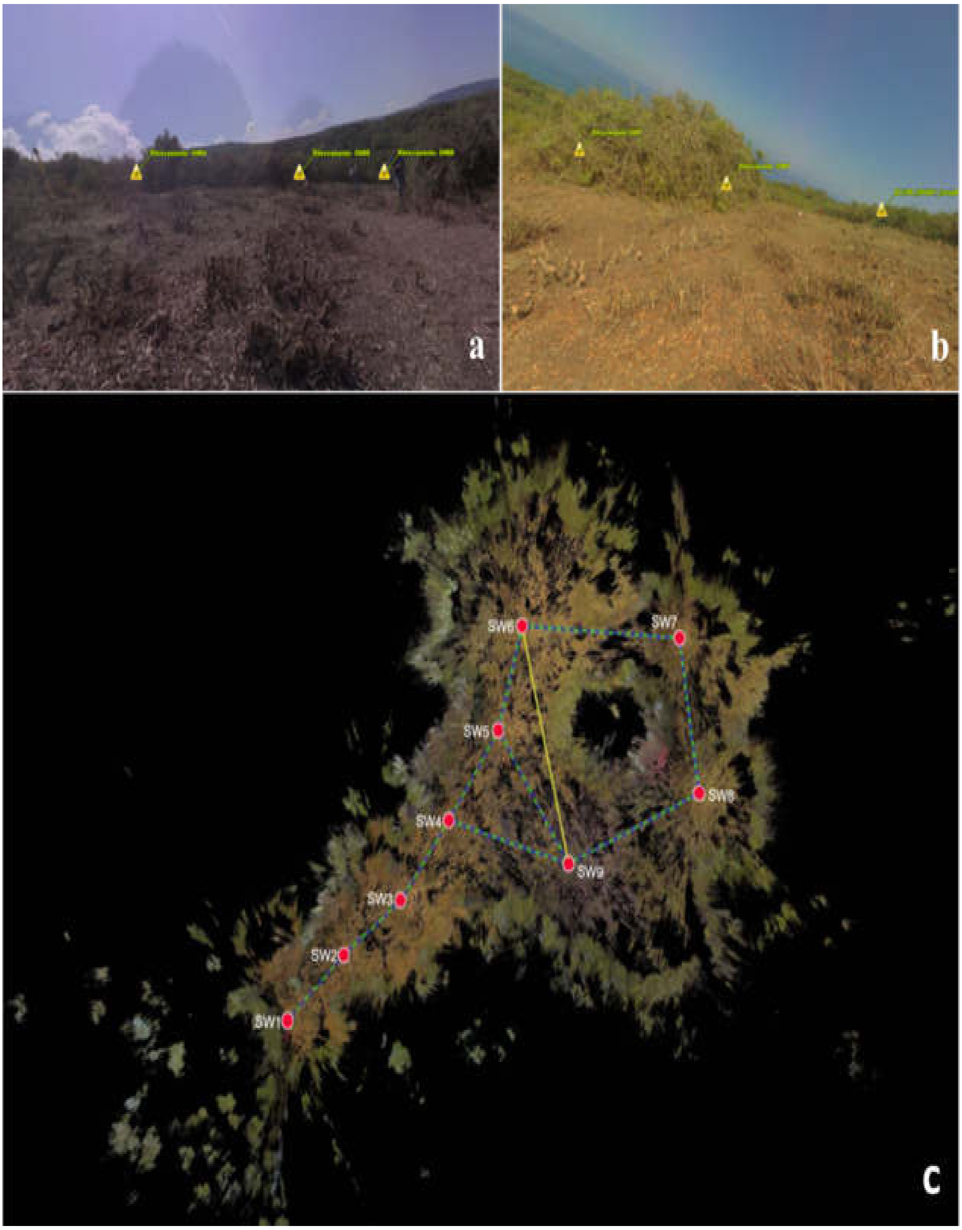

FIGURE 5. Case study 3. a-b) Photographs of some areas of the scene. c) Orthographic view of the point cloud of case study 3 with stations. Symbol: the red dot indicates the station of measure of the scanner.

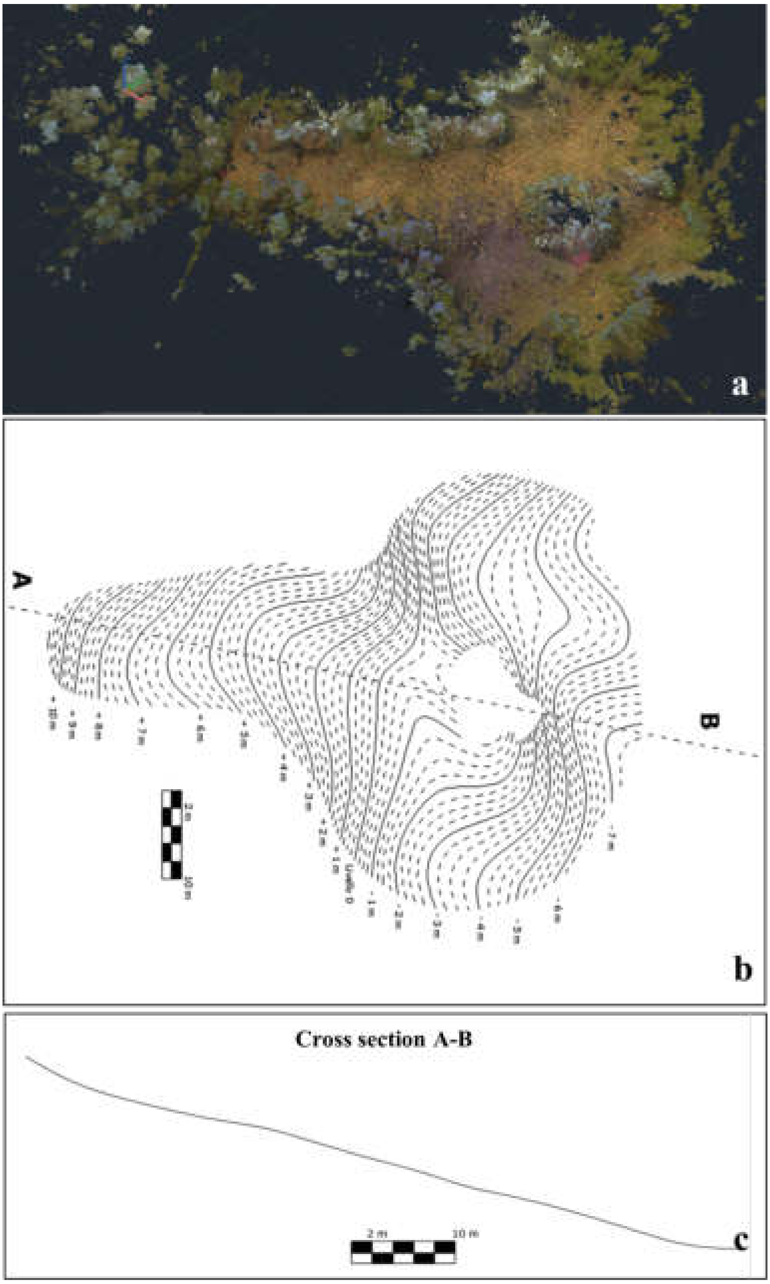

FIGURE 6. Reconstructions of case study 3. a) Orthographic view of the point cloud of case study. b) Topographic map with contour lines at 250 mm (altitude was relative). c) Cross section.

3.4. Case study 4. For the acquisition of this area, six different scans were carried out (Figure 7). The distribution of the stations was irregular on the slope. Stations 1-3-5-6 were arranged along an irregular polygon, delimiting the area of major investigative interest. The first station was 9.06 meters from the second one, the second station was 10.15 meters from the third one, the third station was 11.59 meters from the fourth one, the fourth station was 8.12 meters from the fifth one, the fifth station was 14.75 meters from the sixth one, and the sixth station was 13.07 meters from the first one. In post processing the connections between stations 1-4, 1-3, 3-5, 3-4, 4-2, 4-5, 2-6, 5-6, 6-1 were made, strengthen links and reduce any errors to acceptable values. The robustness of the survey acquired was 71%. The maximum error relating to the whole group was 0.015 meters with an overlap between clouds equal to 23%. Topographic map (Figure 8a) and cross sections (Figures 8b, 9) were obtained by point clouds and 3D model (Figure 8c).

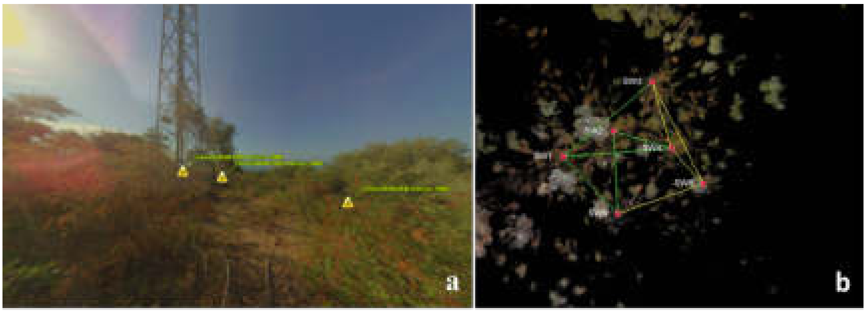

FIGURE 7. Case study 4. a) Photograph of some areas of the scene. b) Orthographic view of the point cloud of case study with stations. Symbol: the red dot indicates the station of measure of the scanner.

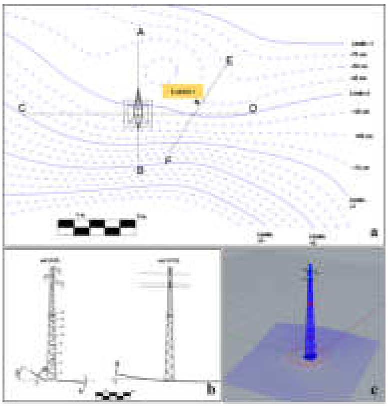

FIGURE 8. Reconstructions of case study 4. a) Topographic map with contour lines at 100 mm (altitude was relative). b) Cross sections. c) 3D virtual model obtained by point clouds. Symbol: yellow dot corresponding to the location of sample 1 (Figure 9).

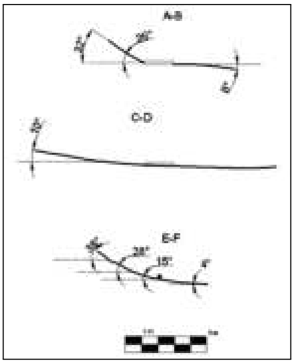

FIGURE 9. Cross sections and angles of the slope.

3.5. Case study 5. The case study 5 was devoted to the reconstruction of the three-dimensional virtual model of a block of rock of investigative interest, related to the scene presented in case study 4. The three-dimensional information was acquired in laboratory by means of a scanner and the triangulation method. The scans were made from three different angles and aligned using markers. Point clouds were obtained by means of a tessellation process and converted into a polygonal mesh. The tessellation process created a network of polygons captured by the scanner. This network of polygons allowed to creating the detailed three-dimensional virtual model of the study target, with a high level of detail due to the high resolution of the scanner used (Figure 10).

FIGURE 10. Reconstruction of the specimen of case study 5. 3D virtual model related to a block of quartzarenite acquired by means of the blue structured light technology in laboratory. The model allows to observe details present on the surface such as the two systems of joints cross-cutting the rock.

4. Discussion and conclusions

Two different modern technologies, laser scanning and structured blue light scanning, were applied for acquiring points in 3D space from real crime scenes and geological evidence, respectively. Different investigative places, large outdoor spaces (case studies 1-2-3-4), and a block of rock (case study 5) collected from the scene of case study 4, were investigated and discussed.

The two applied technologies highlighted as, depending on the difference in size and required resolution of the data, analogous 3D scanning technologies may be differently used. If the laser scanning is suitable for the acquisition of both outdoor and indoor large spaces (m to dam) with precision of the measure of the order of 1 mm, the structured blue light scanning is more suitable for the acquisition of small sized objects (cm to dm) with an accuracy of 200 μm.

From the descriptions of the case studies 1-2-3-4, it was evident that all of them required the scanning of an area from different stations (n. 6, 3, 9, and 6 stations, respectively) varying distances between stations in order to obtain a complete three-dimensional surface survey. In all cases, laser scanning technology resulted able to acquire accurate data even in the presence of vegetation. The robustness of the acquired survey in all cases was considered satisfactory, being values ranging from 65% to 90%. These case studies demonstrated the effectiveness of laser scanning technology in surveying complex surfaces outdoor and the importance of properly planning the station positioning for achieving an accurate survey able to detect all the target of interest. Consequently, one of the main advantages of the use of laser scanning technology in forensics is represented by the possibility of faithfully reproducing the crime scene, offering excellent results also in terms of quantitative measures of specific evidence and time. Notwithstanding, 3D laser scanning, especially when it is applied to survey sites in the countryside, may also present some disadvantages. Among them, the noise that can be caused by the constant movement of vegetation due to wind or other environmental factors. The 3D technologies applied in the present research proved to be particularly effective in the study of the reported investigative cases both allowing to acquire point clouds provided of the adequate precision and guaranteeing repeatability and non-destructiveness of the tests.

The point clouds, creating a faithful reproduction of the spaces at the time of acquisition, allowed to realize the 3D virtual models of the analysed crime scenes by laser scanning and geological evidence by structured blue light scanning, even after the judicial inspection, offering the possibility to coroners, other forensic experts, and judicial authority, to evaluate physical evidence over time and better ascertain the possible compatibility with lesiveness of the victims, the interactions of the victims with the places, and the event dynamics. The research evidenced the advantages of using these modern technologies in order to assist investigators in: i) providing 3D virtual models for reconstructing even complex crime scenes occurred outdoor; ii) reconstructing of the dynamics of events, and iii) individuating possible interactions between the actors of the scene and the surrounding places.

Author Contributions

Conceptualization, F.C., R.S.; methodology, A.Al., G.B., D.S., R.S., E.V.S.; software, A.Al., M.R., F.S.; validation, A.Al., G.B., D.S., R.S., E.V.S.; formal analysis, A.Al., M.R., F.S.; investigation, R.S.; resources, A.Al., F.C., R.S.; data curation, R.S.; writing original draft preparation, R.S.; writing review and editing, R.S.; visualization, A.Al., G.B., F.C., D.S., R.S., E.V.S.; supervision, R.S. All authors have read and agreed to the published version of the manuscript.

Competing interests

The authors declare no conflict of interest.

References

Almerich-Chulia, A. I. and Moreno-Puchalt, J. (2022). "Potential perspectives of 3D laser scanner for real-life domains". In: *Proceedings - 4th International Conference Business Meets Technology 2022*. DOI: 10.4995/BMT2022.2022.15619.

Baldino, G., Mondello, C., Sapienza, D., Stassi, C., Asmundo, A., Gualniera, P., Vanin, S., and Ventura Spagnolo, E. (2023a). "Multidisciplinary Forensic Approach in "Complex" Bodies: Systematic Review and Procedural Proposal". *Diagnostics (Basel)* **13**(2), 310. DOI: 10.3390/diagnostics13020310.

Baldino, G., Ventura Spagnolo, E., Fodale, V., Pennisi, C., Mondello, C., Altadonna, A., Raffaele, M., Salmeri, F., Somma, R., Asmundo, A., and Sapienza, D. (2023b). "The application of 3D virtual models in the judicial inspection of indoor and outdoor crime scenes". *Atti della Accademia Peloritana dei Pericolanti. Classe di Scienze Fisiche, Matematiche e Naturali* **101**(S1), A17. DOI: 10.1478/AAPP.101S1A17.

Barberi, E., Chillemi, M., Cucinotta, F., Milardi, D., Raffaele, M., Salmeri, F., and Sfravara, F. (2023). "Posture Interactive Self Evaluation Algorithm Based on Computer Vision". In: *Lecture Notes in Computer Science*. Vol. 12635, pp. 1516–1526. DOI: 10.1007/978-3-031-15928-2_132.

Barberi, E., Cucinotta, F., Raffaele, M., and Salmeri, F. (2022). "A Hollowing Topology Optimization Method for Additive and Traditional Manufacturing Technologies". *Lecture Notes in Mechanical Engineering*. DOI: 10.1007/978-3-030-91234-5_43.

Barone, S., Cucinotta, F., and Sfravara, F. (2017). "A comparative Life Cycle Assessment of utility poles manufactured with different materials and dimensions". In: *Lecture Notes in Mechanical Engineering*, pp. 91–99. DOI: 10.1007/978-3-319-45781-9_10.

Barone, S., Paoli, A., and Razionale, A. V. (2012). "Three-dimensional point cloud alignment detecting fiducial markers by structured light stereo imaging". *Machine Vision and Applications* **23**(2), 217–229. DOI: 10.1007/s00138-011-0340-1.

Barrile, V., Bernardo, E., Fotia, A., and Bilotta, G. (2022). "Integration of Laser Scanner, Ground-Penetrating Radar, 3D Models and Mixed Reality for Artistic, Archaeological and Cultural Heritage Dissemination". *Heritage* **5**(3), 1529–1550. DOI: 10.3390/heritage5030080.

Brown, G. M. (2000). "Overview of three-dimensional shape measurement using optical methods". *Optical Engineering* **39**(1), 10. DOI: 10.1117/1.602438.

Byrd, H. J. and Sutton, L. (2023). "The Use of Forensic Entomology within Clandestine Gravesite Investigations". In: *Atti della Accademia Peloritana dei Pericolanti. Classe di Scienze Fisiche, Matematiche e Naturali*. Vol. 101. S1, A7. DOI: 10.1478/AAPP.101S1A7.

Caccianiga, M., Caccia, G., Mazzarelli, D., Salsarola, D., Poppa, P., Gaudio, D., Cappella, A., Franceschetti, L., Tambuzzi, S., Maggioni, L., and Cattaneo, C. (2021). "Common and much less common scenarios in which botany is crucial for forensic pathologist and anthropologists: a series of eight case studies". *International Journal of Legal Medicine* **135**(3), 1067–1077. DOI: 10.1007/s00414-020-02456-0.

Carella Prada, O. and Tancredi, D. M. (2010). *The judicial medico-legal inspection. Standards, methodology and medico-forensic elements for investigative activity*. Rome: SEU.

Carew, R. M. and Errickson, D. (2019). "Imaging in forensic science: Five years on". *Journal of Forensic Radiology and Imaging* **16**, 24–33. DOI: 10.1016/j.jofri.2019.01.002.

Cecchi, R., Cusack, D., Ludes, B., Madea, B., Vieira, D. N., Keller, E., Payne-James, J., Sajantila, A., Vali, M., Zoia, R., Cucurachi, N., Schirripa, M. L., Marezza, F., Anzillotti, L., Donato, L., Cattaneo, C., Favretto, D., Pelotti, S., Pinchi, V., Vanin, S., and Gherardi, M. (2022). "European Council of Legal Medicine (ECLM) on-site inspection forms for forensic pathology, anthropology, odontology, genetics, entomology and toxicology for forensic and medico-legal scene and corpse investigation: the Parma form". *International Journal of Legal Medicine* **136**(4), 1037–1049. DOI: 10.1007/s00414-021-02734-5.

Chen, Y.-R., Chang-Liao, Y.-Q., Lin, C., Tsai, D.-R., Lim, J.-H., Hong, R.-H., and Chang, A.-R. (2021). "Forensic Science Education by Crime Scene Investigation in Virtual Reality". In: *2021 IEEE International Conference on Artificial Intelligence and Virtual Reality (AIVR)*, pp. 205–206. DOI: 10.1109/AIVR52153.2021.00046.

Chias, P., Abad, T., Miguel, M. de, García-Rosales, G., and Echeverria, E. (2019). "3d modelling and virtual reality applied to complex architectures: an application to hospitals' design". *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* **XLII-2/W9**, 255–260. DOI: 10.5194/isprs-archives-XLII-2-W9-255-2019.

Christensen, A. (2004). "The Influence of Behavior on Freefall Injury Patterns: Possible Implications for Forensic Anthropological Investigations". *Journal of Forensic Sciences* **49**(1). DOI: 10.1520/JFS2003089.

Cucinotta, F., Paoli, A., Risitano, G., and Sfravara, F. (2018). "Optical measurements and experimental investigations in repeated low-energy impacts in powerboat sandwich composites". *Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment* **232**(2), 234–244. DOI: 10.1177/1475090217720619.

Cucinotta, F., Raffaele, M., and Salmeri, F. (2019). "A stress-based topology optimization method by a Voronoi tessellation Additive Manufacturing oriented". *International Journal of Advanced Manufacturing Technology* **103**(5–8), 1965–1975. DOI: 10.1007/s00170-019-03676-4.

Cucinotta, F., Raffaele, M., and Salmeri, F. (2020). "A Topology Optimization of a Motorsport Safety Device". In: *Lecture Notes in Mechanical Engineering*, pp. 400–409. DOI: 10.1007/978-3-030-31154-4_34.

Cucinotta, F., Raffaele, M., and Salmeri, F. (2021a). "A Topology Optimization Method for Stochastic Lattice Structures". In: *Lecture Notes in Mechanical Engineering*, pp. 235–240. DOI: 10.1007/978-3-030-70566-4_38.

Cucinotta, F., Raffaele, M., and Salmeri, F. (2021b). "A Well-to-Wheel Comparative Life Cycle Assessment Between Full Electric and Traditional Petrol Engines in the European Context". In: *Lecture Notes in Mechanical Engineering*, pp. 188–193. DOI: 10.1007/978-3-030-70566-4_30.

Cucinotta, F., Raffaele, M., Salmeri, F., and Sfravara, F. (2021). "A comparative Life Cycle Assessment of two sister cruise ferries with Diesel and Liquefied Natural Gas machinery systems". *Applied Ocean Research* **112**, 102705. DOI: 10.1016/j.apor.2021.102705.

Donnelly, L. J., Pirrie, D., Harrison, M., Ruffell, A., and Dawson, L. A. (2021). "A Guide to Forensic Geology", 217. DOI: 10.1144/GFG.

Ebert, L. C., Nguyen, T. T., Breitbeck, R., Braun, M., Thali, M. J., and Ross, S. (2014). "The forensic holodeck: an immersive display for forensic crime scene reconstructions". *Forensic Science, Medicine, and Pathology* **10**(4), 623–626. DOI: 10.1007/s12024-014-9605-0.

Fitzpatrick, R. W. and Donnelly, L. J. (2021). “An introduction to forensic soil science and forensic geology: a synthesis”. *Geological Society, London, Special Publications* **492**(1), 1–32. DOI: 10.1144/SP492-2021-81.

Flor, N. (2011). “Technology Corner: Virtual Crime Scene Reconstruction: The Basics of 3D Modeling”. *Journal of Digital Forensics, Security and Law*. DOI: 10.15394/jdfsl.2011.1108.

González-Merino, R., Sánchez-López, E., Romero, P. E., Rodero, J., and Hidalgo-Fernández, R. E. (2021). “Low-Cost Prototype to Automate the 3D Digitization of Pieces: An Application Example and Comparison”. *Sensors* **21**(8), 2580. DOI: 10.3390/s21082580.

Guo, Y., Li, X., Ju, S., Lyu, Q., and Liu, T. (2022). “Utilization of 3D Laser Scanning for Stability Evaluation and Deformation Monitoring of Landslides”. *Journal of Environmental and Public Health* **2022**, 1–14. DOI: 10.1155/2022/8225322.

INTERPOL (2023). “Disaster victim identification”. accessed on 02.06.2023. URL: https://www.interpol.int/content/download/589/file/18Y1344eDVI_Giude.pdf.

Komar, D. A., Davy-Jow, S., and Decker, S. J. (2012). “The Use of a 3-D Laser Scanner to Document Ephemeral Evidence at Crime Scenes and Postmortem Examinations”. *Journal of Forensic Sciences* **57**(1), 188–191. DOI: 10.1111/j.1556-4029.2011.01915.x.

Lo Giudice, R., Galletti, C., Tribst, J. P. M., Melenchón, L. P., Matarese, M., Miniello, A., Cucinotta, F., and Salmeri, F. (2022). “In Vivo Analysis of Intraoral Scanner Precision Using Open-Source 3D Software”. *Prosthesis* **4**(4), 554–563. DOI: 10.3390/prosthesis4040045.

Lombardi, G. (1999). “The contribution of forensic geology and other trace evidence analysis to the investigation of the killing of Italian Prime Minister Aldo Moro”. *J. Forensic Sci.* **44**(3), 634–642. DOI: 10.1520/JFS14523J.

Luhmann, T., Chizhova, M., Gorkovchuk, D., Hastedt, H., Chachava, N., and Lekveishvili, N. (2019). “Combination of terrestrial laserscanning, uav and close-range photogrammetry for 3d reconstruction of complex churches in Georgia”. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* **XLII-2/W11**, 753–761. DOI: 10.5194/isprs-archives-XLII-2-W11-753-2019.

Mangi, D. B., Khan, R., and Jatoi, S. K. (2020). “The Importance of Forensic Protocols with the Role of Forensic Experts and Sindh Police at Crime Scene: A Case of Sindh”. *Global Social Sciences Review* **V**(II), 504–515. DOI: 10.31703/gssr.2020(V-II).48.

Marra, A. C. (2023). “Taphonomical investigation applied to clandestine graves”. *Atti della Accademia Peloritana dei Pericolanti. Classe di Scienze Fisiche, Matematiche e Naturali* **101**(S1), A6. DOI: 10.1478/AAPP.101S1A6.

Marra, A. C., Di Silvestro, G., and Somma, R. (2023). “Palaeontology applied to criminal investigation”. *Atti della Accademia Peloritana dei Pericolanti. Classe di Scienze Fisiche, Matematiche e Naturali* **101**(S1), A4. DOI: 10.1478/AAPP.101S1A4.

Mohamed, A.-M. (2018). “Potential of 3d laser point cloud data usage for the tourism industry”. In: *The International Conference on Civil and Architecture Engineering*. Vol. 12. 12, pp. 1–13. DOI: 10.21608/iccae.2018.30001.

Morabito, M., Mondello, F., and Somma, R. (2023). “Macrobotanic data implementing Forensic Geology investigations”. *Atti della Accademia Peloritana dei Pericolanti. Classe di Scienze Fisiche, Matematiche e Naturali* **101**(S1), A13. DOI: 10.1478/AAPP.101S1A13.

Morabito, M. and Somma, R. (2023). “The crucial role of Forensic Botany in the solution of judicial cases”. *Atti della Accademia Peloritana dei Pericolanti. Classe di Scienze Fisiche, Matematiche e Naturali* **101**(S1), A11. DOI: 10.1478/AAPP.101S1A11.

Murray, R. C. and Tedrow, J. C. (1975). *Forensic geology: Earth sciences and criminal investigation*. Piscataway, United States: Rutgers University Press Address, p. 232.

Naether, S., Buck, U., Campana, L., Breitbeck, R., and Thali, M. (2012). “The examination and identification of bite marks in foods using 3D scanning and 3D comparison methods”. *International Journal of Legal Medicine* **126**(1), 89–95. DOI: 10.1007/s00414-011-0580-7.

Nelis, J., Desmet, S., Wauters, J., Haelterman, R., Borgers, E., and Kun, D. (2018). “Virtual Crime Scene”. In: *2018 IEEE International Conference on Artificial Intelligence and Virtual Reality (AIVR)*, pp. 165–168. DOI: 10.1109/AIVR.2018.00035.

Ogawa, T. and Hori, Y. (2019). “Comparison with accuracy of terrestrial laser scanner by using point cloud aligned with shape matching and best fitting methods”. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* **XLII-2/W9**, 535–541. DOI: 10.5194/isprs-archives-XLII-2-W9-535-2019.

Olsen, M. J. and Kayen, R. (2012). “Post-Earthquake and Tsunami 3D Laser Scanning Forensic Investigations”. In: *Forensic Engineering 2012*, pp. 477–486. DOI: 10.1061/9780784412640.051.

Park, C.-S., Jeon, H.-P., Choi, K.-S., Kim, J.-P., and Park, N.-K. (2018). “Application of 3D Laser Scanner to Forensic Engineering”. *Journal of Forensic Sciences* **63**(3), 930–934. DOI: 10.1111/1556-4029.13632.

Pavliuk, N. V. (2018). “Possibilities of the application of three-dimensional technologies and modern technological means in the crime investigation activity”. *Theory and Practice of Forensic Science and Criminalistics* **18**, 98–105. DOI: 10.32353/khrife.2018.11.

Picozzi, M. and Intini, A. (2009). *Scienze forensi. Teoria e prassi dell’investigazione scientifica*. UTET Giuridica, p. 544.

Prestipino, M., Salmeri, F., Cucinotta, F., and Galvagno, A. (2021). “Thermodynamic and environmental sustainability analysis of electricity production from an integrated cogeneration system based on residual biomass: A life cycle approach”. *Applied Energy* **295**, 117054. DOI: 10.1016/j.apenergy.2021.117054.

Puccini, C. (2003). *Institutions of Forensic Medicine*. sixth. Casa Editrice Ambrosiana.

Puleio, F., Rizzo, G., Nicita, F., Giudice, F. L., Tamà, C., Marenzi, G., Centofanti, A., Raffaele, M., Santonocito, D., and Risitano, G. (2020). “Chemical and mechanical roughening treatments of a supra-nano composite resin surface: SEM and topographic analysis”. *Applied Sciences (Switzerland)* **10**(13), 1–9. DOI: 10.3390/app10134457.

Reed, E. S. (2001). “Forensic Engineering Design Construction And Use Of Economical Human Surrogates”. *Journal of the National Academy of Forensic Engineers* **18**(2). DOI: 10.51501/jotnafe.v18i2.593.

Ren, P., Shui, W., Liu, J., Fan, Y., Zhao, W., and Zhou, M. (2018). “A Sketch-based Rapid Modeling Method for Crime Scene Presentation”. *The Journal of Digital Forensics, Security and Law*. DOI: 10.15394/jdfsl.2018.1484.

Ruffell, A. and McKinley, J. (2008). *Geoforensics*. The Atrium, Southern Gate, Chichester, West Sussex, England: John Wiley and Sons Ltd, p. 332.

Rusman, G. and Popova, E. (2020). “Development of the Software for Examination of the Crime Scene by Using Virtual Reality, Based on Spherical Panoramic Shot and 3D-Scanning”. In: *2020 Global Smart Industry Conference (GloSIC)*, pp. 297–302. DOI: 10.1109/GloSIC50886.2020.9267871.

Saferstein, R. (2017). *Criminalistics: an introduction to forensic science*. 9th. Upper Saddle River, NJ: Pearson Prentice Hall.

Saha, K. K., Tsoulias, N., Weltzien, C., and Zude-Sasse, M. (2022). “Estimation of Vegetative Growth in Strawberry Plants Using Mobile LiDAR Laser Scanner”. *Horticulturae* **8**(2), 90. DOI: 10.3390/horticulturae8020090.

Singh, P., Gupta, N., and Rathi, R. (2021). “Blood pattern analysis—a review and new findings”. *Egyptian Journal of Forensic Sciences* **11**(1), 9. DOI: 10.1186/s41935-021-00224-8.

Somma, R. (2022). “Advances in Flipped Classrooms for Teaching and Learning Forensic Geology”. *Educ. Sci.* **12**(6), 403. DOI: 10.3390/educsci12060403.

Somma, R. (2023a). "A multidisciplinary approach based on the cooperation of forensic geologists, botanists, and engineers: Computed Axial Tomography applied to a case work". *Atti della Accademia Peloritana dei Pericolanti. Classe di Scienze Fisiche, Matematiche e Naturali* **101**(S1), A12. DOI: 10.1478/AAPP.101S1A12.

Somma, R. (2023b). "The space and time dimensions in the criminal behaviour of lust murderers". *Atti della Accademia Peloritana dei Pericolanti. Classe di Scienze Fisiche, Matematiche e Naturali* **101**(S1), A19. DOI: 10.1478/AAPP.101S1A19.

Somma, R. (2023c). "Unraveling crimes with geosciences". *Atti della Accademia Peloritana dei Pericolanti. Classe di Scienze Fisiche, Matematiche e Naturali* **101**(S1), A2. DOI: 10.1478/AAPP.101S1A2.

Somma, R., Baldino, G., Altadonna, A., Asmundo, A., Fodale, V., Gualniera, P., Mondello, C., Pennisi, C., Raffaele, M., Salmeri, F., Ventura Spagnolo, E., and Sapienza, D. (2023a). "Education and training activities in forensic and biomedical sciences: The Laser scanner technology". *Atti della Accademia Peloritana dei Pericolanti. Classe di Scienze Fisiche, Matematiche e Naturali* **101**(S1), A16. DOI: 10.1478/AAPP.101S1A16.

Somma, R., Cascio, M., Cucinotta, F., Mondello, F., and Morabito, M. (2023b). "Recent advances in forensic geology and botany for the reconstruction of event dynamics in outdoor crime scenes: a case study". *Atti della Accademia Peloritana dei Pericolanti. Classe di Scienze Fisiche, Matematiche e Naturali* **101**(S1), A10. DOI: 10.1478/AAPP.101S1A10.

Somma, R., Cascio, M., Silvestro, M., and Torre, E. (2018). "A GIS-based quantitative approach for the search of clandestine graves". *Italy J. Forensic Sci.* **63**, 882–898. DOI: 10.1111/1556-4029.13677.

Somma, R. and Costa, N. (2022). "Unraveling Crimes with Geology: As Geological and Geographical Evidence Related to Clandestine Graves May Assist the Judicial System". *Geosciences* **12**(9), 339. DOI: 10.3390/geosciences12090339.

Somma, R. and Costa, N. (2023). "GIS-based RAG-coded search priority scenarios for predictive maps to prevent future serial serious crimes: the case study of the Florence Monster". *Atti della Accademia Peloritana dei Pericolanti. Classe di Scienze Fisiche, Matematiche e Naturali* **101**(S1), A18. DOI: 10.1478/AAPP.101S1A18.

Somma, R. and Maniscalco, R. (2023). "Forensic geology applied to criminal investigation: a case report". *Atti della Accademia Peloritana dei Pericolanti. Classe di Scienze Fisiche, Matematiche e Naturali* **101**(S1), A9. DOI: 10.1478/AAPP.101S1A9.

Somma, R., Spoto, S. E., Raffaele, M., and Salmeri, F. (2023c). "Measuring color techniques for forensic comparative analyses of geological evidence". *Atti della Accademia Peloritana dei Pericolanti. Classe di Scienze Fisiche, Matematiche e Naturali* **101**(S1), A14. DOI: 10.1478/AAPP.101S1A14.

Somma, R., Sutton, L., and Byrd, H. J. (2023). "Forensic geology applied to the search for homicide graves". *Atti della Accademia Peloritana dei Pericolanti. Classe di Scienze Fisiche, Matematiche e Naturali* **101**(S1), A5. DOI: 10.1478/AAPP.101S1A5.

Spoto, S. E. (2023). "Illicit trafficking of diamonds: new frontiers". *Atti della Accademia Peloritana dei Pericolanti. Classe di Scienze Fisiche, Matematiche e Naturali* **101**(S1), A3. DOI: 10.1478/AAPP.101S1A3.

Spoto, S. E., Barone, S., and Somma, R. (2023). "An introduction to forensic geosciences". *Atti della Accademia Peloritana dei Pericolanti. Classe di Scienze Fisiche, Matematiche e Naturali* **101**(S1), A1. DOI: 10.1478/AAPP.101S1A1.

Spoto, S. E., Somma, R., and Crea, F. (2021). "Using a forensic-based learning approach to teach geochemistry". *AAPP Atti Accad. Peloritana dei Pericolanti Cl. Sci. Fis. Mat. Nat.* **99**(S1), A31, 1–9. DOI: 10.1478/AAPP.99S1A31.

Tagliabue, G., Masseroli, A., Mattia, M., Sala, C., Belgiovine, E., Capuzzo, D., Galimberti, P. M., Slavazzi, F., Cattaneo, C., and Trombino, L. (2023). "Thanatogenic Anthrosols: a geoforensic approach to the exploration of the Sepolcreto of the Ca' Granda (Milan)". *Atti della Accademia Peloritana dei Pericolanti. Classe di Scienze Fisiche, Matematiche e Naturali* **101**(S1), A8. DOI: 10.1478/AAPP.101S1A8.

Telling, J., Lyda, A., Hartzell, P., and Glennie, C. (2017). "Review of Earth science research using terrestrial laser scanning". *Earth-Science Reviews* **169**, 35–68. DOI: 10.1016/j.earscirev.2017.04.007.

Wand, M., Berner, A., Bokeloh, M., Jenke, P., Fleck, A., Hoffmann, M., and Seidel, H.-P. (2008). "Processing and interactive editing of huge point clouds from 3D scanners". *Computers & Graphics* **32**(2), 204–220. DOI: 10.1016/j.cag.2008.01.010.

Wu, C., Yuan, Y., Tang, Y., and Tian, B. (2021). "Application of Terrestrial Laser Scanning (TLS) in the Architecture, Engineering and Construction (AEC) Industry". *Sensors* **22**(1), 265. DOI: 10.3390/s22010265.

Wu, T. H. (1993). "Forensic Engineering, Environmental Case Histories for Civil Engineers and Geologists". *Journal of Environmental Quality* **22**(1), 216–216. DOI: 10.2134/jeq1993.00472425002200010036x.

Yokoi, N., Aizu, Y., and Uozumi, J. (2018). "Analysis of blood coagulation process based on fractality and dynamic characteristic of laser speckle pattern". *Journal of Biomedical Optics* **24**(03), 1. DOI: 10.1117/1.JBO.24.3.031018.

---

[a] Accademia Peloritana dei Pericolanti,
Palazzo Università,
Piazza Pugliatti 1, 98122 Messina, Italy

[b] Università degli Studi di Messina,
Dipartimento di Scienze Matematiche e Informatiche, Scienze Fisiche e Scienze della Terra,
Viale F. Stagno d'Alcontres 31, 98166 Messina, Italy

[c] Università degli Studi di Messina,
Dipartimento di Ingegneria,
C.da di Dio, 98166 Messina, Italy

[d] Università degli Studi di Messina
Dipartimento di Scienze biomediche, odontoiatriche e delle immagini morfologiche e funzionali,
Via Consolare Valeria, 98125 Messina, Italy

[*] To whom correspondence should be addressed | email: rsomma@unime.it

Paper contributed to the workshop on "Advances and applications in geoforensics: Unraveling crimes with geology", held in Messina, Italy (26 September 2022) under the patronage of the *Accademia Peloritana dei Pericolanti*

Manuscript received 18 March 2023; published online 12 September 2023
